Strength Training for Sport

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EDITED BY
William J. Kraemer
Keijo Häkkinen

Handbook of
Sports Medicine
and Science

Strength Training for Sport

IOC Medical Commission Sub-Commission on Publications in the Sport Sciences

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Forewords by the IOC

As recently as 50 years ago, strength training was not only considered ineffective for sports conditioning but potentially detrimental to the performance of athletes competing in particular sports. The various fears have been removed from consideration and an ever-growing body of knowledge has confirmed the efficacy of the proper application of strength training to improved performance in a wide variety of Olympic sports.

This handbook will give to athletes, coaches, doctors all the relevant information concerning this specific training.

I would like to thank the authors for such an educational handbook and the IOC Medical Commission for its constant help to the athletes in their search for excellence.

Juan Antonio Samaranch
IOC President

Volume III in the Encyclopaedia series, *Strength and Power in Sport* (edited by Professor Paavo V. Komi) published in 1993, was devoted to a review of current scientific knowledge pertaining to the anatomical, biomechanical, and physiological factors involved in the expression of strength and maximal power during sports performance.

This handbook, *Strength Training for Sport,* presents highly practical information on strength training programmes to enhance sport performance as based on the scientific information detailed in the Encyclopaedia.

This volume applies information regarding a particularly important area of physical conditioning to the many sports in which strength and peak power are important factors of success. *Strength Training for Sport* constitutes yet another contribution of the IOC Medical Commission to the competitive success, health, and well-being of athletes participating at all levels of competition around the world.

Prince Alexandre de Merode
Chairman, IOC Medical Commission

Preface

This book represents the fundamental knowledge needed by sports medicine and coaching professionals to understand and develop strength training programmes for athletes. The process of exercise prescription in strength training, while at times taking on more mythology than fact, should be based on a scientific approach to the needs of the athlete. Ultimately, individualized resistance training will best optimize the athlete's physical abilities needed to successfully compete and prevent injuries. Nevertheless, the development of a strength training programme must be approached by using the best available knowledge, determining the needs of the athlete and then developing a programme that represents the best starting point ultimately making changes over time with periodized training principles to meet the continuing changes in the needs of the athletes as their strength fitness improves.

This text was developed to give the sports medicine and coaching professionals a fundamental background and understanding about this programme design process and the factors involved with strength training for athletes. Too often, many professionals in various aspects of sport lack a fundamental understanding of the process of strength training programme development and therefore fall victims to myths, fads, zealous philosophies, marketing science and ultimately are not able to carefully evaluate the massive quantity of misinformation being generated by a wide variety of sources on this topic. Strength training has always held a degree of mystery and imagination to people throughout the ages, as it deals with the fundamental human quality 'strength' which has been valued with a reverence and awe as a part of human performance. Yet understanding its development and application to athletic performance has taken years of scientific study to understand its many dimensions and sport-specific applications. The pursuit of knowledge and understanding in a field that still remains dynamic and vital in its present day form requires conscientious study and the desire to be a lifelong student in the field. While this handbook is obviously not meant to provide a comprehensive source of the large body of literature on this topic, suggested readings and some references are provided at the end of each chapter to give you some other sources for further study on the topic covered. Ultimately it is our goal to make you more aware of the fundamental knowledge, process and approach to exercise prescription in strength training for athletes.

William J. Kraemer
Keijo Häkkinen

Acknowledgements

We would first like to thank the International Olympic Committee, its Medical Commission, Prince Alexandre de Merode, and specifically the Sub-Commission on Publications in the Sport Sciences for this unique opportunity to develop such an important handbook on the topic of strength training. We feel that this book will play a very practical role in the understanding of strength training programmes for athletes. Strength training is one of the major cornerstones for any sports conditioning programme directed at improved performance and injury prevention.

We would also like to acknowledge the dedicated efforts of Professor Howard G. Knuttgen for bringing such a handbook to reality and understanding the importance of the topic for all sports. We also thank Mr Nick Morgan for his efforts in the production of this handbook and for having patience with such a demanding process.

As Editors, we feel this book will make a unique contribution to the application of strength training in sports conditioning programmes. The process of developing a strength training programme is now more than ever based on a combination of solid science and careful decisions in its prescription by the strength and conditioning professionals. We acknowledge the important and valuable contributions to the production of this handbook by each of our esteemed colleagues. This was truly an international team effort by a group of scholars who have worked tirelessly in this area of study for many years.

Chapter 1

A brief history of strength training and basic principles and concepts

Introduction

The human ability to generate muscle force has fascinated humankind throughout most of recorded history. Not only have great levels of muscular strength intrigued people from an entertainment perspective but, more importantly, high levels of strength are critical for survival. Although modern technological developments may have modified the need to be able to generate high levels of strength for many daily activities, strength is still one of the fundamental physical traits necessary for human survival. While the use of resistance exercise of various types and forms has become very popular over the past 50 years, the origins of such activities can be traced back to ancient times. The pursuit of sporting achievement has resulted in the increased use of strength training by all athletes to enhance sporting performance. The key to its new popularity as we enter the 21st century is the concept of 'sports-specific' training for athletes. The mythology of strength training has slowly given way to a greater scientific understanding of its basic principles and applications. Nevertheless, the field of strength and conditioning still remains susceptible to fads, misconceptions and zealous philosophies which have little to do with sound scientific-based knowledge and careful exercise prescription for enhanced sport performance for the athlete. The history of strength training gives an important perspective on where we have been and where we may go with this important training technology in sporting development. The keys to optimal exercise prescription are knowledge and the clinical art of its use in the careful process and decision making involved in exercise prescription. A systematic approach is needed for the development of programmes. This requires continued study, evaluation, sport testing, and prudent judgements and decision making in this professional process of programme design for the athlete.

In this chapter a historical perspective and several basic principles will be introduced to gain a fundamental understanding of exercise prescription in strength training.

Historical perspective

Strength in ancient times

As long as 5000 years ago, feats of muscular strength were being noted and admired. Egyptian tombs from *c.* 2500 BC were discovered with artwork on the walls depicting strength contests of various types. Ancient inhabitants of Ireland were known to have competed in weight throwing contests over 3800 years ago. On the other side of the world, strength tests were being used for military purposes during the Chou dynasty in China (1122–255 BC). Thus it becomes readily apparent that long before the more recent civilizations of Greece and Rome, ancient cultures utilized tests of muscular strength for both entertainment as well as utilitarian purposes. What is not clear is what type of structured training programmes were used to prepare for such tests.

In early Biblical times, size and strength were greatly admired (Fig. 1.1). The Old Testament stories of the giant Philistine, Goliath, and the strength feats of Samson are well known. What is also apparent in these stories is that size and strength alone do not necessarily lead to success. In ancient Greek culture, the remarkable lifting exploits of Bybon and Emastus during the 6th century BC are well documented. Such tasks involved lifting heavy stones of varying weights, as uniform lifting implements were unheard of. Perhaps the best known Greek strongman is Milos of Crotona who has been credited with the first use of progressive resistance exercise. It is reported that Milos carried a young calf across his shoulders every day until the beast was fully grown. Eventually he carried a 4-year-old heifer the length of the stadium at Olympia, a distance of almost 200 m. Milos's reign as the strongest of all men lasted many years, and resulted in his being wreathed 22 times at the Olympian, Pythian, Nemean and the Ithsmian Games. But even Milos finally met his match, when he was

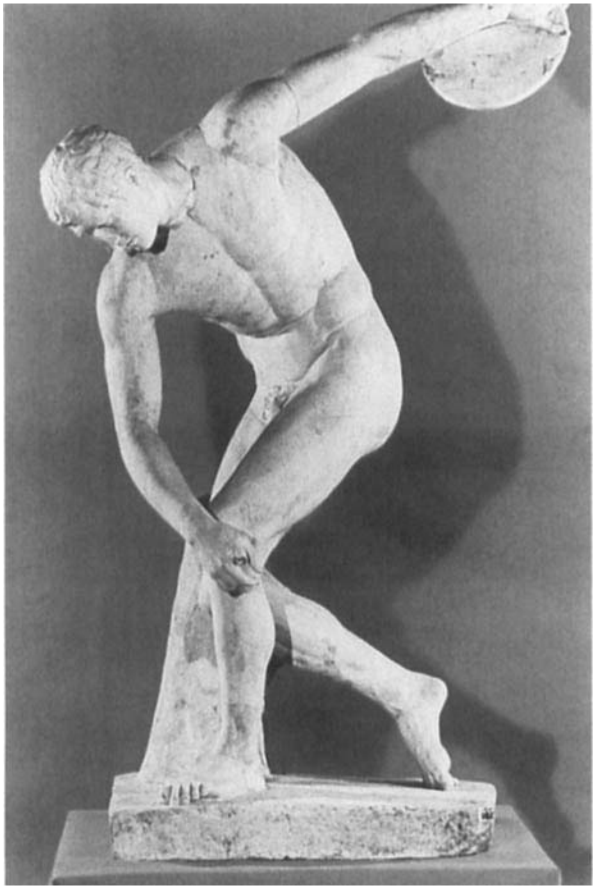

Fig. 1.1 Physical performance through sport competition has been important throughout history. Photo © IOC/Olympic Museum Collections.

eventually defeated in a stone lifting contest by the great Titormus.

The ancient Greeks also used strength building exercises for military purposes. One of the earliest forms of a body building contest can be found in records from the Greek city of Sparta, well known for its military prowess. Spartan men would be paraded naked and judged on their physical development. Those found lacking were summarily punished. The famous Greek physician Galen (129–199 AD) may have been one of the first medical doctors to suggest the efficacy of strength training, and even promoted the use of hand-held weights called halteres. Galen worked extensively with gladiators who depended tremendously on their strength capabilities for survival.

The use of strength building exercises for military purposes was continued by the armies of the Roman Empire. Heavily weighted packs were a commonly used training method that is still used by modern armies. Roman soldiers also utilized overweight swords to help develop their fighting skills.

Contributions from the scientific community

Perhaps the next important development in the progression of strength training came from the scientific community during the Renaissance. It was independently suggested by both Camerarius and Montaigne that training with weights could lead to improved health, enhanced strength and greater effectiveness on the battlefield. In addition to the appreciation of the benefits of such exercise, the study of medicine was allowing great advances in the understanding of the human body. When the Italian scientist Galvani discovered that skeletal muscle was excitable tissue and could be electrically stimulated, a fundamental understanding of the physiology of muscle force production began to evolve. For centuries, the medical community had been amazingly influenced by the teachings and writings of Galen. The medical discipline of human anatomy, however, would be forever changed by the Belgian physician Andreas Vesalius (1514–1564 AD). Vesalius reformed the field of anatomy in part by his revolutionary method of teaching his students. The net result was that he was more actively involved in the dissection and study of the human body, thus contributing to an understanding of it in greater detail. In 1543, Vesalius published the landmark text *De Humani Corporis Fabrica Libri Septum* (Seven Books on the Structure of the Human Body). The detail presented in his text far surpassed any literature on the topic up to that time.

Additional advances in the field of anatomy were made by Bernard Siegfried Albinus (1697–1770 AD). Albinus was Professor of Anatomy and Surgery at the University of Leyden in the Netherlands for 50 years, and was one of the world's foremost experts on anatomy. During this time, his best known contribution to the appreciation of the musculoskeletal system was the publication of the classic works, *Tabulae Sceleti et Musculorum Corporis Humani* in 1747, and *Tabulae Ossium Humanorum* in 1753.

Together with the talented artist Jan Wandelaar, Albinus directed the beautifully detailed artwork that was, and perhaps still is, unparalleled.

Contributions from the field of medical anatomy were to take some of the mystery away from the body system responsible for human movement and exercise. A greater understanding of the body permitted the eventual development of both the basic scientific study and applied fields of muscular performance. Evidence of such an appreciation of muscular fitness can be found in the writings of the great US statesman Benjamin Franklin, who wrote in 1786 that he had been enjoying the benefits of exercising with dumb-bells for over 14 years.

The era of the strongmen

The role of strength training was to receive a large boost in popularity and awareness during the 19th and early 20th centuries. In both Europe and North America, various individuals promoted their muscular strength capabilities for both entertainment and commercial purposes. These early strongmen are responsible for bringing to light the amazing strength potential many humans possess. However, they were also responsible for many of the myths that surround resistance exercise even to this day. As early as 1859, George Baker Winship, a Harvard-trained medical doctor, began touring North America performing feats of strength. Winship was noted for his promotion of the 'health lift', essentially a partial range of motion deadlift. Also in 1859, William Buckingham Curtis began performing strength stunts before admiring audiences. Curtis eventually went on to help create the now famous New York Athletic Club and the Amateur Athletic Union (AAU). During this time various types of resistance exercise became popular at facilities such as the Young Men's Christian Association (YMCA) in the USA.

Richard Pennel is sometimes credited with being the first strongman in North America. Although it was not until 1870 that Pennel began his strength career, he performed for entertainment purposes, not necessarily in an effort to promote health or fitness. The famous Canadian Louis Cyr was known not only for his phenomenal demonstrations of strength, but also for his extremely large size. As Cyr weighed over 136 kg, members of the anti-weight training community noted how large and ponderous individuals like Cyr were, claiming that training with weights would cause one to be excessively large, slow and ponderous. It was explained by some that the most athletic horses of the day were the nimble and explosive thoroughbreds, famous for their racing speed. On the other hand, large muscular draught-horses possessed tremendous pulling strength, but were much slower and less agile than their smaller counterparts. Such thinking had a great effect on the lay public in those days because everyone was familiar with the abilities of horses and the different characteristics of the various breeds. In 1879, William Blaikie criticized Winship's 'health lift' because it produced such undesirable effects as hypertrophy of the forearms, the vastus medialis and the trapezius muscles. Blaikie claimed that such growth would certainly make a person as slow as a draught-horse. Several strongmen attempted to dispel the myth that weightlifting would make a person slow. In 1903 Albert Attila claimed that training with heavy weights did not necessarily do so. The famous Ringling Brothers' Circus performer Arthur Saxon stated that if anything, training with weights only helped improve an individual's speed.

Eventually, several European strongmen were to make a marked statement against such claims. The renowned Eugene Sandow started his career in Europe, and was known for his tremendous strength as well as his muscular build. Promoted by Florenz Ziegfeld for his famous vaudeville show, Sandow toured throughout Europe and North America, demonstrating that an individual could be both strong and physically fit, while possessing an aesthetically pleasing physique. The famed Russian weightlifting champion and wrestler George Hackenschmidt, known as the 'Russian lion', also demonstrated that high levels of physical ability were possible while following a strength training regimen. In a manner somewhat similar to Sandow, Sigmund Klein became well known in the 1920s for his strength capabilities as well as his muscular physique. In addition, Milo Steinborn emigrated to the USA in the early 1900s and gained fame not only because of his strength capabilities but also through his physical accomplishments in the wrestling ring. Despite the appearance of these individuals, it had become an uphill battle to counter the claims that strength training would result in undesirable bulkiness and slowness.

There is an interesting footnote to the story of Milo Steinborn. Although not particularly noted at the time, perhaps one of Steinborn's greatest contributions to the strength world was the barbell he brought with him to the USA. Actually made in Europe, this bar was an early prototype of the modern Olympic-style barbell with the large revolving ends. It was ultimately obtained by Bob Hoffman, founder of the York Barbell Company, who modified it into the barbell widely used today.

Despite the fact that strong, muscular and physically fit individuals were now touring as strongmen, the myth that weight training would cause one to become 'muscle-bound' was promoted by a surprising group of entrepreneurs. A number of individuals known for their strength accomplishments wished to capitalize on their fame. Although they had attained their strength through traditional strength training methods (i.e. barbells, dumb-bells, weight machines), it was clear that it would be difficult to market such training methods via mail order. The weights and equipment used did not lend themselves to easy transport. To counter this problem, several people decided to market alternative methods of training, and dissuaded the public from traditional training methods by claiming such training would result in a 'muscle-bound' condition. For example, Thomas Inch, himself a British weightlifting record holder, claimed that the use of his chest expander spring device was much superior to the use of traditional free weights. Likewise, H.W. Titus made similar claims for his elastic cables, stating that training with weights would result in becoming 'muscle-bound'. In 1911, Max Sick, later known simply as Maxick, promoted a training system consisting of isometric muscular contractions, saying that weight training would cause a person to become slow. One of Max Sick's protégés, Angelo Siciliano, went on to become one of the first body building champions, billing himself as Charles Atlas. Although Charles Atlas trained with standard weights, he marketed the methods of Max Sick, which he called 'dynamic tension'. For many generations, readers of various magazines were familiar with the advertisements of Charles Atlas and the claims that his 'dynamic tension' training methods would give the results usually ascribed to weight training. Even though these individuals used free weights for their own training, their marketing of alternative training methods helped to perpetuate the myth that weight training would make one 'muscle-bound' and slow.

Even the academic community fell victim to the claims of these entrepreneurs. The famous US physical educator R. Tait McKenzie stated in 1924 that too much muscle was unhealthy. Bernarr MacFadden published *Physical Culture*, a popular fitness magazine during the early 20th century, where he claimed in 1912 that weight training would make a person slow. Such thinking perpetuated in the physical education, sports and fitness communities for many years, and can still be found to this day. Ironically, it is very difficult to define precisely the condition of being 'muscle-bound', or find evidence that supports the concept. At best a study in the 1950s showed that if both sides of a joint are not exercised (i.e. flexors and extensors), a reduction in flexibility may result because of an unbalanced strength programme conducted on only one side of the joint.

Early strength training: popular publications

Although the fitness industry has grown astronomically over the past few decades, several individuals were probably most instrumental for the promotion of resistance exercise for sport and fitness purposes. We have already mentioned Bernarr MacFadden and his popular *Physical Culture* magazine of the early 1900s. After World War II, Bob Hoffman, owner of the York Barbell Company, also published strength fitness magazines, *Strength & Health*, and *Muscular Development*, that became the leading publications for those interested in resistance exercise. Along with Hoffman's weight training equipment company and his sponsorship of the premier weightlifting team of the time, his contribution to resistance exercise was undoubtedly crucial during this time of increasing popularity. Two of Hoffman's business rivals, and fellow supporters of the lifting sports, were Perry and Mabel Rader from the little town of Alliance, Nebraska. The Raders also marketed lifting equipment and were known for their enthusiastic support of competitive lifting, but are best known for publishing *Ironman* magazine, which provided an open-minded forum for all types of weight training methods. Mabel Rader was particularly passionate about competitive lifting for women, and was instrumental in initiating some of the early women's competitions in weightlifting, power lifting and body building.

Currently, perhaps the best known publishers in the industry are the Canadian-born Weider brothers, Ben and Joe, who have consistently promoted resistance exercise through their popular magazines. Although modern times have witnessed an increase in the number of speciality publications for every facet of strength and resistance exercise, these early publications laid much of the groundwork for the promotion of strength training worldwide. However, the science of strength training was only in its infancy and so-called 'gym science' was promoted by such publications which remain the 'sound bite' of today's popular press in resistance training around the world.

Organized competitive lifting sports

As various types of weight training began to gain acceptance, the desire to develop organized competitive lifting sports was bound to follow. In Great Britain, the British Amateur Weight Lifters' Association (BAWLA) was formed for such purposes, and recognized a large number of different lifting exercises. Many are familiar with the Scottish Highland Games which have been contested for many years. Most of the events require extreme levels of muscular strength and power. In general, however, the strength sports most noted worldwide are weightlifting, body building and power lifting.

Weightlifting (Figs 1.2 and 1.3)

Also known as Olympic-style weightlifting, this sport was first contested in the Olympic Games in 1896. At first, the lifts contested included both a one-hand and a two-hand overhead lift, with no weight classes. After a brief hiatus in 1900, weightlifting returned to the Olympic Games in 1904, and has been contested ever since. By 1920, three lifts were performed, the snatch, the clean and press, and the clean and jerk. Eventually, the clean and press was discontinued in 1972 because of difficulty in judging the lift. In the USA, weightlifting received a big boost when Bob Hoffman, owner of the York Barbell Company, formed the acclaimed York weightlifting team. For several decades, lifters from this club dominated both USA and world competitions. The reign of the USA in world competition was successfully challenged in the 1950s and 1960s, most notably by the Soviet Union. By the 1970s and 1980s, the transition was complete, with Eastern European countries completely dominating the sport. Contrary to sport science in the rest of the world, considerable scientific effort in the Eastern Bloc countries was devoted to weightlifting, undoubtedly contributing to their success. The weightlifting exploits and contributions of many great Soviet lifters, coaches and sport scientists, such as Alexey

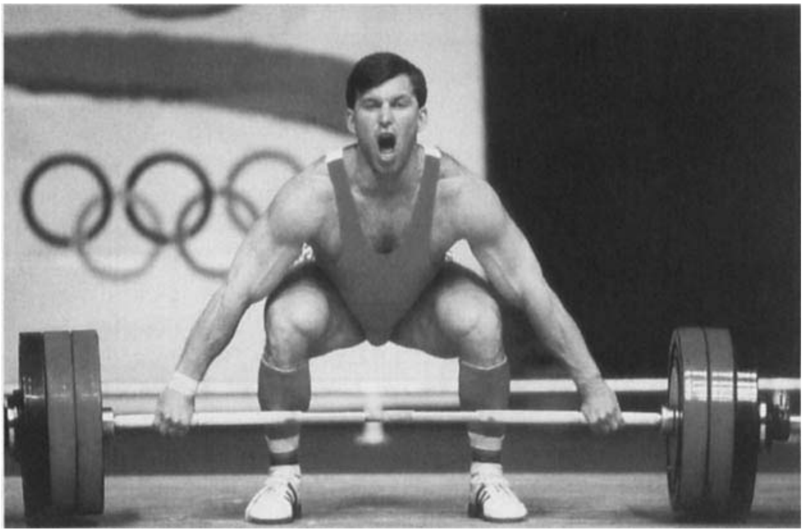

Fig. 1.2 Lifts used in the sport of weightlifting became representative of power development programmes in resistance training. Photo © Allsport/S. Botterill.

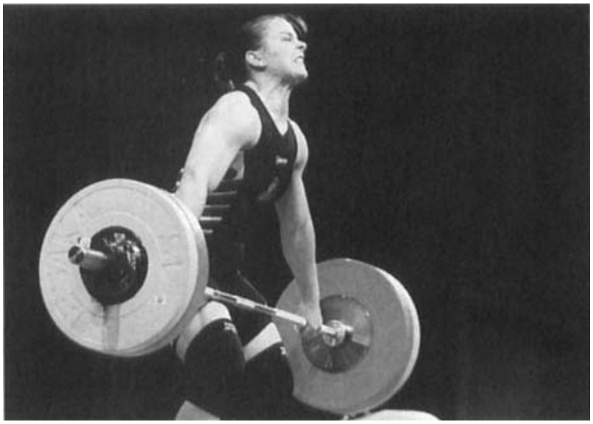

Fig. 1.3 Many sport events require the power and velocity of movement developed with the basic exercises used in the sport of weightlifting. Photo © Allsport/A. Pretty.

Medvedev, Vasily Alexeev and Yuri Verkhoshansky, helped to pave the way for the growth of weightlifting throughout the world.

Currently, weightlifting is still one of the most popular Olympic sports in many countries. In 1987, the first women's world championships was held, and women's weightlifting became a medal sport in the 2000 Olympic Games in Sydney, Australia. Many athletes from other sports currently utilize training methods used by weightlifters. Because of the combination of extremely high barbell velocities and large loads used for the snatch, and the clean and jerk lifts, tremendous levels of power may be generated. As most sporting endeavours require such forces and velocities, the carry-over of weightlifting movements to other sporting activities is readily apparent.

Body building

Contrary to most lifting sports, where lifting maximal weights is the ultimate goal, body building's attraction is the extreme muscular development attained by its participants. Ever since Eugene Sandow amazed the public with his hypertrophied appearance and astounding muscular control in the Ziegfeld vaudeville shows, this sport has attracted a growing and dedicated following. During the 19th century such muscular development was considered purely an interesting attraction at carnivals and on the vaudeville stage and it was not until 1903 that body building began to be organized into an actual competitive contest. Under the guidance of Bernarr MacFadden, publisher of the popular magazine *Physical Culture*, the first competition was held in Madison Square Garden in New York City in 1903. At this time, body building was quite different from the sport as we know it today. Contestants were expected to display physical ability in a variety of manners, and competitors came from many different sporting backgrounds. As there was no established set of rules for body building, the promoters could modify the rules in attempts to maximize the entertainment appeal. These early contests often included various demonstrations of physical ability in addition to the development of a muscular build.

Perhaps the most famous early body builder was Charles Atlas who was awarded the title of the 'World's Most Perfectly Developed Man' in 1921. Charles Atlas would dominate such contests for a number of years. Through his extensive advertising campaign in many of the popular magazines of the next 50 years, many followers became familiar with his promotion of muscular development. Such promotions encouraged skinny young men to avoid getting 'sand kicked in your face' at the beach by becoming more muscular and manly. In this manner, the young lad would retain the admiration of the bikini-clad young lady nearby. This advertising was one of the first portrayals of the fitness industry's use of sexual attraction and sexuality that is so rampant in today's popular body building and fitness publications. It was also through these advertisements that Charles Atlas misleadingly promoted the idea that his own muscularity had been attained by his 'dynamic tension' method of isometric training.

In 1938, the Amateur Athletic Association of the USA sanctioned the first Mr America contest. The 1940 Mr America competition was won by John Grimek, considered by many to be the first modern body building champion. Grimek first embodied the muscular hypertrophy, body symmetry and stage presence that has become so critical for success in this sport. Body building began a tremendous growth in popularity over the next half century. In 1950, the National Amateur British Bodybuilding Association (NABBA) sponsored the first Mr Universe contest, indicative of the sport's growing worldwide appeal. In 1965, the International Federation of Body Builders

(IFBB) promoted the first Mr Olympia, the event that has become the premier competition for the entire sport. Additional high profile contests were sanctioned by the World Body Building Guild (WBBG). Participation by women has also grown, with the first Ms Universe contested in 1965, and Ms Olympia in 1980. Today, as a result of extremely effective marketing by the fitness industry, body building may be the competitive lifting sport most familiar to the average lay person. Numerous sports have incorporated body building training methods, especially when muscular growth is a desired trait.

Power lifting

Consisting of the competitive lifts—the barbell squat, the bench press and the dead lift—power lifting is most popular in North America. Its popularity may be partially attributed to the fact that extremely heavy loads may be lifted, and the need for the close supervision of a coach is less than for the sport of weightlifting. While proper lifting technique is undoubtedly vital for success in this sport, the technique may be adequately mastered much faster than for the weightlifting movements. When first contested, the sport was referred to as the 'odd lifts' because it did not include either the snatch, the clean and press, or the clean and jerk. Worldwide organization of the sport falls under the auspices of the International Powerlifting Federation (IPF). Initially organized in the USA by the AAU, the sport was later administered by the US Powerlifting Federation (USPF), and has since undergone several reorganizations. Through the years, the USA has dominated international power lifting. The first US championships were held in 1964, and the first world championships were held in 1971. As with the other lifting sports, women have become very competitive in power lifting, with the first US women's championships held in 1978, and the first women's world championships contested in 1980. Contrary to its name, maximal efforts in the power lifting events do not develop high levels of power because of the slow movement speed with maximal lifts (power = force × velocity). Instead, the forces developed are extremely high, with world record loads exceeding 450 kg (approximately 1000 lb) for the squat, 320 kg (approximately 700 lb) for the bench press and 410 kg (approximately 900 lb) for the dead lift. Athletes from a wide variety of sports have incorporated the training methods used for power lifting when high levels of muscular force development are required for their sports.

Other sports

Over the past half century, resistance exercise has gained popularity through its use for sports other than weightlifting, body building or power lifting. However, there was often much resistance to strength training because of misconceptions regarding the results. Among the first sports to readily accept resistance exercise to enhance sporting performance were the throwers in track and field. As early as the 1950s and 1960s, the benefits of strength training were readily apparent to these athletes. The four-time Olympic gold medal winner in the discus, Al Oerter (Fig. 1.4), was a devoted strength trainer from an early age, and attributed part of his success to his lifting. Interestingly, one of Al Oerter's early US Olympic track and field coaches instructed him not to involve himself with any strength training for fear that it would hurt his throwing ability. Fortunately, he paid little attention to this, and the rest is part of Olympic history.

In the late 1960s and early 1970s, the sport of American football paved the way for the use of strength training for sporting purposes. Probably the dominant sport on many US college campuses, the use of resistance exercise spilled over to numerous other college sports. In the 1960s, professional American football hired the first full-time professional strength coaches, with the San Diego Chargers and the Chicago Bears leading the way. In Europe, the use of strength training for sporting purposes was at times more readily accepted than in North America, partly because of the input of sport scientists. It is also likely that the confusion created in North America from commercial misinformation had less of an effect on the other side of the Atlantic.

Strength training research

Interestingly, in the early days of strength training research few had extensive personal experience with the modality. One of the earliest researchers to focus on the physiology of muscular strength was

Fig. 1.4 Strength training was promoted by its successful use in the days when it was relatively uncommon as a conditioning modality. Photo © Allsport.

Dudley Allen Sargent (1849–1924), a Harvard-trained medical doctor. Working at Harvard, Dr Sargent developed several methods to assess strength and used these tests to help sport coaches select members of their teams. He developed the well-known Sargent vertical jump test which he called a 'fair physical test of man'. It is still one of the simplest and most effective measures of lower body muscular power. But, as others had been before him, Sargent was hesitant to recommend the use of heavy weights, preferring instead to suggest only the use of light weights. For many years Sargent's advice was taken to heart by many, as evidenced by training facilities that had devices that accommodated only light loads (e.g. wall pulley systems), with no heavy free weights available.

The British physiologist Archibald V. Hill carried out much research on muscle performance. Although he spent much of his research efforts on the muscle of aerobically trained individuals, his work was instrumental to the understanding of skeletal muscle structure and function. In 1922, together with his colleague Otto Meyerhof, Hill was awarded the Nobel prize for his scientific accomplishments. The German physiologist Werner W. Siebert was the first to determine that gross muscle hypertrophy, such as observed with strength training, was caused by the increasing size of the muscle fibres, not to an increased number of fibres (i.e. hyperplasia).

In 1948, T.L. DeLorme and A.S. Watkins made a significant breakthrough in the scientific study of resistance exercise. Working with soldiers being rehabilitated from injuries suffered during World War II, Watkins developed a structured long-term training programme that would counter the debilitating effects of muscle atrophy common in this population. Watkins determined that a 10 repetition maximum (10 RM) load was optimal for muscle growth. Originally, he stated that 70–100 repetitions per exercise were required for positive results, but later amended it to 20–30 repetitions per exercise. German physiologist Erich A. Müller, with his colleague Theodor Hettinger, contributed to the field in 1953 with his observations that isometric exercise could contribute to muscle strength gains. In 1961 the Russian scientist L.P. Matveyev greatly expanded on the concept of a structured training programme and his model of periodization provides the basis for much of the current resistance exercise training theory.

The 1960s marked a significant increase in the applied study of resistance exercise. This research activity is perhaps best exemplified by the work of Richard A. Berger who performed a number of investigations over the next few decades, designed to study the efficacy of variations in the resistance exercise training stimulus. Using various combinations of sets, repetitions and relative intensities, Berger helped clarify the importance of proper resistance exercise prescription. Ironically, however, even today there are those who propose training methods that are contrary to the research generated almost a half century ago.

In recent years, the sport science community has placed a greater emphasis on the importance of resistance exercise. Numerous professional sport science organizations have helped support this increased emphasis, such as the American College of Sports Medicine, the European College of Sport Science and the International Federation of Sports Medicine. One of the leading organizations for the study and promotion of optimal performance through resistance exercise is the National Strength and Conditioning Association (NSCA). Founded in 1978, this organization has done much to legitimize the role of resistance exercise, not only for sporting populations but also for a myriad of other applications (e.g. fitness and health). With members around the world, it was the first organization to have as its primary aim sporting enhancement through total strength and conditioning programmes. Its research journal *The Journal of Strength and Conditioning Research*, established in 1987, has grown into the only targeted journal focused on this aspect of scientific research. Its educational aim is to 'bridge the gap' between the scientists and field practitioners.

Undoubtedly, resistance exercise will continue to evolve as new training methods and applications are developed. With the new 'information age' the amount of misinformation, poor science, corporate influences and emotional opinions will challenge the ability of professionals to evaluate information and determine its context and meaning to them as they develop strength training programmes. Through the combined efforts of athletes, coaches, the medical community and sport scientists, the effectiveness of such training will continue to improve and contribute to the sporting performances of the future. Ultimately it is the athlete who should benefit from the whole process. The responsibility of sport medicine professionals is to give the athlete the best available advice based on sound science and professional judgements, thereby allowing them to optimize their physical development and help them to reach their potential and realize their dreams!

Basic principles of resistance training

This section provides information on the basic principles of resistance training. This will serve as an introduction to the science of resistance training as well as prepare the reader for more specialized topics in the later chapters.

Muscle actions

Muscle tissue is quite unique in that it can develop force in response to an electrical stimulus carried by the nerves from the area of the brain that controls movement. When the muscle responds, the force (pulling effect) it develops is applied to the bones to which it is attached resulting in a turning effect or *torque* about the joint between the bones. The resulting action is dependent on how strongly the muscle is stimulated and the degree to which it will develop force. There are three possible outcomes (Fig. 1.5).

1 *Isometric action.* Torque produced by the muscle will be opposed by an equal torque and no movement will occur.

2 *Concentric action.* Torque produced by the muscle will be greater than the resistance to movement and the bones will move as the muscle shortens.

3 *Eccentric action.* Torque produced by the muscle will be opposed by a greater torque opposing the muscle action and the bones will move as the muscle is lengthened by this resistance.

Isometric actions are also termed 'static' as no movement occurs. However, in natural movements a concentric action is often preceded by an eccentric action. This is called a stretch-shortening cycle (SSC). Concentric and eccentric actions and SSC are termed dynamic because movement results. To produce the highly skilled movement of which the human body is capable, force production of the many hundreds of muscles in the body has to be precisely controlled.

How is the force of the muscle action controlled?

Neural control of muscle actions is quite complex, particularly when one considers the adaptations that occur with training.

Motor unit recruitment

The basic functional unit of the neuromuscular system is the motor unit. A motor unit is composed of a neurone running from the CNS to the muscle at which point its axons split and connect to the surface of the muscle fibres. The neurone and the fibres it innervates

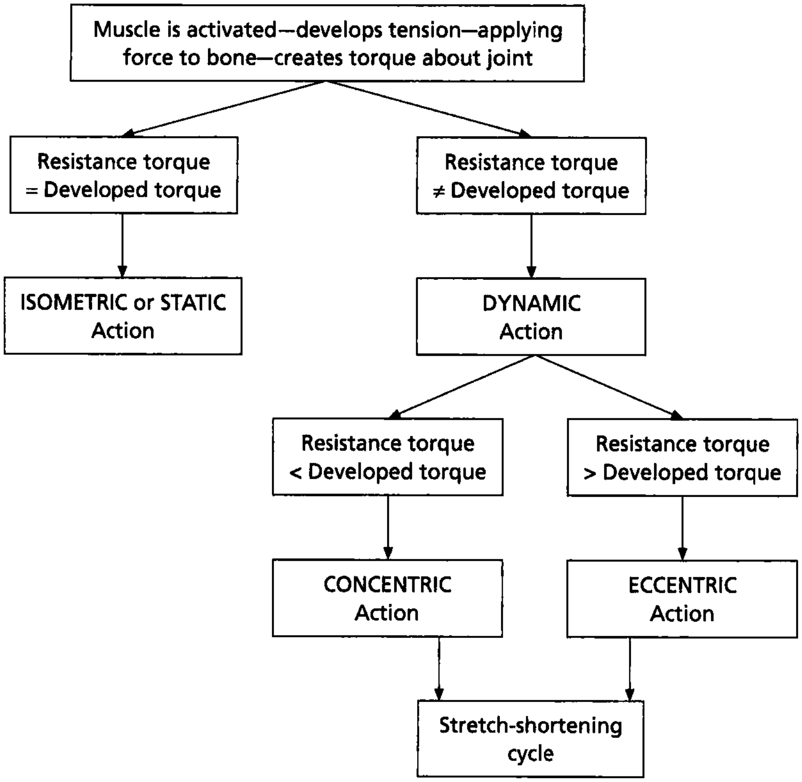

Fig. 1.5 Possible outcomes of muscle activation.

are termed a motor unit. Each motor unit may consist of tens or even hundreds of muscle fibres, and each muscle might include many hundreds of motor units. To produce a given muscle action, the brain 'recruits' or activates a certain percentage of the motor units contained in that muscle. Thus, one method of increasing or decreasing the force produced by the muscle is to recruit more or less of the total number of motor units.

Not all of the motor units in a muscle have an equal chance of being activated at a given level of force because most muscles of the body have a mixture of different types of motor units with specific capabilities. Some motor units are better suited to producing high forces at a fast rate and the muscle fibres in these motor units are called fast twitch. There are other motor units that are specialized for producing force repeatedly or over a long period of time. They have high endurance. The muscle fibres in these motor units are called slow twitch. This is a very versatile mechanism because by having a mixture of types of motor unit making up a muscle and its neural activator provides the muscle with both endurance and strength. The 'Size Principle' states that at low levels of muscle actions, only the slow motor units will be recruited; however, as we increase the force up to maximal development more of the fast motor units are recruited. In addition, under special circumstances selective recruitment of fast motor units (e.g. high threshold motor units) can be recruited first with the slow motor units inhibited to optimize the performance of fast muscle actions. It is thought that this may be an important training adaptation for speed/power athletes.

Firing frequency

Muscle fibres are activated by a train of electrical impulses transmitted down the neurone. Increasing the firing rate (frequency) with which these impulses are sent down the neurone is a mechanism by which a single motor unit can increase the force it produces. It has been observed that during maximal voluntary actions the firing rate is well above that required to elicit maximum isometric force. The high rate will, however, result in an increased rate of force development with the highest motor unit firing rates being recorded during maximal ballistic actions.

Modification by muscle and tendon receptors

The nervous system has many mechanisms for providing feedback in the form of information on the forces applied, joint position and muscle length changes. This is necessary so that movement can be monitored and controlled and also to prevent injury by limiting the contraction force of the muscles. The stretch reflex is mediated by receptors in the muscle and muscle spindle. Research has indicated that this reflex may be one reason why a muscle can produce more force after it has been suddenly stretched. This mechanism is important in what are termed SSC movements that predominate in most sports. The Golgi tendon organ may have a role in inhibiting the force production of muscle to prevent forces being produced which could tear muscle and tendon. However, the function of this reflex is still controversial.

Coordination and skill

The expression of strength is determined by the interaction between agonists, antagonists and synergists involved in the joint movement. To produce high force the agonist muscle must be able to apply great force and there must be a complementary relaxation of the antagonists (ranging from 10 to 80%). This requires the development of coordination and, as such, strength is very much a learned skill.

Characteristics of muscle tissue affecting strength

Muscle cross-sectional area

There is a clear relationship between the cross-sectional area of the muscle and the force that the muscle can produce. Thus, in general, the larger the muscle then the stronger it is. For this reason a primary goal of many strength programmes is to produce hypertrophy, an increase in muscle size, because, regardless of all the other factors discussed, strength will increase with muscle growth.

Muscle fibre type

Muscle is composed of two broad categories of fibre type and their classification is based on how fast they contract (twitch speed) vs. how much endurance they possess. Thus, slow twitch fibres (Type I fibres) and fast twitch fibres (Type II fibres) are the basic broad categories of muscle fibres that exist in the human body. Because of differences in the proteins that make up the contractile machinery, the structures which mediate force development and the enzymes that limit the speed of the chemical reactions resulting in force development, fast twitch fibres can produce more force per cross-sectional area than slow twitch fibres. Furthermore, fast twitch fibres can produce higher maximal power output. Thus, an athlete with a high proportion of fast twitch fibres in their muscles will be inherently stronger, faster and more powerful than a person who has predominantly slow twitch. At the extreme ends of the running spectrum, this would be demonstrated by athletes such as marathon runners, who have a high percentage of slow twitch muscle fibres and, at the other end, 100-m sprinters who have a high percentage of fast twitch fibres, which help mediate their performances. Many athletes need a variety of physiological capabilities and therefore have a combination of fibre types, tending to be around the 50% slow and 50% fast twitch fibre range ± 10% depending on the differences in the demands of their sports (e.g. soccer players and tennis players).

The percentage of muscle fibre types and the number and size of muscle fibres found in the muscles of an athlete will in part dictate force, power, speed and endurance capabilities available upon recruitment of the motor units. With the use of the 'Size Principle', resistance training typically recruits both slow and fast twitch muscle fibres with increasing loads. Again, under certain circumstances with power training, inhibition of the slow twitch motor units occurs and selective use of the fast twitch motor units may be seen (Fig. 1.6).

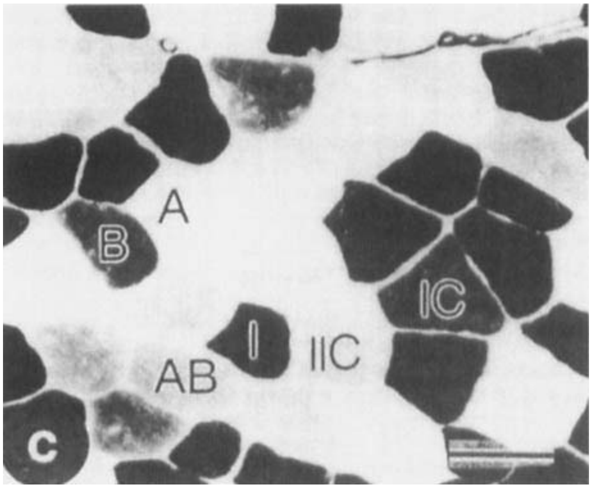

Fig. 1.6 Human skeletal muscle fibres. Histochemical staining at pH 4.6, black fibres Types I and IC (slow twitch); white fibres Types IIA and IIC and grey fibres Types IIAB and IIB (fast twitch). (Courtesy of Dr Robert S. Staron, Ohio University.)

Strength training

Adaptation

If a lift in a building was required to carry its maximum capacity from the ground floor to the roof top each day it would not increase in its performance and be able to carry more people. It is more likely to deteriorate: its bearings will wear, the electric motor will become less efficient and overall performance will decline. The human body is a very different machine because it has the ability to respond to a stimulus, such as the work of running or the stress of lifting weights, by altering its very structure and function to be able to perform that activity better in the future. This is termed *adaptation* and it is the basis of physical training. A number of features of adaptation must be considered.

First, the body must have a biological mechanism enabling it to make the adaptation. For example, shortening the length of the bones of the upper arm and forearm would greatly increase the amount of weight that could be lifted in the bench press as a result of increased mechanical advantage, but is not a process the body is capable of undertaking. Increasing the size of the muscles that perform the bench press would also allow the body to lift more weight and this is certainly an adaptation that is within our physiological capabilities. Secondly, the adaptation is very specific to the stimuli, such that heavy strength training tends to produce an increase in muscle size, whereas swimming produces an increase in the heart's ability to pump blood. The concept of specificity will be discussed in more detail later in this chapter.

Progressive overload

A training adaptation occurs in response to a progressive 'overload'; a situation in which the body is required to perform exercise beyond which it is accustomed or which is seen in normal daily activities. In terms of strength training, this overload is the requirement of the neuromuscular system to exert forces which are more than those required during the activities of daily living. In general, the extent of the training adaptation is related to the degree of overload such that, in general, greater overload results in more rapid and larger biological changes (Fig. 1.7). However, this process involves both neural and hypertrophic adaptations in muscle and long-term progression requires proper progression through periodized training programmes which will be discussed below.

Minimum intensity

When training for strength, there appears to be a load below which no training adaptation will result (Fig. 1.7). This may vary depending on training state, muscle group and between individuals; however, the lifting of very light loads without maximal effort seems to be ineffective for increasing strength and muscle power.

Progressive resistance training

In order to stimulate the neuromuscular system toward adaptations conducive to increase muscle strength and power, training must be performed which places the system under greater load than it is accustomed to. This is termed progressive overload and in terms of strength development translates into using the muscles of the body to exert forces at or near

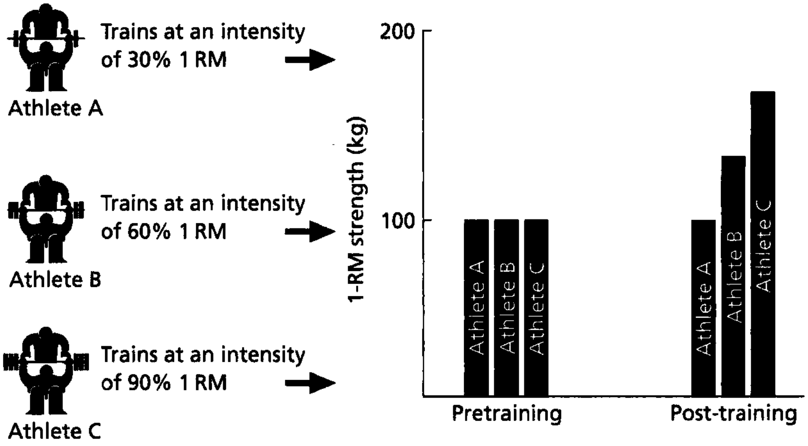

Fig. 1.7 The overload principle dictates that the more a given task exceeds the level and type that the body is accustomed to then the greater the training adaptation. Furthermore, there may be a minimum intensity below which there is no stimulus for adaptation. In this example three theoretical athletes can each bench press 100 kg during a maximum lift before the training programme. Each commences 12 weeks of bench press training with athlete A lifting 30% (30 kg) during each set, athlete B 60% (60 kg) and athlete C 90% (90 kg). Athlete C is training with a greater overload and this results in greater increase in strength than athlete B. Athlete A may not increase in strength at all because such a low intensity is not sufficient overload to stimulate adaptation.

their maximum potential. The neuromuscular system adapts to the training with increases in muscle size, improved coordination of agonists, better motor unit recruitment and, at higher firing frequencies, reductions in antagonist coactivation, and the result is an increase in strength. However, as strength increases, the initial overload becomes less and less relative to the increased strength capability and thus the stimulus to adapt declines if one continues to train progressively with the same absolute loads. Progression of loads becomes paramount and the use of variation in training with multiple plans of periodization is important to adapting to the loading of muscle.

This brings us to the very important concept of progressive resistance training. To continue to elicit gains in muscle strength and power, the loads must be progressively increased in a manner (i.e. periodization of training) so that the relative intensity remains high enough to provide an adequate overload during certain phases of the training cycle. By expressing intensity as percentage of 1 RM (% 1 RM) or specifying a load which can only be lifted a given number of times, the overload is progressive because as strength increases so do the training loads and thus relative intensity is maintained (Fig. 1.8).

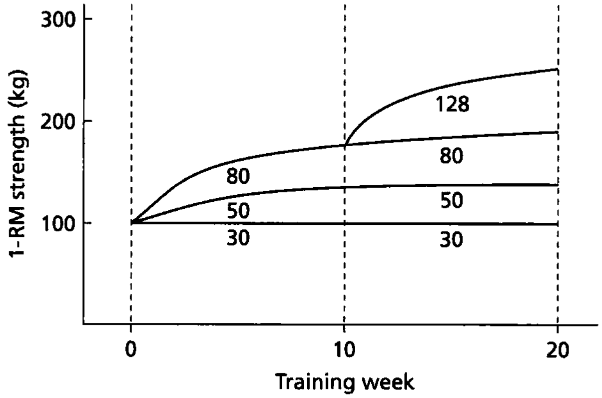

Fig. 1.8 The absolute load must increase as strength increases to maintain the same relative overload. An athlete's pretraining 1-RM strength is 100 kg and he or she begins training at an intensity of 80% (80 kg). If after 10 weeks 1 RM has increased to 160 kg, the relative training intensity of 80 kg is now only 50%. The resistance should be progressively increased to maintain the same relative load.

Repetitions, sets, rest and sessions

Many programme variables can be manipulated to provide various forms of overload and thus result in very specific training adaptations. This will be discussed in more detail in later chapters but it is important to define and understand these programme variables. The basic unit of a resistance training session is the *repetition*. For a given training movement, a repetition is the completion of a whole cycle from the starting position, through the end of the movement and back to the start. For isometric training, a repetition refers to one muscle action at a specific joint angle.

When a series of repetitions is completed this is termed a *set*. During the set, the neuromuscular system will fatigue and performing the exercise will become more difficult. At the completion of the required number of repetitions or when the athlete is no longer able to carry out any more repetitions, the set is completed. He or she then waits until the neuromuscular system recovers and then completes further sets of exercise. The period between sets is called *rest* or *recovery* and is another important programme variable which can be altered to achieve specific training goals (e.g. improved tolerance of high acidic conditions). During an exercise session a series of sets of different exercises will be completed. The term exercise *session* refers to the block of time devoted to the training. One can have more than one exercise session in a day if it is separated by a recovery interval.

Intensity, frequency and volume

Intensity refers to the relative load or resistance that the muscle is exercising against; looking at it another way, the percentage of the muscle's maximum force that is to be exerted during the training movement. This is often expressed just in this manner as '% of 1 RM', the load lifted as a percentage of the maximum that the individual can lift only once. Another common method for describing intensity is in terms of repetition maximum. That is, the intensity is described in terms of how many repetitions can be completed before muscular failure occurs and the load cannot be lifted again. Repetition maximum zones are also used where the athlete does not have to target a precise number but be within a three repetition zone (e.g. 6–8 RM). Thus, a 3-RM load is a higher intensity than a 10-RM load and a 1–3 RM zone is a heavier training zone than a 5–6-RM zone.

The number of training sessions completed each week is termed *frequency*. *Volume* gives an indication of the total amount of work that is completed while training. Volume of exercise in resistance training is typically calculated by taking repetitions × sets. Some people use 'sets × repetitions × the resistance used' to determine total work but this is not the classic definition of volume.

Window of adaptation

The degree of adaptation and thus increase in strength that can be realized from resistance training is determined to a large extent by how well the particular strength quality is already developed in the individual. There are biological limits to how much the body can adapt and therefore how strong a person can become. This concept is discussed below. Based on this, the adaptive capacity can be thought of as a range from someone with no strength training experience to the elite strength athlete. For someone with no resistance training background the window of adaptation is quite large and starting a training programme will elicit large and rapid increases in muscle strength. However, as he or she becomes stronger and moves towards his or her genetic potential the window shrinks and gains will become harder to achieve. Several aspects need to be considered here. First, an athlete who has never really trained with weights will increase in strength and power with even the most basic resistance training programme. He or she will then plateau and gains will become harder to produce; here more innovative programming is required. Secondly, after several years of resistance training the athlete will adapt very quickly with limited performance gains to a given resistance training programme and so variation in programming becomes much more important. Ultimately, the closer the athlete is to his or her full potential physiologically the more sophisticated the programmes must be to maintain such a high level of adaptation. This is where the sports medicine professional is challenged and experience comes into play with the management of elite athletes.

Limits to strength development

Regardless of the amount and quality of training there are limits to the maximum force—or any other trainable variable—that can be achieved. These limits are genetically determined and relate to the muscle and bone structure, number of muscle fibres in each muscle, muscle fibre type and endocrine status (e.g. level of testosterone secretion). However, it requires many years or even decades of dedicated training to reach such a limit and from an untrained state the athlete can increase strength several hundred per cent over their careers. In addition, the multitude of adaptations needed by many athletes leads to a continued sophistication in their body's muscular development over time (e.g. from a young novice to a seasoned veteran competitor).

Specificity

Adaptations by the neuromuscular system and thus improvements in performance are specific to the exact type of resistance training performed. This specificity of training applies to all features of the exercise.

1 *Muscle groups involved in the exercise.* Strength will only be increased in the muscle groups used in the training. There are some caveats on this relating to the principle of cross transfer discussed shortly.

2 *Movement pattern.* Because a considerable part of strength adaptation during the initial adaptations involves changes to the neural activation of the muscles, the further one moves away from the specific movement the less the carry-over of strength increases. For example, it has been shown that performing the leg press exercise results in increased strength in that exercise but less strength gain when tested for squat strength which is a very similar but not identical exercise. This specificity relates to posture, timing of joint movement and ranges of joint movement.

3 *Joint ranges of movement.* This will be discussed further because there are other considerations beyond movement pattern alone. The strength increases gained are specific to the joint angles at which one exercises. For example, if one trains using quarter squats where one only squats to a shallow knee angle, strength will be increased as a result of the training. However, if one were required to squat to greater depths, the increases in strength would diminish the deeper the squat. This joint angle specificity is even more evident for isometric training. Research has shown that performing isometric training at a particular angle, for example 90° of elbow flexion, will result in increases in strength. However, if isometric elbow flexor strength is tested at angles other than 90° less strength improvement will be exhibited the further one tests from the training angle.

4 *Velocity of contraction.* Velocity specificity of resistance training is currently one of the most contentious issues in the field of muscle strength and power development. Studies using isokinetic testing and training methods have found that strength increases are specific to the velocity at which one trains. If one trains at a slow movement velocity one tends to increase strength at that velocity, and strength at higher velocities, which are more common in sport, is not effected. Based on this, it has been recommended that resistance training be performed at a high speed if the purpose of the training is to increase power output.

5 *Type of muscle action.* Strength increases are specific to mode of the muscle action used during training. For example, isometric training produces increases in isometric strength but dynamic strength is not altered significantly, or concentric-only training does not produce as large strength gains during eccentric contractions as eccentric training.

Cross transfer

Despite previous comments with regard to the specificity of resistance training it has been observed in a number of studies that the training of one limb is associated with increased voluntary strength in the contralateral untrained limb and the effects of skill training may also be transferred in a similar manner. It appears that the increase in voluntary strength in the untrained limb is attributable to neural adaptation. This is supported by the observation that there is no increase in muscle size, muscle fibre size, or evoked contraction strength in the untrained limb. Perhaps the most interesting example of this phenomenon is the finding that there also may be an increase in strength in a contralateral limb after training with imagined (not real) contractions. However, the meaning of such a finding is presently unclear but cross transfer has been used successfully in injury rehabilitation.

Reversal

Just as the body adapts to overload by increasing

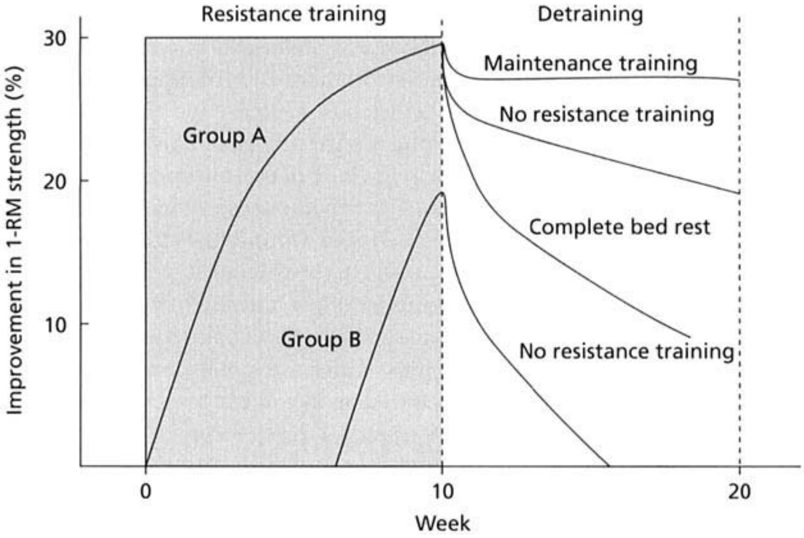

Fig. 1.9 Increases in strength and power diminish when training is reduced. The greater the improvement achieved while training, the longer it takes to return to pretraining levels. Athletes in Group A train for 10 weeks and then undergo various detraining. Group B train for 4 weeks. Training volume can be reduced for Group A and most of the strength gains already achieved will be retained. This is termed *maintenance*.

performance it also modifies capacity in response to a decrease in physical activity. When one stops regular resistance training, the strength level gradually returns to what it was prior to the commencement of the programme. Importantly, the higher the level of strength that was attained through training then the longer it takes to return to pretraining levels (Fig. 1.9). Furthermore, one can reduce the amount of resistance training performed each week and still maintain strength at or near the level that was attained through training. In other words, the volume of training required for *maintenance* of strength is much less than that required achieving a given strength level. Nevertheless, intensity used in such maintenance programmes must remain high.

Interference

Aerobic endurance exercise, such as jogging, swimming or cycling, when performed concurrently with a resistance training programme has the potential to compromise strength and power increases if performed at a high enough intensity and volume. This will be discussed in more detail later in the book. The mechanism appears to be competition between biological adaptations towards increasing muscle strength and power vs. aerobic capacity. The result is that strength and power do not increase to the same degree as they would if only strength training were performed. Often this is a necessity of the target sport or activity. For example, high levels of muscle strength and power are essential to the sport of basketball, but the athlete must also have excellent aerobic endurance to allow them to play at fast pace for the duration of the game.

For most sports the phenomenon of interference can be accommodated by prioritization of training goals using periodization in the training programme. The general goal is to have periods when the focus is to increase muscle size and strength and during these phases the volume of cardiovascular and muscle endurance training is minimized. This permits the body to adapt optimally towards increased strength and power but be aware that aerobic capacity may fall. If the sport requires good aerobic endurance then the athlete needs to train towards this goal and so strength training volume can be reduced in favour of endurance training. Similarly, maximal force and power will decrease during this training phase. The goal, however, is to continue sufficient resistance training to *maintain* strength and power and prevent injury as much as possible during the competitive season although a large volume of endurance training and game play may be interfering with strength and power expression. In basketball it has been shown that the demands of the playing season alone can result in reductions in vertical jump if not accompanied by an in-season heavy resistance training programme.

Variation in training

If one were to designate two factors which should be kept at the forefront when designing resistance training programmes, the first would be the principle of *specificity* already discussed and the second would be *variation* in training. To provide an overload and thus continue to stimulate the body to adapt the training must be novel, it must change in character, and the more novel the task then the greater will be the changes in performance capacity towards the new task.

Here is where the art and science of strength and conditioning come into play. It is relatively straightforward to design a resistance training programme which involves performing, say, three sets of 6 RM with six different exercises. As strength increases then the 6-RM load lifted increases and thus the overload is maintained. However, such a programme involves no variation and will not prove as effective as a programme with greater variation in exercise selection, intensity and volume. Furthermore, going to muscular failure or RM at every workout may also create too much of an overtraining stress and compression on the joints, and variation is required in this aspect of training too. This topic will be covered in greater detail in the later sections on *periodization* but the principle of *variation* relates to changes in programme characteristics to match changing programme goals as well as to provide a changing target for the body to adapt towards. Planned rest periods are also important in the concept of variation in training. Anecdotal evidence suggests that athletes with an extensive resistance training background adapt to a change in programme characteristics much more quickly than a novice. Thus, it is prudent to design resistance training programmes for experienced lifters which vary as often as every 2–4 weeks. The importance of variation in training for maintaining motivation should not be underestimated. Making the programme novel and varying the programme parameters is important to avoid boredom, staleness and overtraining.

All programme parameters can be modified to achieve variation in the training. Intensity and volume are obvious choices and it is well accepted that within a week there should be heavy and light days and the volume should undulate over periods of 4–12 weeks or longer. However, subtle changes to exercise for example may include:

- varying the depth of the squat or leg press exercise;
- performing explosive exercises;
- altering the exercises for the same muscle group;
- slowing the tempo down and using ‘super slow’ training;
- combinations of supersets, prefatigue, upper and lower body combinations; and
- heavy eccentric training.

The key is to alter the nature of the overload to encourage the neuromuscular system to continue to adapt.

Active insufficiency

Many muscles of the body are multiarticulate: they cross more than one joint and therefore can produce movement at each of the joints they cross. However, a muscle can only shorten by a certain amount, typically to 50% of its resting length. The result is that if the muscle is already shortened about one joint then it cannot contract very forcefully to produce movement over the other joint that it crosses. This is termed *active insufficiency* and has significance for resistance training. In selecting certain exercises one can change the emphasis on a given muscle group. For example, when training the calf muscles, ankle plantar flexion can be performed with the knee extended (standing calf raise) or flexed (seated calf raise) and switch the training emphasis from the gastrocnemius to the soleus. In standing calf raise the gastrocnemius is lengthened over the knee joint and so is the primary muscle producing the ankle plantar flexion. However, in a seated calf raise the gastrocnemius is already shortened about the knee joint and cannot contribute much force about the ankle. The soleus becomes the prime mover in this case.

Passive insufficiency

A muscle can only be stretched to a certain extent. Multiarticulate muscles are lengthened over all the joints they cross. If a given muscle is already in a lengthened state to allow movement to the end of range for one joint, then it may not be able to be lengthened further to permit full range of motion at the other joint it crosses. This is termed *passive* *insufficiency*. For an application of this principle to exercise we will again use the gastrocnemius and soleus. To adequately stretch the muscles of the calf one has to perform two stretches: one with the knee extended, which tends to place the gastrocnemius on stretch, and the other with the knee bent to stretch the soleus. As soon as you bend the knee, the gastrocnemius is no longer fully lengthened about the knee and so can allow more dorsiflexion of the ankle. The soleus then becomes the limiting muscle and so is effectively stretched.

Task- and athlete-specific strength

The principle of training *specificity* has already been discussed. Clearly, the neuromuscular system has both neural and muscular avenues for adaptation to training. Depending on the characteristics of the training programme, the capacity for strength and power will alter to fit the requirements while other features may decline. For example, performing very slow heavy resistance training to increase maximal force in, say, the squat exercise, may result in a reduction in ability to rapidly develop muscle force and contract the muscles at high velocity. The result is a reduction in explosive muscle performance. It is therefore essential to determine the specific neuromuscular characteristics required by the target sport activity and then design the resistance training programme to develop strength and power needed which is specific to that task. Often this requires the use of both heavy slow resistance training created by heavy resistances together with the periodized use of lighter resistances (e.g. 30–45% of 1 RM) to develop explosive strength needed for the high power outputs needed in many sports.

Task-specific strength necessitates the specific requirements of the target activity to be determined. A movement analysis must be completed to determine the muscle groups, type of contraction, velocity of movement, requirement for SSC movements, loads lifted or moved, duration of activity, requirements for sustained high energy output, rest periods available and injury risks. From this analysis the aspects of neuromuscular performance that are required can be prioritized and a programme designed which will develop task-specific strength in the athlete.

The less developed a particular component of performance, the greater the window for adaptation. Therefore, it is crucial that the abilities of the athlete are determined and the strength qualities in which they have high levels and those in which they are weak are highlighted. This has been termed *strength diagnosis* and can involve a range of tests of neuromuscular performance to assess all aspects of strength and power performance.

The task- and athlete-specific strength characteristics must then be combined to determine the optimal training programme design. This involves general exercises for strength and power development together with a sport-specific exercise component to any training programme. It is less beneficial to use only sport-specific exercises in a programme as there is a significant transfer gained from general strength power exercises (e.g. normative movements for each of the major muscle groups in the body) to almost every sport. Clearly, if a particular strength quality is found to be a high priority for the task (e.g. rate of force development) and the athlete is considered weak in this quality, training which enhances this ability will have the greatest impact on sport performance.

In the next chapter, the factors involved in training specific characteristics of muscle performance will be discussed. Resistance training is directed toward specific characteristics of muscle that can be enhanced to improve sport performance. These traits are the fundamental core of training-induced adaptations consequent to a resistance training programme.

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Chapter 2

Training-specific characteristics of neuromuscular performance

Neuromuscular adaptation

Training-induced adaptations in the neuromuscular system

The production of maximal force and power, also called the 'explosive strength' of the human body, involves several structural and functional components. The nervous system is divided into three compartments that interact with each other and with the musculoskeletal system (Fig. 2.1). The production of force involves the generation of a command by a high-level controller (central command) which is then transformed by the low-level controller (the spinal cord or brainstem) into motor unit activation of the requisite muscles. The central nervous system has a major role in activating the muscle and in determining the final force (and power) output of a short duration. The commands from the high- and low-level controllers may also be modified by feedback from peripheral sensory receptors or the high-level controller. Most people are unable to attain complete voluntary activation of the muscles partly as a result of a suboptimal corticospinal drive. The degree to which a person can voluntarily activate muscles—maximal voluntary neural drive to the muscle—can depend on the muscle(s) in question to be activated, the type and time/velocity of muscle activation, and the trainability status of the subject. In addition, the coactivation of the antagonist muscles plays a specific part in determining the final net strength production of the agonists in question.

In Fig. 2.1 a schematic summary of the effects that strength and power training can have on the neuromuscular system is presented. Strength and power training leads to specific adaptations in all of the compartments of the nervous system as well as in the muscle tissue itself (Fig. 2.2). Several factors, such as the type, intensity of various exercises as well as the duration of resistance training period, determine the nature and magnitude of training-induced functional and structural adaptations in the neuromuscular system. The degree of training-induced muscle hypertrophy is also influenced by hormonal factors.

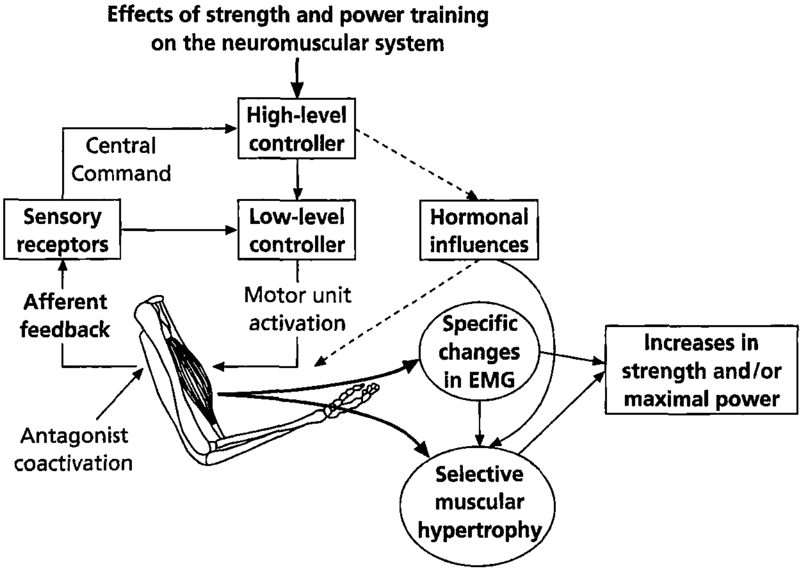

Fig. 2.1 Schematic summary of strength and power training-induced adaptations in the neuromuscular system. (Modified from Häkkinen 1994a.)

Fig. 2.2 Sports-specific strength training leads to specific neuromuscular adaptations needed for optimal performance in sports. Photo © Allsport/G.M. Prior.

Training-induced neural adaptations can be measured using invasive techniques, in which needle or fine-wire electrodes are inserted into muscle (allowing single motor unit recordings) or indirectly, by analysing changes taking place in electromyographic (EMG) activity of the trained muscles (using surface electrodes) recorded during voluntary isometric, concentric, eccentric or stretch-shortening cycle actions. The degree of training-induced muscle hypertrophy can be measured by analysing the size of individual muscle fibres (taking a muscle biopsy) or by analysing the cross-sectional area of the muscle by means of an ultrasonic apparatus, computed tomography or magnetic resonance imaging. The specific changes in various EMG variables and the degree of selective muscular hypertrophy during strength and/or power training are closely related to specific increases in maximal force and power of the trained muscles.

Acute neuromuscular responses to heavy resistance exercise and recovery

Heavy resistance 'neural' session

One of the basic principles of strength training is that a typical heavy resistance training session leads to acute fatigue in the neuromuscular system observed as decreases both in the maximal voluntary neural activation and in maximal force of the exercised muscles. The magnitude of this acute fatigue-induced decrease in the neuromuscular performance is related to the overall volume, intensity and type of the session, the recovery between sets, and muscle fibre distribution as well as to the training background of the subject. Figure 2.3 shows how maximal force of the leg extensors decreased in both male and female strength athletes during the course of an extremely strenuous 'neural' type of training session (20 × 1 × 100% 1 RM). 'Neural' loading refers to a maximal force training session in which very high loads (such as 80–90–100% of 1 RM) are used by performing only a low number of repetitions (such as 1–3) per set. The decreases in strength in both sexes took place gradually but after 8–10 sets became greater in men than those recorded in women. The maximum voluntary activation of the loaded muscles also decreased during the course of the session in both sexes and was slightly greater in men (Fig. 2.4a) than in women. These findings support the suggestion that a heavy resistance session leads to acute fatigue not only in the contractile characteristics of the exercised muscles but also in the nervous system. To which extent the decrease in the discharge rate of motor units may have been caused by the actual decrease in central neural drive and how much it was modified by

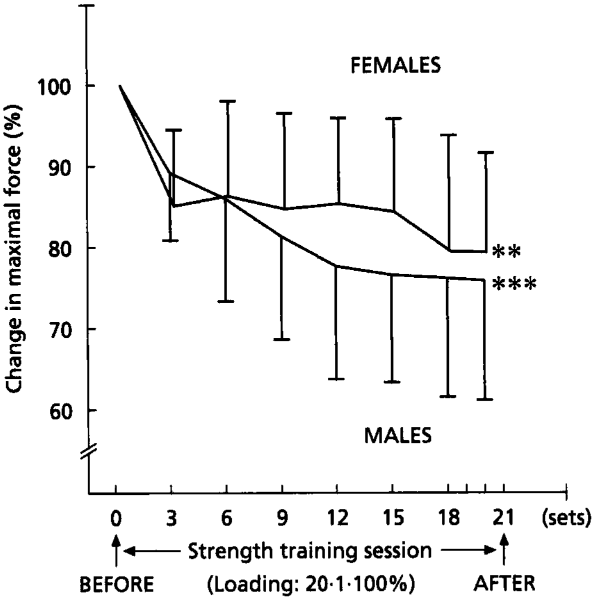

Fig. 2.3 Mean relative changes (± SD) in maximal isometric bilateral leg extension force during the heavy resistance loading session in male and female strength athletes. (From Häkkinen 1993.)

proprioceptive feedback from the muscle is difficult to interpret. The results presented in Fig. 2.4(b) show how the training protocol led to considerable acute changes in the shape of the isometric force–time curve indicating a decrease in the explosive force production of the exercised muscles. This type of loading of the neuromuscular system is accompanied by a significant lengthening in the time of relaxation in both sexes.

The early recovery of maximal force after the above mentioned training session took place in women somewhat quicker than in men (Fig. 2.5). However, the observation that on the second day of rest the maximal force values in both sexes were still slightly lower than their initial pre-exercise values indicates the magnitude of the strain of the loading used. The recording of both neural activation and force production characteristics of the exercised muscles are useful tools in evaluating the loading characteristics during the course (and after) of various strength training sessions in attempts to tailor training sessions for an individual male or female athlete at a given time.

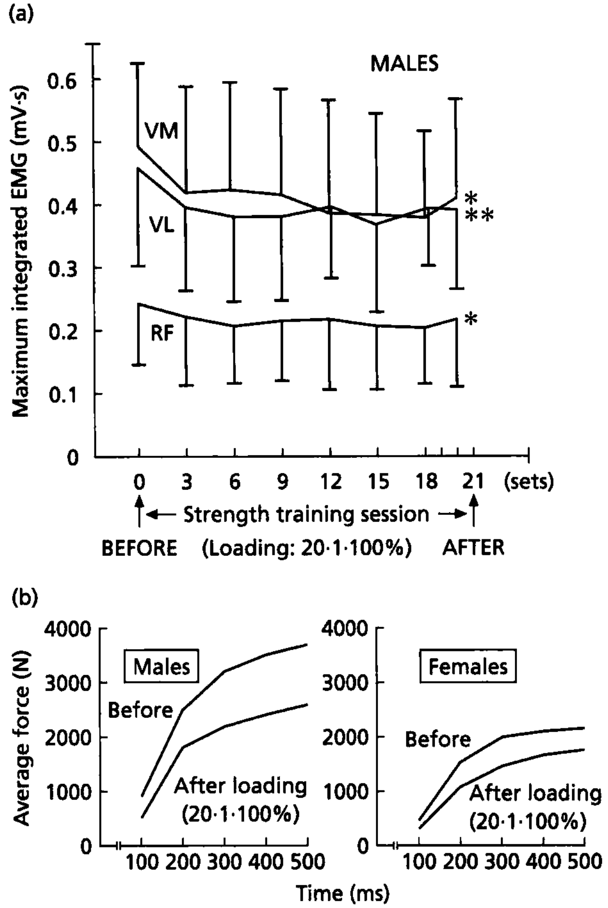

Fig. 2.4 (a) Mean (± SD) maximum voluntary activation (integrated EMGs) of the vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) muscles in the maximal isometric bilateral leg extension action during the heavy resistance loading session in male strength athletes.
(b) Average force–time curves of the leg extensors in the rapidly produced maximal bilateral isometric leg extension action in male and female strength athletes before and immediately after the heavy resistance loading session. (From Häkkinen 1993.)

Heavy resistance 'hypertrophic' session

A typical 'hypertrophic' (usually medium or high loads, such as 60–80% of 1 RM, by performing multiple repetitions, such as 6–12 in each set, until concentric action failure) type of heavy resistance training session with a high volume (such as 4–6 sets) leads to drastic acute fatigue in neuromuscular performance

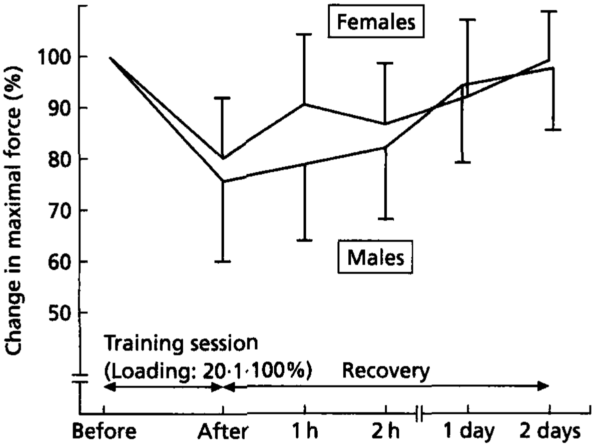

Fig. 2.5 Mean (± SD) relative changes in the maximal bilateral isometric leg extension force in male and female strength athletes immediately after the 'neural' type of heavy resistance loading session and during the recovery period of rest after the termination of the session. (From Häkkinen 1993.)

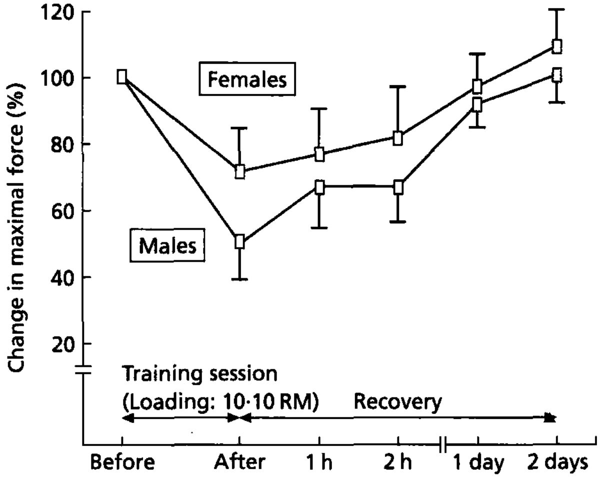

Fig. 2.6 Mean (± SD) relative changes in the maximal bilateral isometric leg extension force in male and female strength athletes immediately after the 'hypertrophic' type of heavy resistance loading session and during the recovery period of rest after the termination of the session. (From Häkkinen 1994a.)

with a great accumulation of blood lactate and a considerable acute hormonal response. Women usually exhibit less fatigue than men. Acute fatigue is observable in the contractile characteristics of the loaded muscles as a marked decrease in maximal force as shown during a high-volume training session in Fig. 2.6 and also by acute worsening in explosive force production and relaxation of the exercised muscles. However, the acute decreases observed in the maximal voluntary activation of the loaded muscles indicate further that considerable fatigue may also take place in the nervous system, because each set was performed until concentric action failure. The magnitude of this acute fatigue-induced decrease in neuromuscular performance is related to the overall volume, intensity and specific type of the session, modified by the recovery between the sets, muscle fibre distribution and the training background of the subject. The recovery from fatigue can take quite a long time and the fact that on the first day of rest the force values in men were still lower than their pre-exercise values (Fig. 2.6) indicates possible sex differences in fatigue and recovery processes from it. Both sexes attained their basal strength levels on the second day of rest, indicating that the overall volume of the hypertrophic protocol used was very high. It is important to point out that despite the recovery in maximal force the basal serum testosterone concentrations remained lowered 2 days after the strenuous hypertrophic session described above.

'Explosive' resistance loading

A typical 'explosive' (low loads such as 30–60%of 1 RM but using high or maximal movement velocity in each repetition) or power-type training session also leads to acute fatigue in the neuromuscular performance in both men and women (Fig. 2.7). This is observable by acute decreases not only in maximal force but also in explosive strength as indicated by the changes in the shape of the force–time curve during the initial portions of the curve. The acute decreases observed during the initial portions (0–100 ms) of the integrated EMG–time curve of the loaded muscles, accompanied by low postloading blood lactate concentrations, suggest that explosive type of loading results primarily in acute central fatigue and/or impaired neuromuscular propagation associated with fewer peripheral aspects of fatigue. The time needed for recovery after explosive types of protocols is related to the overall volume and type of the session, the recovery between the sets, muscle fibre distribution, sex and the training background of the subject (Fig. 2.8).

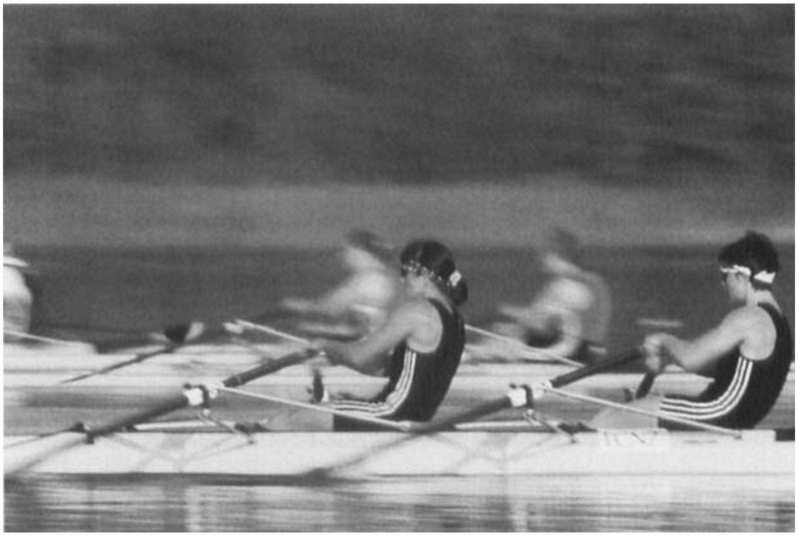

Fig. 2.7 Combinations of explosive power and local muscular endurance are needed by many athletes for success in competition. Photo © Allsport/S. Botterill.

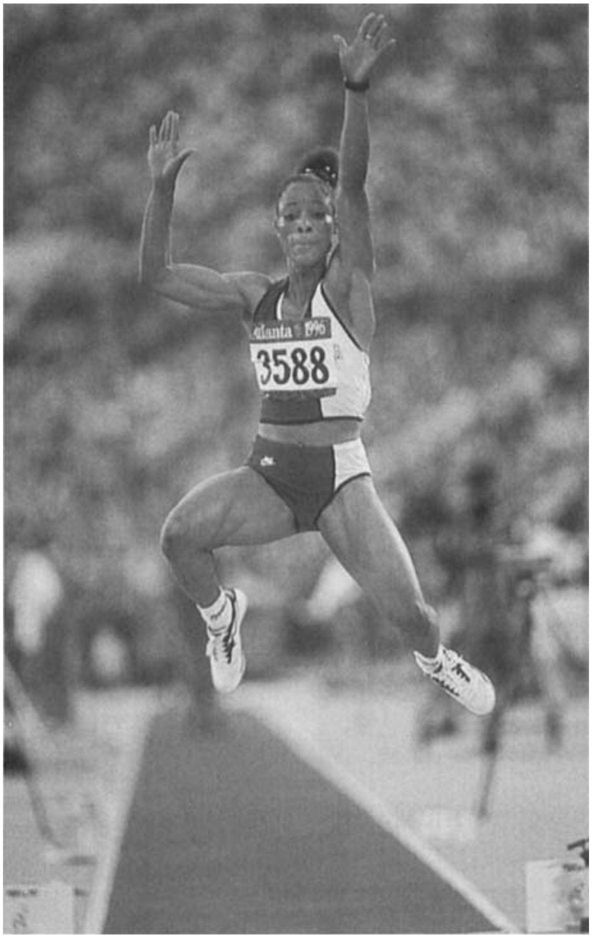

Fig. 2.8 (*left*) In some events, power produced in less than a tenth of a second can impact success in sports performance. Photo © Allsport/T. Duffy.

Neuromuscular adaptations to prolonged strength training

Previously untrained subjects

A major part of the strength gains during the initial weeks or couple of months of strength training in previously untrained men and women is accounted for by adaptations in the facilatory and/or inhibitory neural pathways acting at various levels in the nervous system (see Fig. 2.1). This is also true of athletes who have not previously participated in a strength training programme. Although the actual forms of neural adaptations are difficult to reveal, strength training changes both the quantity and quality of activation so that: (i) activation of the agonists is increased; and/or (ii) there is a reduction in the antagonist coactivation; and/or (iii) there is improved coactivation of the synergists.

An increase in the maximal activation of the agonists is undoubtedly a desirable phenomenon taking place during strength training in both male (Fig. 2.9) and female athletes (Fig. 2.10). However, the time course of neural adaptations may be slightly different between the sexes, because the increases in the maximum EMGs of trained muscles in women

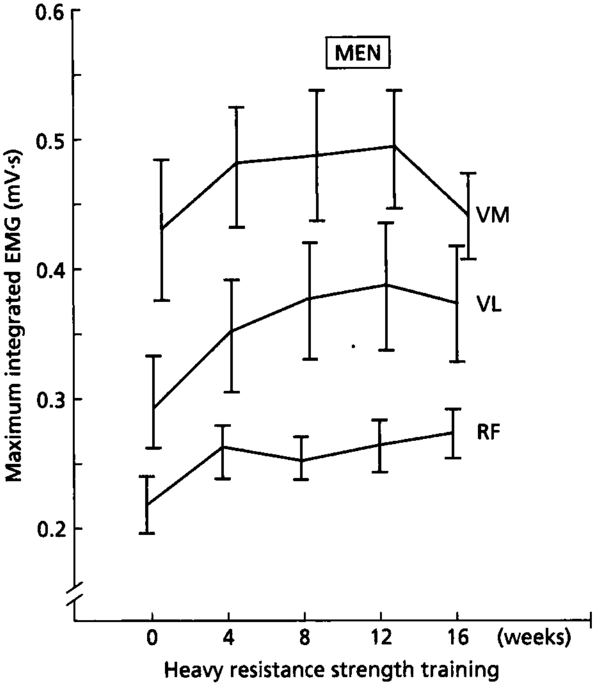

Fig. 2.9 Mean (± SE) maximum voluntary activation (integrated EMGs) of the vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF) muscles in the isometric leg extension action in males during strength training. (From Häkkinen & Komi 1983.)

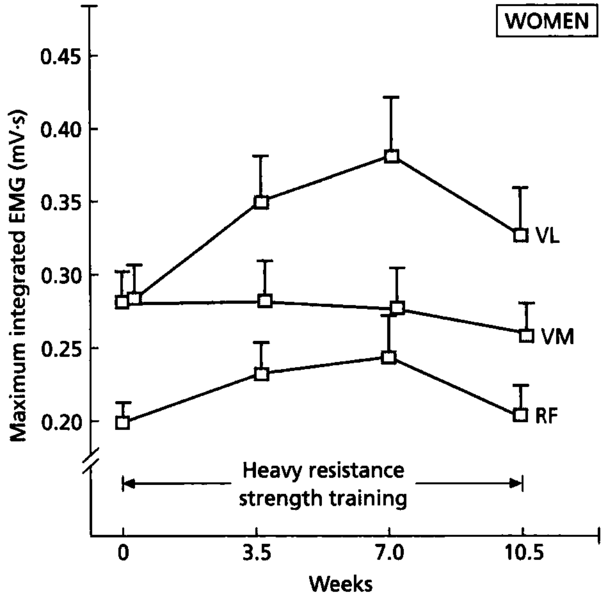

Fig. 2.10 Mean (± SE) maximum voluntary action (integrated EMGs) of the vastus lateralis (VM), vastus medialis (VM) and rectus femoris (RF) muscles in the isometric leg extension action in females during strength training. (From Häkkinen 1994a.)

seemed to plateau slightly earlier than in men. This may have some practical relevance to the planning of the training process to optimize 'neural' strength training stimuli for the nervous system. Nevertheless, the increase in the quantity of EMG in both sexes suggests that the number of motor units recruited have increased and/or the motor units are firing at higher rates, or some combination of the two has taken place. Training can also lead to decreases in coactivation of the antagonists contributing to the net strength development of the agonist muscles.

Prolonged strength training in both men and women leads to muscular hypertrophy of trained muscles. The increase in the cross-sectional area of the muscle comes primarily from the increase in size of individual muscle fibres and to some degree from the increase in non-contractile connective tissue between the fibres, probably with no addition in fibre number. The relative enlargements in muscle cross-sectional area in women during strength training of a few weeks or months are usually similar in magnitude compared to men. Because the magnitude of neural adaptations and the degree of hypertrophy are similar in women and men during short-term strength training of a few months, overall strength development over that time period remains about the same between the sexes. However, women may demonstrate larger interindividual variation in strength development compared to men. As a result of hormonal differences between the sexes, especially in the basic concentration of blood testosterone, the ultimate degree of muscular hypertrophy and strength development caused by strength training will remain smaller in women than in men over prolonged training periods of several months and years.

Explosive resistance training which utilizes lower loads but high movement velocities results in improvements in all force portions of the force–velocity curve, but the changes in the high force portions are smaller than during typical heavy resistance training. Accordingly, explosive resistance training-induced changes in the shape of the force–time curve are greater in the early than the high force portions of the curve. The specific changes are because explosive resistance training results in great increases in the amount of neural input to the trained muscle during a short period of time, as indicated by a specific shift in the early portions of the EMG–time curve of rapid isometric action in both men and women (Fig. 2.11). Power-type strength training-induced adaptations in rapid voluntary and/or reflex-induced neural activation of the trained muscles can be observed during high velocity concentric exercises as well as in various high velocity stretch-shortening cycle exercises (such as drop jumps). Nevertheless, these neural adaptations are primarily responsible for several experimental findings of strength and/or power gains during explosive resistance training with only minor muscular hypertrophy. Although neural activation of agonists during various explosive exercises is very high, the time of this activation is so short that training-induced muscular hypertrophy takes place to a lesser degree than during typical heavy resistance training (Fig. 2.12). Explosive resistance training can also lead to a decrease in the antagonist coactivation. Various maximal force and explosive strength training regimens should be well spaced or even mixed and matched with the specific requirements of the sports event as well as of an individual athlete at a given time.

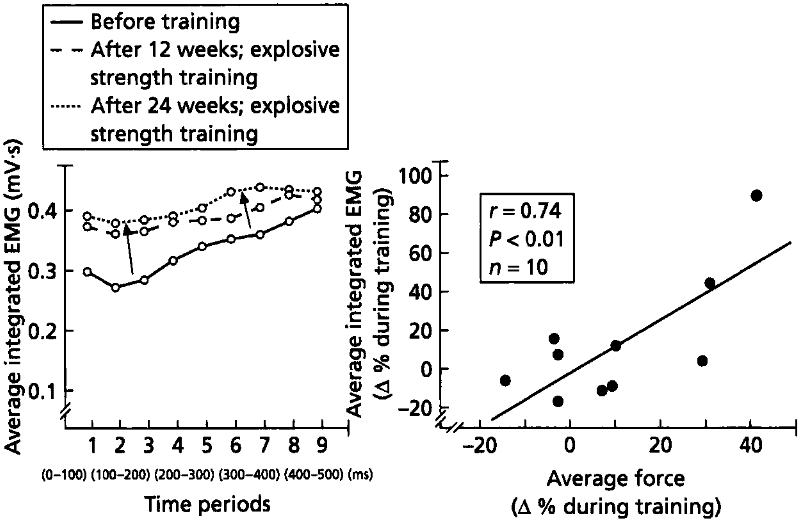

Fig. 2.11 Maximum average voluntary activation (integrated EMG)–time curve of the rapid maximal isometric leg extension action (left) and the relationship between the individual changes in the maximal averaged 'early' (integrated) EMG and the individual changes in average explosive force of the trained muscles (right) in males during explosive strength training. (Modified from Häkkinen 1994a.)

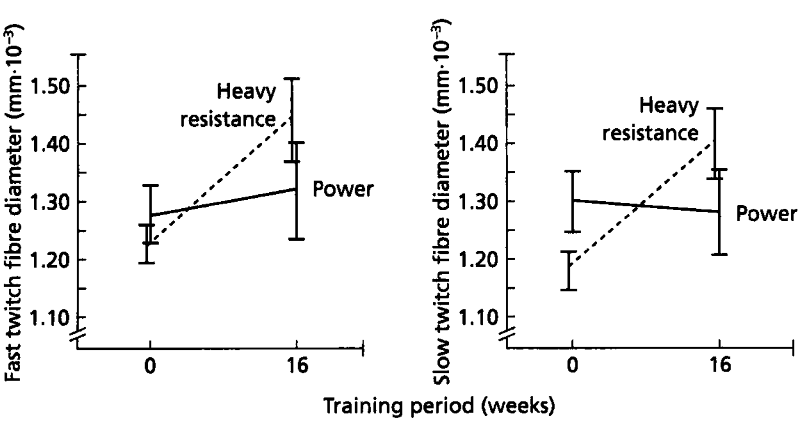

Fig. 2.12 Average fibre areas (diameters) of fast twitch (Type II) and slow twitch (Type I) muscle fibres before and after heavy resistance or power (explosive strength) training. (Modified from Komi *et al.* 1982.)

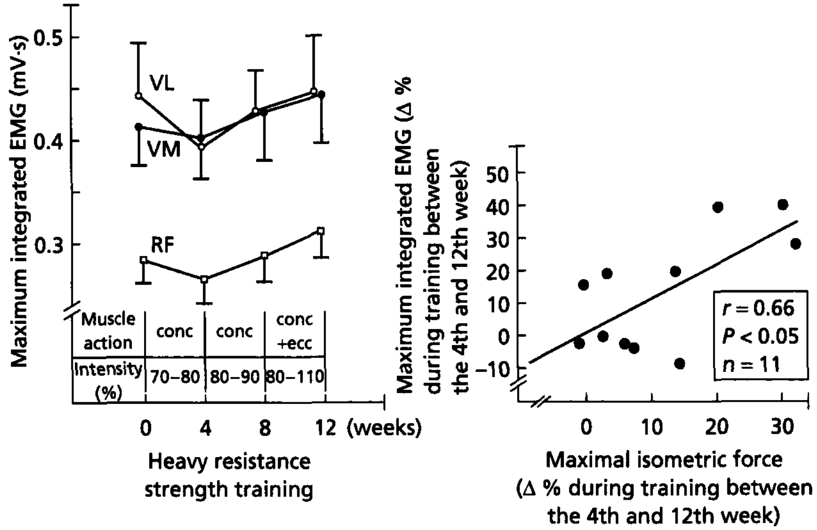

Fig. 2.13 Mean (± SE) maximum voluntary activation (integrated EMGs) of the vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) muscles in the maximal isometric leg extension action and individual changes in integrated EMG and maximal force in males during strength training using different intensities (percentage load ranges of 1 RM). (From Häkkinen *et al.* 1985a.)

Neuromuscular adaptations in strength athletes

'Neural' strength training

It is reasonable to expect that the maximum EMG, after a large initial increase, would only increase at a diminished rate during the later months or years of training. In strength athletes, who already have a strength training background of several years, further increases in the maximum EMG and strength are limited in magnitude. When strength athletes trained for a few weeks with submaximal loads, and performed only submaximal number of repetitions per set, the maximum EMGs decreased (Fig. 2.13). In order to produce further increases in the maximal voluntary neural activation of the muscles, the training intensity in strength athletes should be kept very high or maximal (e.g. 80–90–100% 1 RM) and/or at progressively increasing levels. In addition, the intensity (and volume) of training should be optimally matched to meet individual needs. When only a few repetitions (such as 1–3) are performed in each set of the exercises with very high loads, muscular hypertrophy of trained muscles may remain relatively minor. This is advantageous for many sports, because this type of training may lead to some increase even in the maximal force per cross-sectional area of the muscle.

It is known that strength performance in elite strength athletes may be brought to the peak level not necessarily during a 'normal' training period but more likely after some period of reduced training. A periodical decrease in the volume of training with no changes (or even some increase) in the training intensity has been shown to be advantageous for optimum peaking. Although the mechanisms leading to the optimum peak level are not well known, the short-term increase observed in the maximum EMGs of trained muscles during the reduced training period of 1 week suggests the important role of the nervous system in periodization of training for optimum peaking (Figs 2.14 and 2.15). In addition, the distribution of the volume of training into smaller units—such as two separate training sessions a day—may create more optimal conditions, especially for the nervous system, contributing to further strength development in both male and female strength athletes. Both the volume and loading intensity of strength training in both male and female strength athletes should be matched to meet individual needs at a given time.

'Hypertrophic' strength training

A requirement for training-induced hypertrophy is high tension of a muscle for a sufficient duration which somehow provides the signal for increased uptake of amino acids and enhanced synthesis of contractile proteins. The repeated process of damage

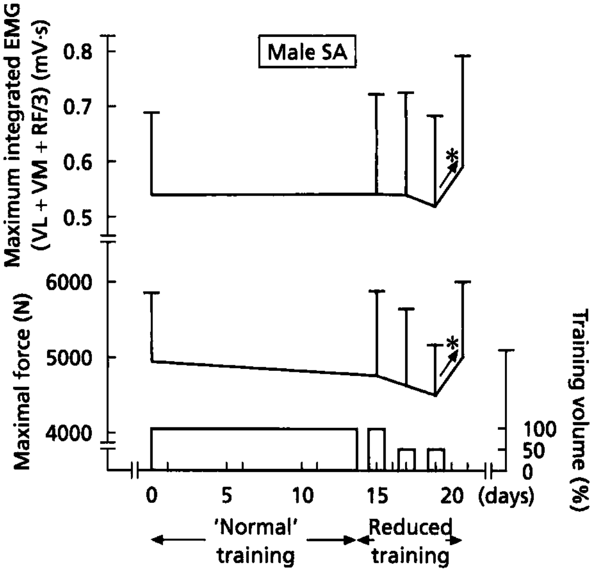

Fig. 2.14 Mean (± SE) maximum voluntary activation (integrated EMGs) of the muscles and maximal force of the isometric leg extension action in male strength athletes (SA) during 'normal' strength training (with high volume) followed by a period of reduced (lowered volume) training. (Modified from Häkkinen *et al.* 1991.)

Fig. 2.15 Periodization of training is vital for optimal peaking in strength and power sports. Photo © Allsport.

and repair during and between training sessions may result in an overshoot of protein synthesis. The ultimate degree of hypertrophy may be obtained by using heavy but submaximal loads (such as 60–80% of 1 RM) and by performing multiple repetitions (such as 6–12) in each set until concentric failure, with a short recovery period between the sets. Muscle hypertrophy can also be non-uniform along the belly of the muscle and between the individual components of the muscle group. The basic serum levels of endogenous anabolic and/or catabolic hormones usually remain within the normal physiological range during strength training of a few weeks or months. However, during more prolonged training periods with high volumes, the individual changes in hormone balance may indicate the trainability status of the athlete creating a greater need for tailored training programmes in order to optimize the training process. In addition, in women, interindividual differences in serum testosterone levels are great and women having lower testosterone levels may not be able to gain the same degree of muscle hypertrophy and strength as women having higher serum testosterone levels. Because of basic hormonal differences between men and women, the ultimate degree of muscle hypertrophy and strength development will be less in women than in men during prolonged hypertrophic strength training of several months and/or years.

Strength development

Effects of different training regimens on maximal force development

Pretraining status

It is well known both from scientific research and practical experience that large initial increases in

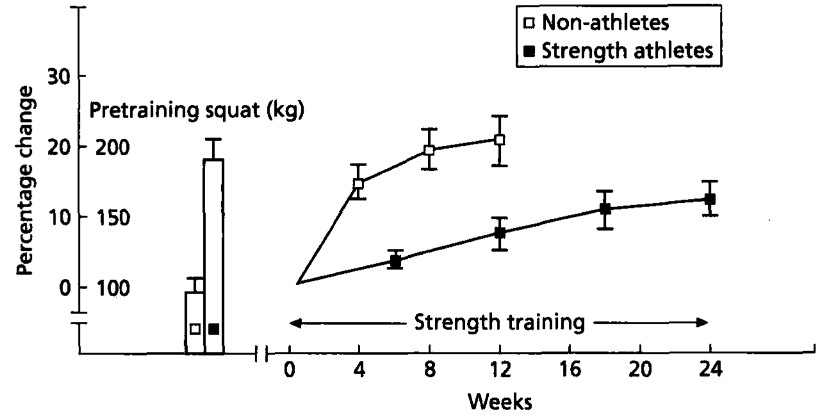

Fig. 2.16 Mean (± SE) maximal pretraining results in the squat lift and the relative changes in the squat during strength training in non-athlete males and male strength athletes. (Modified from Häkkinen *et al.* 1994a.)

strength of initially untrained healthy subjects are rather easily obtained during progressive strength training. For example, increases as great as 10% can be obtained among these subjects after only 1 week of training provided that the training stimulus, especially in terms of the loading intensity (% of 1 RM) is 'sufficient'. On the other hand, among strength athletes such as weightlifters, strength development may be restricted to as little as 2–5% over a 1-year training period. Figure 2.16 shows that individuals who had low initial levels of strength were able to increase their strength after 3 months of heavy resistance training to twice the degree of strength athletes who had 6 months of similar strength training. It is also well known that large interindividual variations occur in strength development, especially during prolonged strength training. If subjects vary with respect to their pretraining status, it is no doubt difficult to compare the effects of different strength training regimens on maximal force development.

Specificity of strength increase during isometric, concentric and eccentric strength training

Isometric strength training

Isometric strength training was very popular and extensively studied by scientists in the 1950s and 1960s. Research concurred with the overload principle, that only an increase in the intensity of muscle activity beyond that previously demanded of a muscle can be used to increase strength during training. Maximal or near maximal contractions have been used in isometric strength training designed to increase muscular strength. The beneficial effect of isometric strength training is obtained when maximal contractions are used and when the product of contraction duration times the number of contractions per day is large. Most gains in isometric strength training are made within a few weeks of the start of training. Further increases in strength after that time require, for example, a change in the training regimen. It is reasonable to make adjustments to the duration of the training contractions as well as to the frequency of the repetitions and sessions to suit the needs of different muscles and athletes. Often isometrics can be specifically used to help develop certain angles in the range of movement which are limiting to the overall performance of the dynamic movement or are sports specific (e.g. wrestling grips) in nature (Fig. 2.17). They provide an additional 'tool' for sports-specific development of exercises.

The specificity of effects of isometric strength training on the neuromuscular system deserves some attention. First, isometric training tends to produce strength gains specific to the joint angle trained. In order to effect strength gains throughout the range of motion, several joint angles need to be trained. Secondly, isometric strength training produces an increase in isometric strength and, to a lesser degree, in dynamic strength. Thirdly, in line with the principle of the specificity of the training, typical high tension isometric strength training has only minor effects on explosive force production of trained muscles. There are practical conditions when

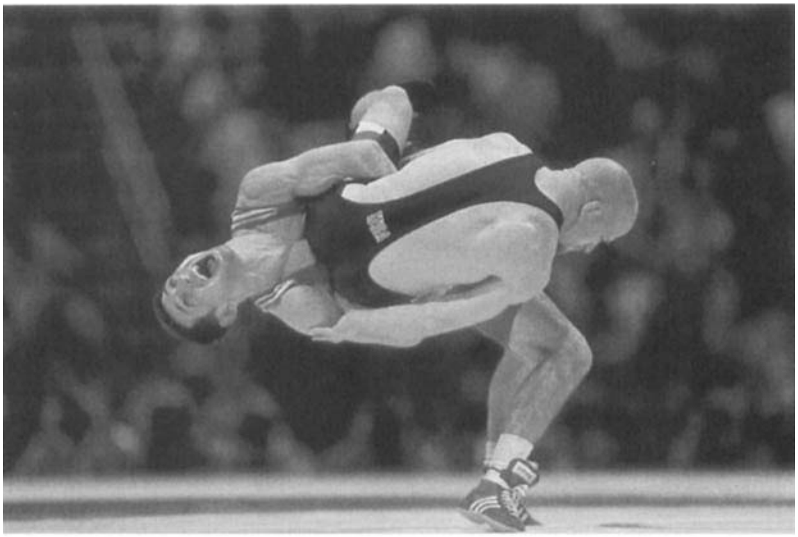

Fig. 2.17 Isometric strength is a vital aspect of many sport performances such as wrestling where hand grips are important to many moves. Photo © Allsport/D. Leah.

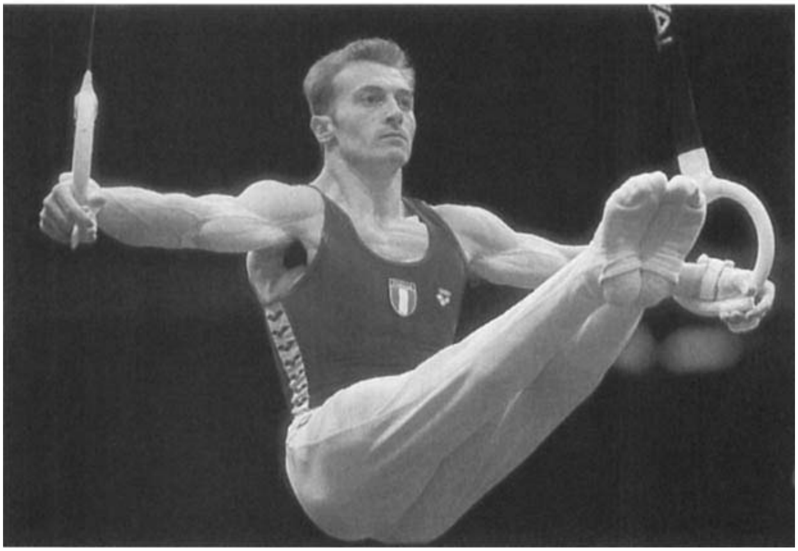

Fig. 2.18 Isometric muscle actions are often used within the context of a dynamic event such as gymnastic routines. Photo © Allsport/M. Powell.

isometric strength training can be successfully utilized; for example, in various forms of rehabilitation as well as during immobilization. It can form a part of an overall strength training programme to bring additional training stimuli to strength development of various athletes (Fig. 2.18). Often it is used in the weight room as a form of 'functional isometrics' where isometric training is performed at the angle where there is a 'sticking point' in the range of motion for an exercise.

Concentric strength training

The basic principles of strength training (concentric strength training) of 'heavy resistance and low repetition' and/or 'progressive resistance' were introduced more than 50 years ago. It is difficult to make exact quantitative observations, but it appears that in line with the overload principle, muscle strength is increased most during concentric strength training by using heavy weights and few repetitions. The ineffectiveness of light loads in increasing maximal force during concentric strength training cannot be avoided by increasing the amount of the total work. In the case of concentric 'isokinetic' strength training it is important to pay attention to the question of specificity of the training. Isokinetic strength training can be effective and useful, for example in rehabilitation; however, it seems to produce an increase specific to isokinetic strength and to a lesser degree in the dynamic strength characteristics of trained muscles. This should be kept in mind, especially in strength training of athletes approaching and during the competition season.

Eccentric strength training

If the overload principle is strictly followed, it might imply that high-tension eccentric actions will result in the greatest increases in strength during training. Eccentric strength training has been investigated extensively since the end of the 1960s. The research findings indicate that training with heavy resistance eccentric exercises is no doubt effective in strengthening muscle but it might not be more effective than either isometric or concentric strength training. The role of training specificity is of importance in the case of eccentric training. Eccentric strength training may lead to increases specific to eccentric strength, while an increase in concentric strength takes place to a lesser degree. Although the most beneficial effects of eccentric strength training result from high loads (such as 120–130% of 1 RM), some caution must be exercised to avoid too simple generalizations of the overload principle (Fig. 2.19).

High tension eccentric strength training is often associated with muscle soreness especially during the initial days and/or weeks of training. The initial training phases may therefore be linked with depressed strength. When the soreness is reduced and/or disappears, eccentric strength training leads to increased muscle strength. Severe muscle soreness can be reduced and/or avoided if the training loads in eccentric exercises are not are maximal during the initial phases of training but are increased gradually during the course of the training. Often, eccentric training can be used as a 'change up' or variation in a training stimulus to provide optimization of the programme.

Fig. 2.19 Eccentric strength is important for many aspects of sports performance such as landing from a vault in gymnastics. Photo courtesy of Ball State University Photo Services.

Comparisons between different contraction types used in strength training

Finding the most beneficial strength training method is one of the targets of scientific research. However, research results on the effects of different strength training regimens on maximal force development have not been totally consistent and sometimes have even been contradictory. A part of this conflict results from the fact that it is easy to demonstrate improvements in muscular strength with various training methods in initially untrained subjects. Moreover, difficulty also exists in comparing results because of a lack of appropriate uniformity in experimental designs. The studies have differed with respect to length of training period, to loads used in each training regimen, to the number of muscle contractions used in the sets and/or in the sessions. Some conflicting results may be partly brought about by the specificity of strength training, because the type of muscle actions used in training and in testing may be interrelated.

It can be concluded that no type of muscle actions—isometric, concentric or eccentric—used in short-term strength training of a few weeks has been proven to be superior. This overall conclusion tends to apply also to other 'subtypes' of strength training, such as 'isokinetic' and/or variable resistance training. During the early weeks of a training period, increases in maximal force are not strictly related to the type of muscle contraction used, because strength is easily increased provided that the loading intensity exceeds normal requirements and the overall amount of training is 'sufficient'. After a couple of months of strength training utilization, combinations of concentric and eccentric training actions may result in greater increases in strength than that of concentric exercise alone. It is reasonable to use mostly concentric training contractions and various combinations of concentric and eccentric (and/or isometric and/or isokinetic) contractions at a given time for additional training stimuli and to avoid a plateau in strength development. Because strength development appears to be very individual, there is also a need for tailored programmes and a proper periodization of strength training. This is true both for men and women.

Specificity of heavy resistance training on the force–velocity and force–time curves

Both scientific and practical attention should be paid to the specificity of strength training on force production characteristics of trained muscles. Typical heavy resistance training which utilizes high training loads with slow contraction velocities tends to lead to improvements primarily in maximal muscle force, i.e. in the high force portions of the force–velocity curve (Fig. 2.20). The influence of strength training becomes gradually less in the high velocity end of the force–velocity curve. However, improvements both in the force and velocity portions of the force–velocity curve take place simultaneously to some degree during strength training only in training conditions where high training loads are produced explosively with an exceptionally short duration. Because the effective time taken by muscles to contract in normal movements, and especially in sporting activities, is known to be very short, the phenomenon of the specificity of strength training should be paid considerable attention for planning proper strength training programmes for athletes of various sports events.

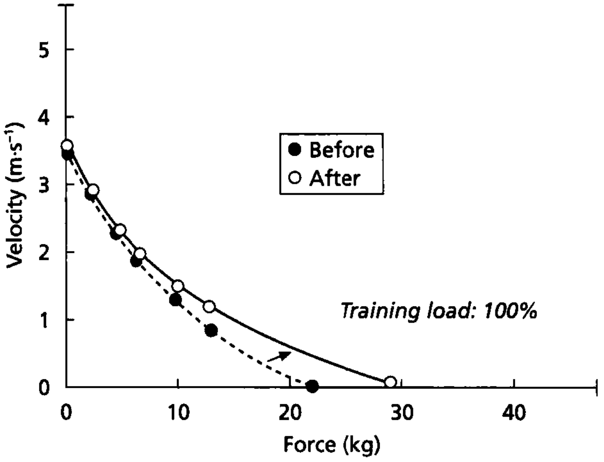

Fig. 2.20 The concentric force–velocity curve of the elbow flexors before and after strength training with high loads. (Modified from Ikai 1970.)

The specificity of heavy resistance training on muscular performance is clearly demonstrable by specific shifts of the isometric force–time curves. The changes during strength training take place primarily in the high force portions of the curve, while the changes become gradually smaller in the very early parts of the force–time curve both in men (Fig. 2.21) and women. The small shifts during strength training in the early portions of the force–time curve tend to take place primarily during the initial few weeks of training. An observation which deserves further attention is that when strength training is continued intensively for several months, no improvements or even some periodic shifts backwards could be observed in the very early portions of the force–time curve. Reduction in explosive force production as early as after a couple of months of strength training may be great during eccentric strength training which

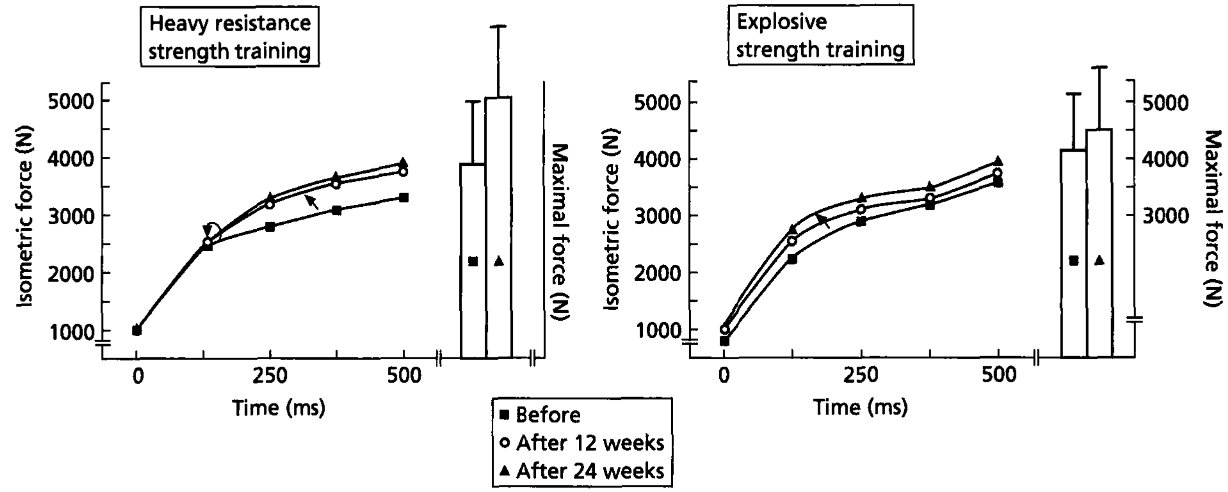

Fig. 2.21 Average force–time curves and maximal peak force of the isometric bilateral leg extension action in males before and after heavy resistance or explosive strength training periods. (Modified from Häkkinen *et al.* 1985a,b.)

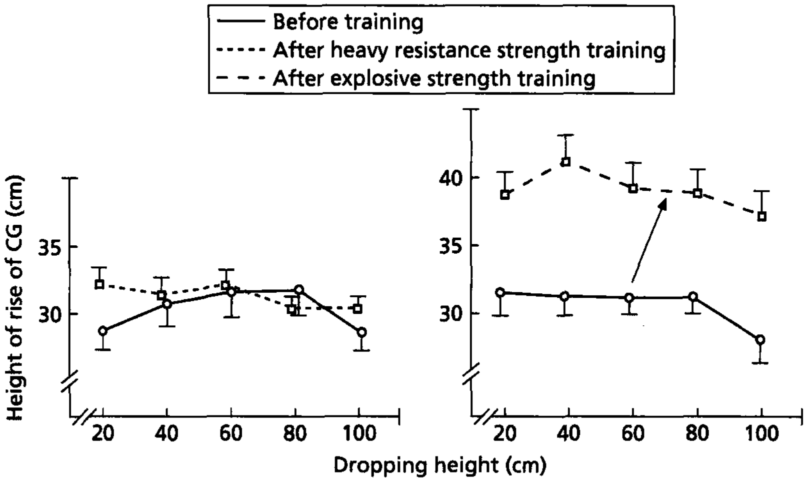

Fig. 2.22 Vertical jumping heights in the drop jumps before and after heavy resistance or explosive strength training. CG, Centre of gravity. (Modified from Häkkinen 1994a.)

utilizes high tension contractions of long duration. Although high tension eccentric strength training may be very beneficial for maximal force development, it should be utilized only periodically to avoid a possible reduction in explosive force production of trained muscles. These observations should be borne in mind when designing resistance training programmes for athletes.

The specificity of heavy resistance strength training on neuromuscular performance can be demonstrated most obviously in stretch-shortening cycle exercises, in which high contraction velocities are utilized. Neither short-term nor prolonged heavy resistance strength training result in marked changes in performance during drop jumps performed from dropping heights from 20 up to 100 cm (Fig. 2.22). This seems to be true with regard both to the tolerance and utilization of different stretch loads. This no doubt has practical relevance in strength training, especially among power athletes.

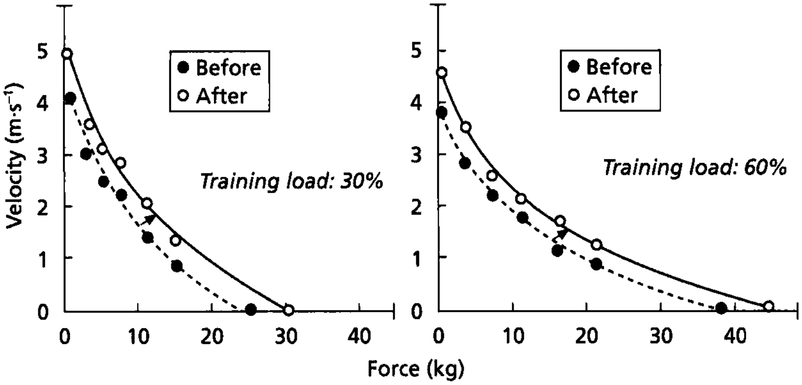

Fig. 2.23 The concentric force–velocity curve of the elbow flexors before and after explosive strength training with a load of 30 or 60% of 1 RM. (Modified from Ikai 1970.)

Power development

Specificity of power-type strength training on the force–velocity and force–time curves

It has been shown that the effect of training on the shape of force–velocity curves is related to the training loads and velocities used. In power training, training loads are usually much lower (such as 30–60% of 1 RM) than in heavy resistance strength training but contraction velocities are much higher. This type of strength training results in improvements in all portions of the force–velocity curve but changes in the high force portions of the curve are smaller than during heavy resistance strength training (Fig. 2.23). On the other hand, if the training is very close to the velocity end of curve, then the training effect is primarily in velocity characteristics. This is true both for men and women. These observations have practical relevance for planning training programmes to match the need for maximal force and explosive force production among athletes.

Power training also influences the force–time curve, so that the changes are relatively greater in the very early portion of the force–time curve than in the high force portion. Figure 2.21 demonstrates the concept of specificity on the shape of the force–time curve between heavy resistance and power training regimens. This specificity is similar in both sexes. Maximal force and explosive strength training regimens should be well spaced or even mixed and matched with the specific requirements of the sports event and with the individual athlete at a given time.

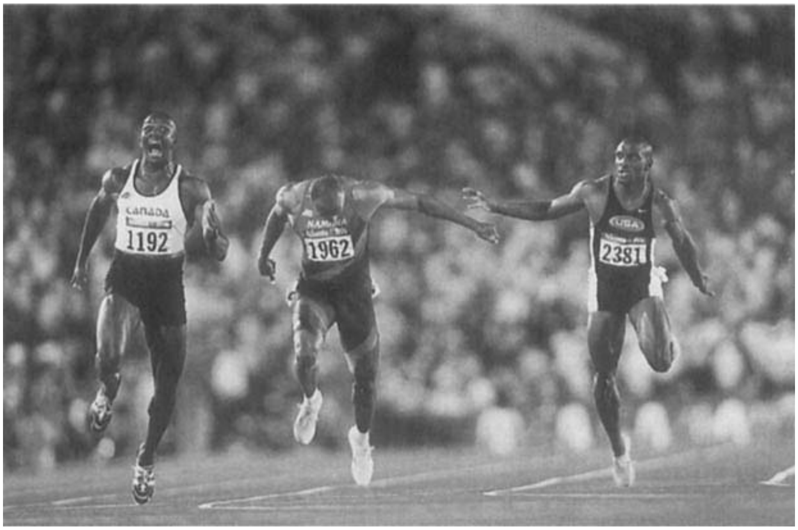

Fig. 2.24 Ballistic, high-velocity lifting is needed to improve power development and transfer training effects to events such as sprinting where foot contact times are < 100 ms. Photo © Allsport/M. Hewitt.

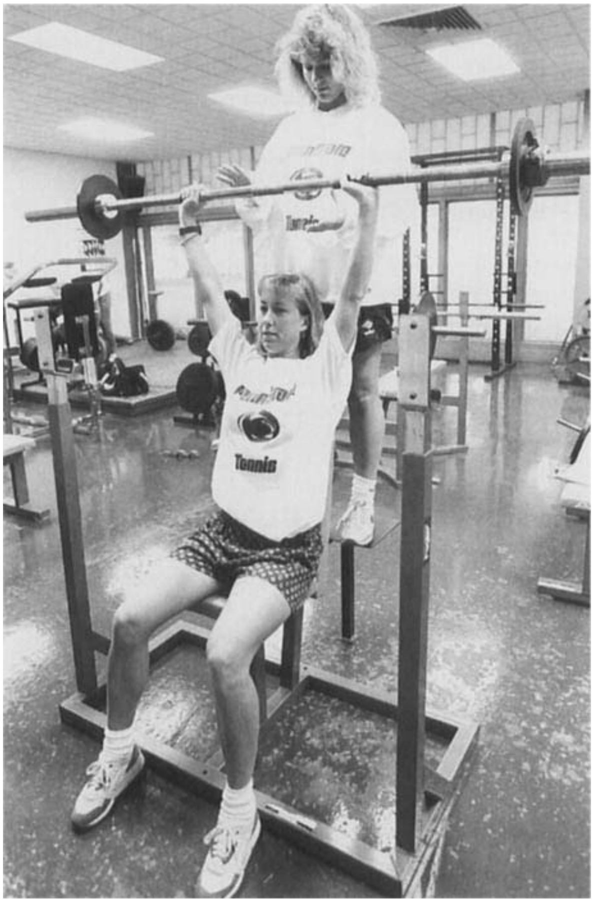

Fig. 2.25 Proper training will assist in the development of sports-specific attributes needed for performance success. Photo © University Photo/Graphics, The Pennsylvania State University/D. Shelly.

The role of muscle elasticity is important for explosive force production of muscles. It is a phenomenon characteristic of stretch-shortening cycle exercises. The influence of power training is pronounced during stretch-shortening cycle exercises in which very high contraction velocities are utilized (Fig. 2.24). In drastic contrast to typical heavy resistance training, power training which includes various specific jumping exercises results in great increases in tolerance to and utilization of stretch loads both in men and women. This is true especially in previously untrained subjects who do not have this type of training background (Fig. 2.25). This type of power training is important for athletes of almost all sports events. However, careful attention should also be paid to the selection of proper stretch loads to optimize the benefits obtained from these type of stretches during training.

The next chapter explores the basic concepts of designing a strength training workout. Understanding the programme variables is vital to making the training session sports specific.

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Chapter 3

Developing a strength training workout

Individualizing a strength training programme

Sport conditioning programmes should optimally be individualized because the limits of performance are highly variable even for athletes within the same sport. This will promote optimal training adaptations. Individual differences in the magnitude of an adaptational response to a given exercise stimulus support the need for the use of individualized programmes. For example, if a whole team performs the same weight programme for the sport the percentage gains in 1-RM strength, power and/or performance will differ among individual athletes as not all athletes will bring the same physiological training status or needs to the conditioning programme. Thus, general programmes written for a sport should be viewed only as a 'starting point' for an individual athlete. The example programmes given in this handbook are such starting points and try to reflect the various conceptual perspectives in designing a programme for a specific sport. It is then left up to the coach/trainer to individualize the programme to meet the specific needs of the athlete. Ultimately, the concepts of 'specificity', 'progressive overload' and 'variation' (periodization) in training become fundamental to the development of a successful team and/or individualized training programmes.

The key to optimal programme design is the identification of specific variables which need to be controlled in order to better predict the training outcomes from the exercise stimulus that is created. The most challenging aspect of resistance training exercise prescription is making decisions related to the development and changes of an individual's training programme. The challenge is to make appropriate changes in the resistance training programme as sport fitness improves and the specific needs and requirements become more obvious. This requires a system of evaluation of each training goal. This means that sound coaching decisions must be made based upon factual understanding of resistance training, the needs of the sport, individual training responses and testing data. Therefore, planning and changing the exercise prescription is vital for the success of any resistance training programme. An understanding of resistance training exercise prescription allows for better quantification of the exercise stimulus. Planning ranges from the development of a single training session to the variation of the programme over time. The ability to better quantify the workout and evaluate the progress made toward a specific training goal are the basic hallmarks of solid programme design which lead to optimal physical development. Resistance training programmes have for many years been a source of mystery. Too often athletes just try to copy what the 'champion' does but this can be a formula for failure if the actual requirements of the athlete do not match the programme used. Training goals are related to the specific types of adaptations needed, which in turn drive the performance outcomes. Thus, the best programme is designed to meet the needs and goals of a specific athlete within the context of the sport (Fig. 3.1).

The concept of a 'window of adaptation' means that at the start of training the potential for change in a specific variable (e.g. 1 RM in the bench press) can be great. The window of adaptation should be small at the end of an effective training programme. It may also be small at the start of the training programme if the athlete has already developed a high level of fitness in a particular variable from prior training. Here is where careful decisions have to be made with regard to the 'prioritization' of training. Do you maintain load intensity or put in the vast amount of work necessary to increase it to enhance an already high level training variable, or do you maintain the sport fitness level while prioritizing other performance variables? The answer is both difficult and complex as one does not have an endless amount of time to train and overtraining must be avoided. If the performance is directly related to the training variable (e.g. vertical jump for a high jumper) then focused attention must be paid to this variable at all times. The question often arises as to whether other

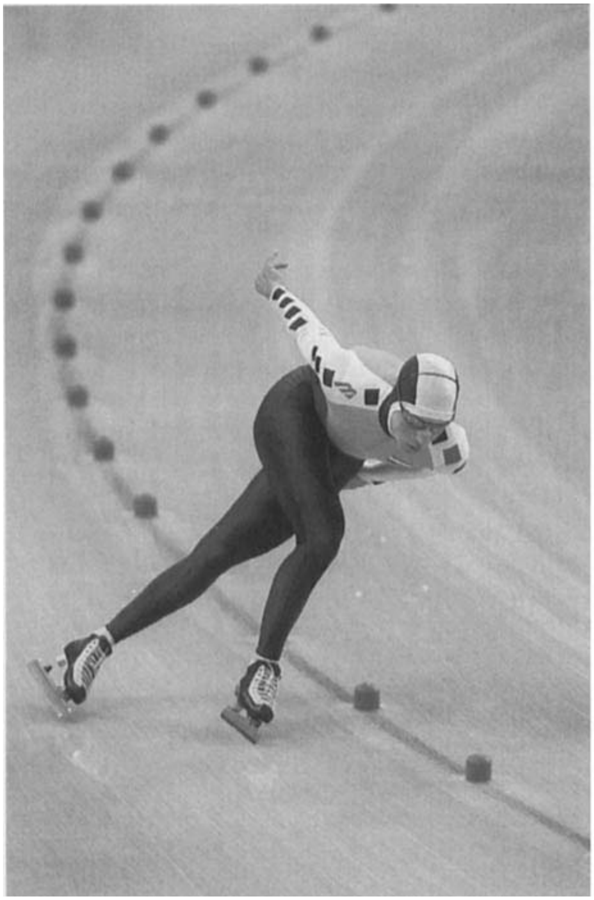


Fig. 3.1 Training programmes should reflect the needs of the sport but also the individual needs of the athlete in order to optimize performance. Photo © Allsport/S. Botterill.

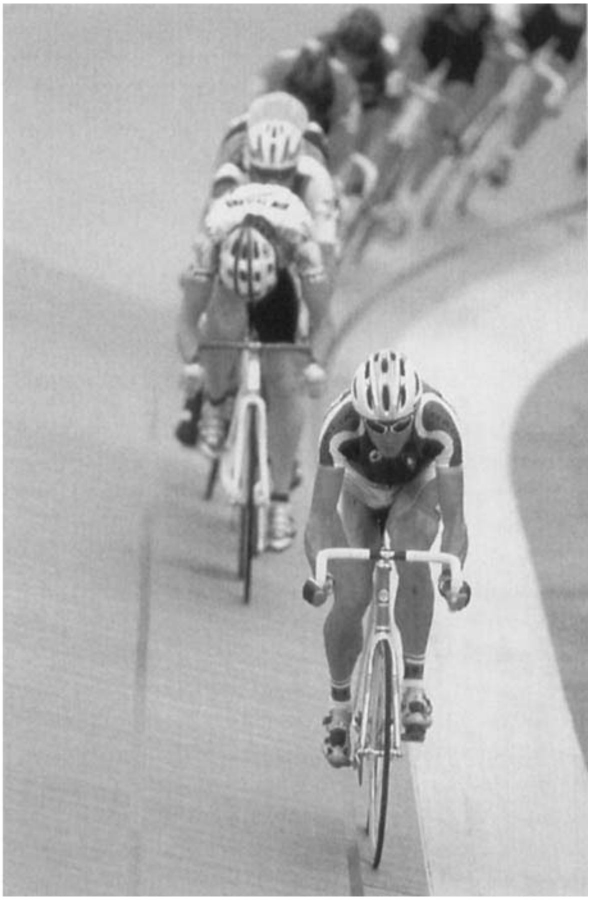


Fig. 3.2 The quality of training in today's conditioning programmes is vital for sports performance success. Photo © Allsport.

types of training can enhance or augment the resistance training programme (e.g. plyometrics plus resistance training for the high jumper) as this would reduce the amount of time spent on one particular exercise protocol (e.g. hang cleans for the high jumper). Thus, training priorities must be made for each athlete's resistance training programme.

In addition, training expectations must be kept in perspective. Gains will be made relative to an individual's potential for adaptation and fitness level. In the case of an elite athlete, one-quarter of a pedal revolution, a small gain of a few tenths of a second, 1 or 2 cm or 1 or 2 kg in performance may be the difference between 25th place and the gold medal. Thus, the level of fitness remains specific to the amount of 'carry-over' the training has to the sport performance. Some very small gains can take tremendous effort and large amounts of time to achieve in the weight room because of the high starting level of fitness already achieved. Such commitment of effort and time needs to translate to improved performance, or training time is not being used efficiently.

In today's training programmes it is becoming obvious that the 'quality of training' is vital to the success of many strength and conditioning programmes (Fig. 3.2). Quality relates specifically to the exercise stimulus needed to make improvement in a particular trainable feature of the neuromuscular system that is related to performance.

In highly trained athletes the gains made may be quite small or difficult to measure over short training periods (e.g. 8–12 weeks). In a study examining previously strength trained athletes who had a choice between different frequencies of training per week over a 10-week off-season conditioning programme, the groups that chose 3 and 6 days a week made no gains in 1-RM bench press. It can be speculated that the 3 days a week programme was not a sufficient stimulus to elicit significant strength increases in already conditioned American football players who had participated in an intensive in-season heavy resistance training programme. The lack of changes in bench press 1-RM strength for players using a 6 days a week programme may have been caused by an overtraining syndrome, while squat 1 RM improved for all groups except the 3 days a week group. Such data indicate that the length of the training programme, the fitness level of the athlete in a particular lift or performance task, and the frequency of training and the volume of the training session can all influence the training adaptations. The expectation of continual gains in strength in the same exercise (e.g. bench press) by some athletes, such as shot putters, may be unrealistic as long-term plateaux can result. Nevertheless, if the exercise has direct carry-over to the event or sport activity continual inclusion of the exercise in the programme may be vital for maintaining the high level edge in competition. In addition, supplementary exercises (e.g. plyometrics) or exercise movements may also have a vital role in augmenting the primary exercise's effectiveness and progress (Fig. 3.3).

Each programme must be designed to meet the individual athlete's needs and training goals. It is especially important that the individual athlete's fitness level be evaluated and understood by the athlete, trainer and/or coach. One of the most serious mistakes made in designing a workout is placing too much stress on the athlete before it can be tolerated. A coach or trainer must be sensitive to an individual's starting fitness level and ability to tolerate the exercise stress. Successful recovery is a very important factor in optimal training for athletes. This implicates the many choices of acute programme variables in designing a resistance training programme that allows for adequate recovery. The major response to this challenge has been in the use of periodized training programmes which carefully prioritize the training goals over time (Fig. 3.4).

When designing training programmes for a sports team, it is common to distribute a programme for all of the team members to perform (e.g. a soccer programme) but generalized programmes will not

Fig. 3.3 Stretch-shortening cycle training (plyometrics) can be an supplementary conditioning modality to augment training results in many sports, such as downhill skiing. Photo © Allsport/C. Brunskill.

Fig. 3.4 General programmes for team sports can only act as a starting point for training as individualization must be used to optimize the training outcomes for each athlete. Photo © Allsport/J. Jacobsohn.

produce the same results in all individuals. Thus, a general programme written for a particular sport should be viewed as a 'starting point' for each individual. Changes and programme progression should be based upon the needs of each athlete. Additions or deletions to a general programme are often needed to address individual goals for an athlete's development that are not addressed in the general programme. With the greater use of computer monitoring systems, the possibility of improved individual monitoring for large groups of athletes and programme feedback for achieving individualized resistance training programmes continues to improve and becomes easier to implement.

Exercise prescription

Resistance training exercise prescription has for a long time been more of a 'coaching art' than a pure science. However, the science of conditioning can have a vital role in the whole process. With increasing technology the feedback to the athlete, trainer and coach is greater than ever before. Use of training technologies in the weight room, which provide more and more feedback and information, will be the trend for the 21st century. Computer integration even with the barbell will make the process of evaluating and creating the exercise stimulus even more sophisticated and require coaches and trainers to view the profession of strength and conditioning from a completely different perspective. The trainer or coach must make programme decisions based upon sound scientific rationale, yet every decision requires good coaching judgements. Therefore the prescription of any exercise requires a solid understanding of the underlying scientific principles involved. It also depends upon the ability to distinguish clearly between approaches to conditioning based on sound factual principles and scientific investigation vs. unfounded anecdotal opinion or pseudoscientific information which plagues the information age (e.g. internet sites). Soundly based knowledge will assist in the development of better resistance training programmes and a logical development of successive training sessions. New training technologies will also influence the process by giving the coach more feedback on the important qualities of the workout (see Chapter 2) with new equipment that will be able to quantify the training stimulus better and provide computer feedback on training session performances (Fig. 3.5).

The developmental process of programme design is discussed in this chapter. There is a need to address the basic questions involved in the manipulation of training variables. The specific combination of choices made for each training variable will determine the type of exercise stimulus presented to the body and the adaptations which mediate these changes.

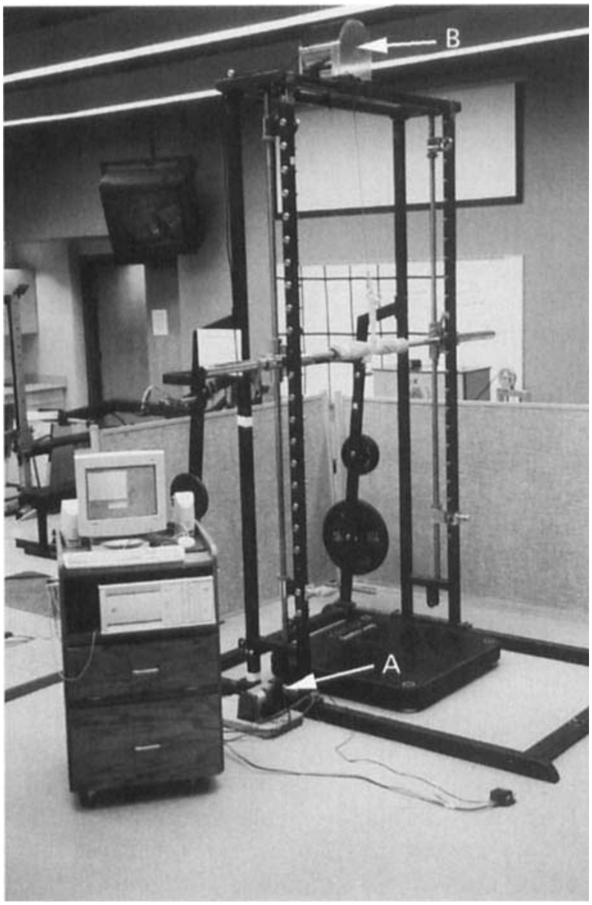


Fig. 3.5 The Ballistic System is an example of the application of the latest technology to strength training. A computer constantly monitors movement of the barbell using a linear transducer (A) providing feedback of force, velocity and power during the athlete's performance. An electronic brake (B) can be used to limit the impact forces and eccentric load on the athlete or to modify the concentric resistance profile.

The major resistance training programme design components are:

- needs analysis;
- acute programme variables;
- chronic programme manipulations; and
- administrative concerns.

Each of these components will be discussed below in the context of designing resistance training programmes.

Needs analysis

A needs analysis consists of answering some initial questions which affect the other three programme design components. It is important that time be taken to examine these questions. The major questions in a needs analysis are the following.

1 What muscle groups need to be trained? What exercises are used for these muscle groups?

2 What are the basic energy sources (e.g. anaerobic, aerobic) which need to be trained?

3 What type of muscle action (e.g. isometric, eccentric actions) should be used?

4 What are the primary sites of injury for the particular sport or prior injury history of the athlete?

Biomechanical analyses to determine what muscles need to be trained

The first question requires an examination of the muscles and the specific joint angles designated to be trained. For any activity, including sports, this involves a basic analysis of the movements performed and the most common sites of injury. With the proper equipment and a background in basic biomechanics, a more definitive approach to this question is possible. With the use of a slow-motion videotape, the coach can better evaluate specific aspects of movements and can conduct a qualitative analysis of the muscles, angles, velocities and forces involved. The decisions made at this stage help define one of the acute programme variables—choice of exercise. Although a complete analysis would be beyond the typical field situation, recording of electomyographic (EMG) activity to determine the muscles involved in a sport activity would be of help. This might be accomplished by carefully studying the biomechanical literature on various sports and conditioning activities.

As has been pointed out in prior sections of this book, specificity is a major tenet in resistance training and is based on the concept that the exercises and resistances used result in training adaptations which will transfer to better performance in sport or daily activity. Resistance training is used as it is often difficult if not impossible to overload sport movements without risk of injury or dramatically altering sport skill technique. Specificity assumes that muscles must be trained similar to the sport or activity in terms of:

- the joint around which movement occurs;
- the joint range of motion;
- the pattern of resistance throughout the range of motion;
- the pattern of limb velocity throughout the range of motion; and
- types of limb movement (e.g. concentric, eccentric, isometric or stretch-shortening cycle).

Resistance training for any sport or activity should include a full range of motion exercises around all the major body joints. However, training designed for specific sports or activity movements should also be included in the workout to maximize the contribution of strength training to performance. The best way to select such exercises is to analyse biomechanically, in quantitative terms, the sport or physical activity and match it to exercises according to the above variables. Few such analyses of sports or activities have been performed to date, yet biomechanical principles can be used in a qualitative manner by an interested athlete or coach to select exercises intelligently. EMG of the agonist and antagonist muscles to determine muscle activation in a sport skill would also provide additional information, if the laboratory capability is available. By viewing slow-motion video tapes one can also determine some basic biomechanical information about the sport activity.

1 View a video tape of a sporting performance or activity.

2 Select a movement which appears to involve high-intensity physical exertion critical to the performance (e.g. the drive portion of a sprint stride; the push-off in a high jump; the arm swing in a volleyball spike).

3 Identify the body joints around which the most intense muscular actions occur.

4 Determine whether the movement is concentric, isometric or eccentric.

5 For each joint identified above, determine the range of angular motion.

6 Try to determine the range of motion around each body joint of interest.

7 Estimate the velocity of movement in the early, middle and late phases in the range of motion.

8 Select exercises to match the limb ranges of motion and angular velocities, making sure that the exercises are appropriately concentric, isometric, eccentric or stretch-shortening cycle.

9 Make the exercise the most difficult at the point in the range of motion where intensity during the target activity is greatest.

Ideally, this analysis should be followed up with appropriate resistance exercises in the weight room that train the specific muscles and joint angles involved. The resulting programme should have all of the elements of the sports biomechanics included.

Each exercise and resistance used in a programme will have various amounts of transfer to another activity or sport. The concept of 'transfer specificity' is unclear to many coaches and trainers. Every training activity has a percentage of carry-over to other activities. Except for practising the specific task or sport itself, no conditioning activity has 100% carry-over. However, some activities have a higher percentage carry-over than others because of similarities in neuromuscular recruitment patterns, energy systems and biomechanical characteristics. Yet most of the time, one cannot use the sport or activity to gain the necessary 'overload' on the neuromuscular system, and this is why resistance training is used in the conditioning process. A misleading concept used by some coaches has been that one just needs to get stronger and only address the 'strength' aspect of muscular performance. This is false as one needs to train the characteristics of muscle which most impact on performance, and 1-RM strength is only one of several trainable variables (e.g. power, rate of force production, local muscular endurance) in muscular performance. Each of these variables is unique and interacts to produce different training effects over time.

Prioritization of training programme goals is vital to address enhancement of sports performance. Prioritization involves carefully deciding which feature of neuromuscular performance will be focused upon during a training cycle. It has been shown that it is difficult to develop all features of muscle to the same extent at the same time. Therefore, periodized training programmes will prioritize specific features (e.g. power) and use specialized workouts to address specific variables. The optimal training programme maximizes carry-over to the sport or sport skill being trained for and therefore understanding what the critical factors are in sporting performance is vital to programme success.

Determining the energy sources used in the activity

Every sport or activity uses a percentage of all three energy sources. This energy demand can be stable, at a steady state of muscle activation, but in most sports this energy demand is dynamic with the percentage contribution of each of the energy sources varying as the competition continues and the body tries to meet the neuromuscular demands of the motor unit recruitment. The energy sources to be trained have a major impact on the programme design (e.g. does the athlete need repetitive high intensity endurance or is it just one maximal effort?). Resistance training is usually more appropriate for anaerobic energy sources (adenosine triphosphate-phosphocreatine (ATP-PC) and lactic acid sources) than it is for aerobic metabolism. Typically, the length of the activity gives the first clue as to where the major energy contribution comes from. Activities that range from 1 to 10 s have a high contribution coming from the ATP-PC energy system. As the duration of the activity continues, energy sources are derived more and more from both glycolytic (lactic acid system) and aerobic energy sources. When high lactate concentrations are observed it is usually because there is enough recovery or contribution from the aerobic energy sources to allow the activity to continue and lactate to accumulate, as in freestyle wrestling where one match can result in lactate concentrations of over 20 $\mathrm{mmol \cdot l^{-1}}$. The contribution of the aerobic energy system with such interval-type high-intensity training or competition can be as great as 40 or 50%. The type of energy metabolism used in the sport will dictate in part what the resistance training programme will need to address. As in the case of freestyle wrestling, development of muscular endurance along with the necessary power under conditions of fatigue (high lactate concentrations with associated disruptions of the acid–base balance in the body) will implicate a programme design that is far from just a pure strength/power programme.

Selecting a resistance modality

Decisions regarding the use of isometric, dynamic concentric, dynamic eccentric, stretch-shortening cycle and isokinetic modalities of exercise are important in the preliminary stages of planning a resistance training programme for sports performance. The basic biomechanical analysis described above is used to decide what muscles to train and to identify the type of muscle action involved in the activity. Most resistance training programmes use several types of muscle actions. One factor that separates elite power lifters from less competitive power lifters is the rate at which the load is lowered in the squat and bench press. Elite power lifters lower the weight at a slower rate than less competitive lifters even though the former use greater resistances. In this case, some eccentric training may be advantageous for competitive power lifters. As another example, many holds in wrestling involve isometric muscle actions of various muscle groups. Therefore, inclusion of isometric training for some movements (e.g. hand locks) will help in the conditioning of wrestlers for improved performance (Fig. 3.6).

Injury prevention exercises

It is also important to determine the primary sites of injury in a sport and understand the prior injury profile of the individual. The prescription of resistance training exercises will be directed at enhancing the strength and function of tissue so that it resists injury better, recovers faster when injured and reduces the extent of damage related to an injury. The term 'prehabilitation' (the opposite to rehabilitation) has become popular in many sports. This term refers to the prevention of initial injury by training the joints and muscles that are most susceptible to injury in a sport. The prevention of re-injury is also an important goal of a resistance training programme. Thus, understanding the sport's or activity's typical injury profile (e.g. shoulders in diving, back and ankles in tennis) and the individual's prior history of injury can help in properly designing a resistance training programme (Fig. 3.7).

Programme design

After the needs analysis has been completed a specific training programme is designed which addresses the exact needs of the athlete. Acute programme variables concern the designing of one specific training session. Chronic programme manipulations (periodization)

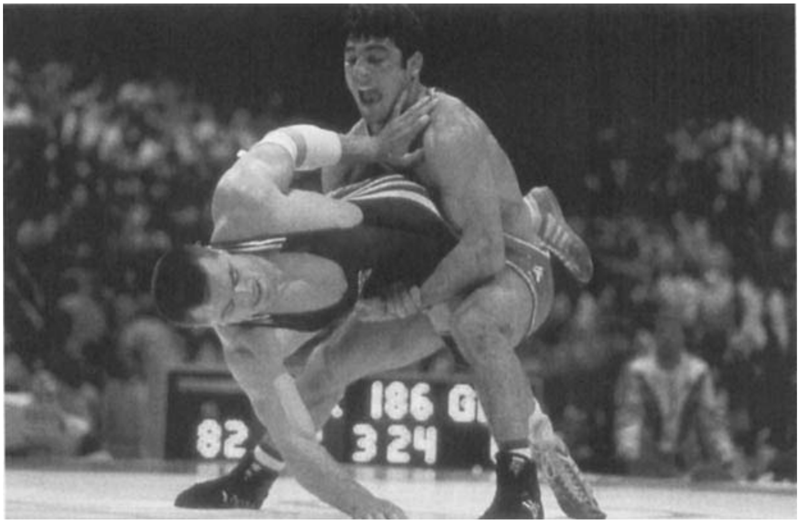
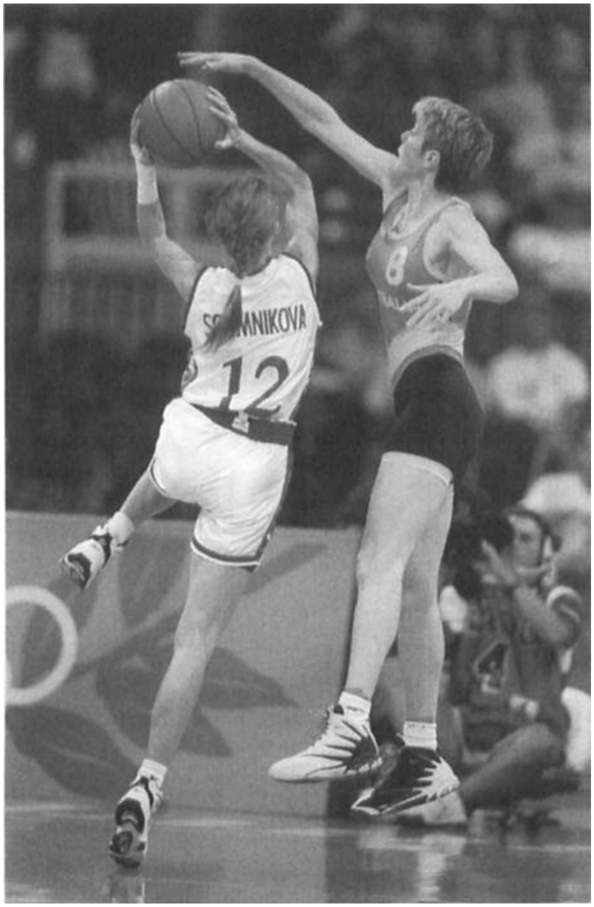


Fig. 3.6 While often forgotten in many modern training programmes, isometric muscle actions need to be included in many sports-specific programmes, such as wrestling. Photo © Allsport/G.M. Prior.



concern the changes made in the acute programme variables over time. Changes in the acute programme variables will help to prioritize and develop a strategy for the progression plan for an entire training period. Periods of training are planned over many months or several years and have made 'periodization' of training a vital feature in the manipulation of acute programme variables in chronic programme design (Fig. 3.8).

Acute programme variables of a single training session

The acute programme variables describe all possible single training sessions. By carefully examining each of the variables in detail and making decisions about them, a training session is designed. From a single training session developed for the athlete at one point in time, the training history starts. Training sessions are created which meet the progressive needs and goals of the athlete as he or she moves into the longitudinal progression of a periodized training programme.

An almost infinite number of workout protocols can be created by manipulating the acute programme

Fig. 3.7 (*left*) Resistance training is very important to prevent injuries in sports. Photo © Allsport/A. Bello.

Fig. 3.8 Proper technique and spotting are vital to optimal training effects and safety.

variables. This is very positive as it gives the coach a very powerful set of training tools to work with in the development of the athlete. In the same way as a carpenter with a tool-box filled with different tools to perform very specific jobs when building or fixing a structure, so the strength and conditioning coach has a very powerful set of 'tools' available to build and develop the athlete. The training session is specific to the choices made regarding each variable. The following are the major programme variables which must be carefully examined and addressed in every resistance training session. If not directly accounted for, the impact of any of one or combination of these variables can result in a random or confounding effects on the desired exercise stimuli being created by the programme. Random effects of training variables not accounted for (e.g. exercise order) in programme design may reduce the predictability of the ultimate training adaptations desired.

There are many different weight training systems that have been used over the years to develop strength (e.g. pyramid system, heavy light system, super pump system). Popular magazines also feature many different workouts for various purposes. What contributes to such a single workout design and how might it affect the acute physiological stimulus presented to the body? In other words, what factors describe each of these systems? This remained unclear until, in 1983, Kraemer analysed weight training systems and developed an analytical set of variable domains which comprise the major factors in each cluster of variables. They were called the acute programme variables and this allowed the systematic study of certain variables beyond the 'resistance load' of the exercise while expanding the view of the single workout and its potential for physiological influence on the body's adaptations. The acute programme variables which describe a single workout session of are as follow.

Choice of exercise

This variable has within it a host of different decisions which must be made, from the type of weight training equipment to the type of muscle action used in the workout. With the movement of the human body being so diverse, the number of possible angles and exercises are almost as limitless as the body's functional movements. A change in angle affects what muscle tissue is activated. Using magnetic resonance imaging (MRI) or EMG recording technologies, it has been shown that changes in the type of resistance exercise used change the activation pattern of the muscle. Muscle tissue which is not activated (e.g. no tension development in the muscle fibre with no recruitment of the associated motor unit) will not directly benefit from the resistance exercise. Studies have demonstrated that musculature that is not trained will not exhibit any of the adaptation or performance benefits of trained muscles. Exercises should be selected which stress the muscles and joint angles designated by the needs analysis. Exercises can be arbitrarily designated as primary exercises and assistance exercises. Primary exercises are the exercises which train the agonists in a particular movement. They are typically major muscle group exercises (squat, bench press, hang pulls). Assistance exercises are exercises which train smaller muscle groups and help to support and stabilize the movement produced by the agonists (tricep press, lateral pull down, bicep curls). As discussed earlier, typically there is a reduction in the coactivation of the antagonists to allow more efficient movement by the agonist muscles.

Exercises can also be classified as structural (multijoint) or body part (isolated joint). Structural exercises include those whole body lifts which require the coordinated action of many muscle groups and coordination of joint movements (e.g. close kinetic chain exercises). Power cleans, power snatches, deadlifts, lunges and squats are good examples of structural whole body exercises which require this type of intermusucular communication and coordination of force production (Fig. 3.9). Exercises can also be classified as multiple joint exercises—exercises which use more than one joint to perform—or single joint exercises. For example, the bench press which involves movement of both the elbow and shoulder joints is a multijoint exercise. A bicep curl is a good example of a single joint exercise. Many primary or core exercises can also be structural exercises in nature.

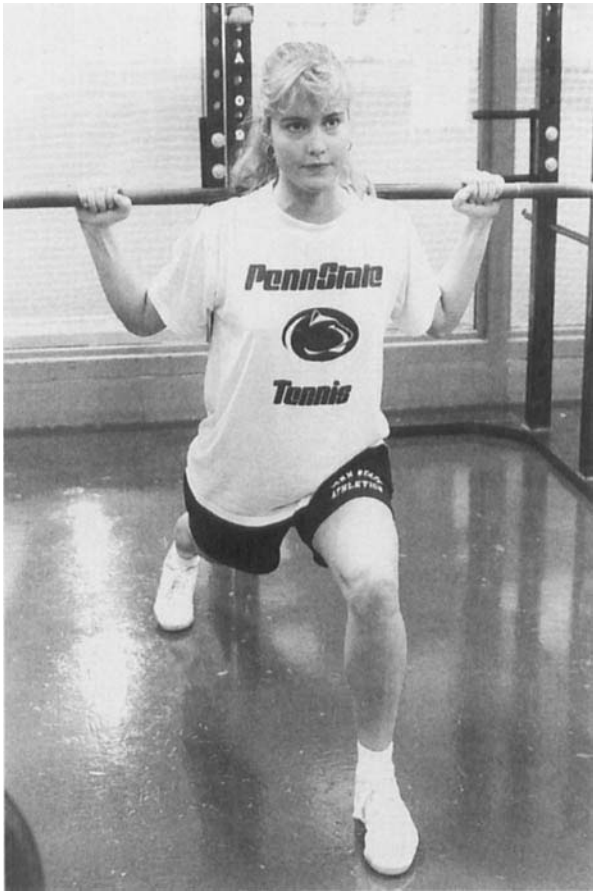


Fig. 3.9 Lunges are one example of an important structural exercise needed for unilateral strength and power development. Photo © University Photo/Graphics, The Pennsylvania State University/D. Shelly.

Exercises which try to isolate a particular muscle group are considered to be body part, isolated joint, or single joint exercises. Bicep curls, sit ups, knee extensions and knee curls are examples of isolated single joint or body part exercises. Most assistance exercises could also be classified as body part or single joint exercises.

Structural or multijoint exercises require neural communication between muscles and promote coordinated use of multijoint movements. It is especially important to include structural and multiple joint exercises in a programme when whole body strength movements are required for a particular activity. Volleyball, basketball, wrestling, soccer, weightlifting and track and field are such sports. In these sports whole body strength/power movements are the basis of success in spiking, tackling, kicking, jumping, performing takedowns and throwing. Often, structural exercises involve advanced lifting techniques (e.g. power cleans, power snatches) which require additional coaching beyond simple movement patterns. Trainers and coaches should have the experience and ability to teach these lifts before including them in a training programme. The time economy achieved with structural and multiple joint exercises is an important consideration for an athlete or team with a limited amount of time per training session (e.g. in-season programmes).

Order of exercise

For many years the order of exercise in resistance training programmes consisted of performing large muscle group exercises prior to exercising the smaller muscle groups. It has been shown that by exercising the larger muscle groups first, a greater intensity or more effective training stimulus can be presented to all of the muscles involved in an exercise. This concept was realized by using the order of performing structural or multijoint exercises first in the workout followed by smaller single joint exercises (e.g. hamstring or bicep curls). In addition, one might also want to perform the more complex multijoint exercises (e.g. power cleans) first in order to enhance learning and technique mastery. The rationale to this order of exercise is that exercises performed in the beginning of the workout are the ones which require the greatest amount of muscle mass to perform or, in the case of complex exercises, take the longest time to learn. Thus, these order profiles focus on gaining a greater training effect for the large muscle groups and/or performing the exercises with greater precision and optimal technique. This can be achieved more effectively before fatigue sets in.

Different exercise orders to the above are obviously possible and may have their own rationale and support for their use. When an athlete is faced with performing maximal whole body power moves under conditions of great fatigue (e.g. freestyle wrestling in the last minute), one may find support for placing power cleans at the end of a workout. This would help to enhance and evaluate power production under conditions of fatigue similar to the sport's metabolic environment late in a match. Pre-exhaustion methods use this method and reverse the order of the exercises so that the small muscle groups are exercised prior to the larger muscle groups, thereby creating fatigue in many of the same muscles needed to perform the whole body exercise movement. This typically results in a lower amount of weight that can be used in the large muscle group exercise. An example is performing knee extension and flexion exercises followed by squats. Another method of pre-exhaustion involves fatiguing synergistic or stabilizing muscles before performing the primary exercise movement. An example of this concept is performing lateral pull downs or military presses prior to performing the bench press exercise. Data do exist to indicate that fatigue may stimulate strength development as it has been shown that continuous repetition resulted in greater strength gains than when rest was taken between repetitions. Thus, accumulation or fatigue may be a physiological signal. How this is related to pre-exhaustion techniques remains unclear. The advantages and disadvantages of pre-exhaustion exercise orders in optimizing strength and power gains remains highly speculative but may be of great help in developing functional strength and power under conditions of high levels of fatigue similar to a sport (e.g. wrestling, 400-m sprint in swimming) (Fig. 3.10).

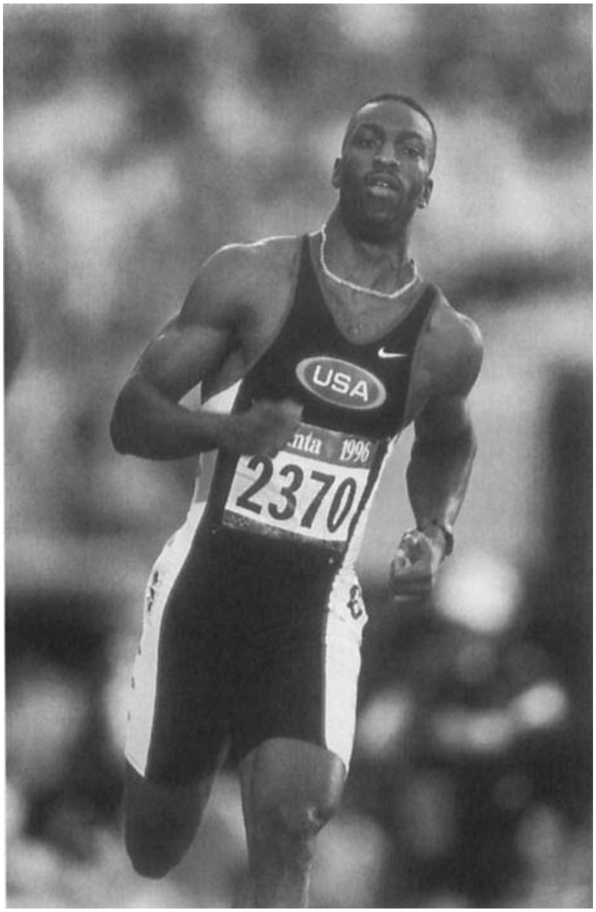


Fig. 3.10 Many athletic events must develop the ability for powerful muscle actions under conditions of fatigue. Photo © Allsport/G. Mortimore.

The priority system has also been used extensively in resistance training. When using the priority system, the training session for the day will focus on one or two particular exercises. A training session can have each exercise in the workout listed in order. The priority system will help one to focus on the specific goals for each training session and eliminate excessive fatigue during the performance of a particular exercise if it is prioritized to be first in the training session.

A corollary to the priority system is that power type exercises (e.g. power cleans, plyometrics) should be performed early in a session. This allows the athlete to develop and train maximal power prior to becoming fatigued. This would limit the development of maximal power. However, in some instances, power type exercises may be performed later in the session, as discussed above, to help develop the ability to produce high levels of force under conditions of fatigue. For example, in basketball it is important not only to have a high vertical jump, but also to be able to jump maximally during the final minutes of a game when an athlete may be very fatigued. Here again, one might see the rationale to have some training sessions where the power exercises are performed later in the session in order to evaluate and develop maximal power under conditions of sport fatigue (e.g. vertical jump ability in a fatigued state). Extreme care must be given to proper exercise techniques and spotting when such an order is used in a training session as fatigue typically leads to poor technique.

Another consideration in the exercise order is placing exercises which are being taught or practiced—especially complex movements—in the beginning of the exercise order. For example, if an athlete was learning how to perform power cleans, this exercise would be placed in the beginning of the workout so motor skill performance and learning would not be inhibited by fatigue or loss of concentration.

The ordering of exercises also involves the orders used in various types of circuit weight training protocols. The question of whether one follows a leg exercise with another leg exercise, or whether it is appropriate to proceed to another muscle group have to be addressed. The concept of pre-exhaustion can come into play here too. Arm-to-leg ordering allows for some recovery of the arm muscles while the leg muscles are exercised. This is the most common order used in designing circuit weight training programmes. Athletes who are just starting to utilize a resistance training programme in some sports (e.g. tennis, baseball, softball) are many times less tolerant of pre-exhaustion and arm-to-arm and leg-to-leg exercise orders or stacking exercises for a particular muscle group because of high blood lactate concentrations (10–14 $\text{mmol}\cdot\text{l}^{-1}$) especially when rest periods between exercises are short (10–60 s). This is especially true when the circuit training programme does not match the metabolic profile of the sport (e.g. baseball vs. low rest circuit). Stacking exercises is a common practice among athletes who require this type of muscular endurance under conditions of fatigue.

One final consideration for exercise order is the fitness level of the individual. Training sessions should never be designed which are too stressful for the individual, especially an athlete just starting to use resistance training as a supplementary training programme for his or her sport. The exercise order can have a significant impact on the training stimulus stress level in a training session.

Number of sets

Not every exercise in a workout needs to have the same number of sets performed. The number of sets used in a workout is directly related to the training goals of the joint or musculature being trained. The number of sets are part of a volume calculation in strength training. Typically, 3–6 sets are used for an exercise to achieve the optimal adaptations, especially in athletes. It has been suggested that multiple set systems work best for development of strength, power, size and local muscular endurance, and the gains made will be at a faster rate than gains achieved through single set systems. To date no single set system has ever been shown to be superior to a multiple set programme. The importance of resistance exercise volume (sets × repetitions) for strength, local muscular endurance, and especially muscle size gains during the early phases of a programme, have been demonstrated over long-term training programmes (> 3 months). Thus, when time demands are of major concern to the trainer or coach, reducing the volume of exercise to one may not be the most effective strategy. Furthermore, when training some characteristics of muscle performance such as power, low repetition sets (1–3) are needed for optimal quality. Therefore this type of training needs a multiple set presentation to expose the body to an adequate volume of exercise in a training session.

The use of a single set of an exercise is effective for individuals who are just starting a resistance training programme (e.g. just starting an exercise programme). One set programmes, more accurately called low-volume programmes, might also be used as a short-term maintenance programme or as a low-volume recovery phase in a periodized strength training programme. Again this can be viewed differently for each exercise over the entire training cycle. In more highly trained athletes, strength gains are not as great as when low-volume programmes are used in comparison with higher volume periodized training programmes. This may be because of the need to maintain high levels of activation of the musculature.

Once an initial strength fitness level has been achieved, a multiple presentation of the stimulus (3–6 sets) should be used. The importance of variation in the exercise volume (sets × repetitions) is a vital concept in training progression. This is especially true for athletes who have already achieved a basic level of training or strength fitness. The interaction of the number of sets with the principle of variation in training or, more specifically, 'periodized' training, augments subsequent training adaptations. The time course of volume changes is also a very important factor in varying the exercise stimulus in periodized training programme. The use of any 'constant volume' training programme for athletes can lead to staleness and lack of effective changes in performance over the training cycle.

Rest periods between sets and exercises

One of the more overlooked variables in exercise prescription has been the length of the rest periods between sets and exercises. Recently, the influence of rest periods in dictating the stress of the workout and the amount of resistance that can be used has been realized. Rest periods between sets and exercises determine how much of the ATP-PC energy source is recovered and how high lactate concentrations are in the blood. Optimal recovery from a set of repetitions in a heavy resistance exercise session is also a function of the recovery process in the nervous system. The nervous system must be capable of activating the necessary motor units to exert a force to match the loading of the next set of repetitions in strength and power training workout. The rest necessary, especially between sets but also between exercises, is related to both recovery and fitness of the bioenergetics and nervous systems.

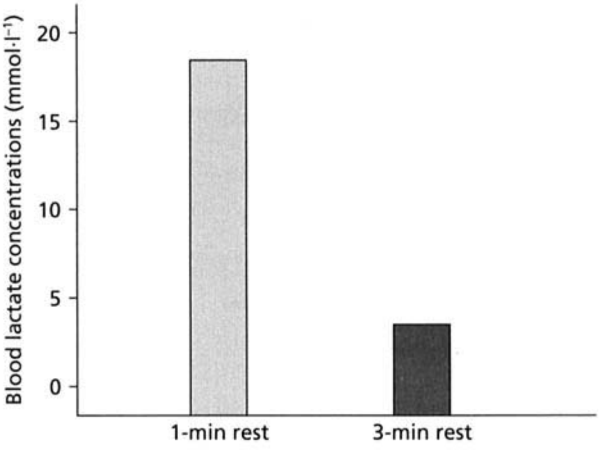


Fig. 3.11 Lactate responses to the same eight-exercise workout using multiple sets with the only variable being a 1- or 3-min rest period between sets and exercises.

Many studies have shown the dramatic influence of rest periods on blood lactate and hormonal concentrations, with metabolic responses to resistance exercise protocols demonstrated in both men and women. Figure 3.11 shows the response of blood lactate to long vs. short rest period lengths for an eight total body exercise protocol using a multiple set workout design for a single exercise session. Sets and exercises were separated by rest periods of either 1 or 3 min. Changing rest periods between sets and exercises has dramatic effects on many different physiological variables but the impact is similar in both men and women; less rest results in higher blood lactate responses to the workout.

From a practical standpoint it has been demonstrated that short rest programmes can even cause greater psychological anxiety and fatigue and this requires coaches and trainers to prepare the athlete for high intensity metabolic workouts in the weight room. This might be caused by the greater effort, fatigue and higher metabolic demands (e.g. high lactate production). The psychological ramifications of using short rest workouts must also be carefully considered when designing a training session. While the psychological demands are higher, the changes in mood states do not constitute abnormal psychological changes and may be a part of the arousal process before a demanding workout (e.g. increased anger about the workout demands).

The frequent use of such low rest, high intensity workouts with short rest periods and heavy resistances should be slowly introduced into a training programme as tolerance of increased muscle and blood acid levels (decreased pH) and the acid–base buffer mechanisms in the body adapt. However, if such adaptations are vital to a sport (e.g. wrestling or 400-/800-m track events) the periodization and use of such protocols progressing from long to short rest periods may be necessary in training for enhanced sport performance. Training acid–base aspects usually requires about 8 weeks to enhance the natural buffer mechanisms in the body (e.g. bicarbonate buffer system in the blood). Such a programme is usually performed within the context of a more classical strength/power training programme for a sport (e.g. two high lactate workouts and two strength/power workouts in a week cycle) or as a pre-season programme for 8–12 weeks prior to the start of the wrestling or track season.

Rest periods of < 60 s are considered to be very short rest periods and usually associated with use of lighter weights. Rest periods of around 90–120 s are considered short rest periods and loads are usually in the range of about 10–12 RM. As loads get heavier, more and more rest is needed for optimal neural recruitment, with rest periods of 3 min or longer being considered long rest periods. The impact of rest period length on physiological variables has been reviewed in several studies by Kraemer and colleagues (see recommended reading). Short rest periods while increasing the physiological stress response (higher lactate, growth hormone, cortisol, adrenaline (epinephrine) concentrations) help to develop a type of local muscular endurance with the loads that can be handled. Rest periods of < 90 s need to be carefully progressed towards over a training period of about 6–8 weeks. Symptoms should be carefully monitored (e.g. nausea, dizziness, faint spells) and rest increased if such changes occur in the workout. Table 3.1 presents a qualitative overview of rest periods as they relate to physiological stress.

Resistance used

The amount of resistance used for a specific exercise is probably the most important variable in resistance training. It is the major stimulus related to changes observed in measures of strength, power and local muscular endurance. When designing a resistance training programme, a resistance for each exercise must be chosen. The basic test consists of determining the number of repetitions a person can perform to exhaustion in lifting a certain mass. The mass (kg or lb) is then described in terms of a 'repetition maximum' or RM. For example, a person lifts a mass of 72 kg 10 times before exhaustion; therefore, 72 kg is identified as the person's 10 RM for the particular body movement and conditions of the test (e.g. free weight vs. exercise machine, free cadence vs. controlled cadence). If the largest mass this person can lift without repetition is 98 kg, this mass is identified as the 1 RM, the person's strength score for the movement according to this procedure.

Performance assessment and exercise prescription can then be accomplished in terms of the mass of a specific RM or percentages of the mass of the 1 RM. Determination of a 1 RM in this manner for each body movement constitutes the most common approach internationally for assessing the strength of the particular muscle groups performing the movement.

Sets can be prescribed on the basis of previous recordings of the RM vs. assigned weights: light (12–15 RM), medium (8–10 RM) and heavy (3–5 RM). As a person experiences increasing RMs for a particular mass lifted, the exercise prescription is modified upward in terms of the weight indicated for the light, medium and heavy ranges.

Typically, one uses a training RM target (a single RM target, 10 RM) or RM target zone (a range such as 3–5 RM).

As the strength level of the athlete changes over time the resistance is adjusted so a true RM target or RM target zone resistance is used. Moving away from the 6 RM or less strength stimulus zone the gains in strength diminish until they are negligible. The strength gains achieved above 25-RM resistances are small or non-existent and perhaps related to enhanced

Table 3.1 Rest period lengths between sets related to resistance training programme design.

Rest period length (s)	Comments
0–30	Very, very short rest Results in almost no recovery from prior sets and force production is typically reduced with each subsequent set, loads are typically limited to very light loads (12 RM or higher). Such rest period lengths are typically not used if higher loads are to be lifted
31–60	Very short rest As the rest increases to 60 s, it allows heavier loads (e.g. 10 RM) to be tolerated with high glycolytic and physiological stress responses to workout protocols
61–90	Short rest Allows heavier loads to be lifted. Typically, 90 s is used as a starting point for programme progressions using shorter rest periods
91–120	Moderate rest A typical rest period length for many strength training programmes using moderate loading patterns
121–180	Long rest Typically used when loads start to become heavier in a training programme, e.g. 10 RM and lower intensities
> 180	Very long rest Used when very heavy loads are to be lifted or when high velocity or power output is desired with each repetition. Rest periods of up to 7 min may be used to assure complete energetic and neurological recovery prior to another set attempt

motor performance, mostly learning effects when they occur. A variety of individual responses as a result of genetic predisposition and pretraining status affect the training increases observed. However, after initial gains because of learning effects, heavier resistances will be necessary to optimize muscle strength and size gains.

Another method of determining resistances for an exercise involves using a percentage of the 1 RM (e.g. 70 or 85% of 1 RM). If the trainee's 1 RM for an exercise is 50 kg, an 80% resistance would be 40 kg. This method requires that the maximal force in various lifts used in the training programme be evaluated regularly. This method is highly valuable and important when performing power training, where the loads should be in the range of 30–60% of 1 RM for optimization of the training load used in such high velocity or explosive strength training. This makes the percentage of 1 RM vital to success in power training. If 1-RM testing is not carried out regularly (e.g. once every 2 weeks), the percentage of 1 RM used in training decreases and therefore the training intensity is reduced. From a practical perspective, use of percentage of 1 RM determination for many lifts may be more administratively challenging because of the amount of testing time required if maximal force stimulus is desired for all workouts in the 2-week cycle. Unless there is a training cycle of a few weeks when the athlete is peaking (e.g. weightlifter or shot putter) and the loads are maximal or near maximal then little testing is needed during such a training cycle to determine percentage of 1 RM. Use of an RM target or RM target zone allows the individual to change resistances in responses to stay at the RM target or within the RM target zone thus developing the characteristics associated with that portion of the RM continuum. While the target training zone should be achieved (load should only allow, for example, 3–5 repetitions in the 3–5-RM zone) with a given load, going to complete failure on every set may not optimize strength or power and may be detrimental to joints causing joint pain and overuse stress, especially in master athletes. Thus, athletes will often train at a percentage less (10–30% less than the 3–5-RM loads used in a prior workout) than a training zone for a prior workout in a given week. This allows for a load that does not require maximal effort and can act as a change up or recovery cycle or workout based on lower intensity. Nevertheless, prescription of exercise using percentages can be more challenging, especially if one is responsible for training large groups of athletes, as more frequent testing is needed, if not common to the sport (e.g. weightlifting).

The use of percentage of 1 RM resistances is warranted for lifts related to the competitive Olympic lifts of the clean and jerk and the snatch. As these lifts require coordinated movements and optimal power development from many muscles to result in correct lifting technique, the movements cannot be performed at a true RM or to momentary failure. The reduction in velocity and power output experienced in the last repetition of an RM set are not conducive conditions for such structural lifts related to the Olympic competitive lifts (e.g. power cleans, snatches, power snatches, hang cleans). Therefore, percentage of 1 RM is warranted to calculate resistances for such lifts correctly.

In a couple of classic studies the relationship between the percentage of 1 RM and the number of repetitions that can be performed was studied in both trained and untrained men and women. It was demonstrated that this relationship varies with the amount of muscle mass needed to perform the exercise (e.g. leg press requires more muscle mass than knee extensions). When using machine resistances with 80% of 1 RM, previously thought to be primarily a strength related prescription, the number of repetitions that could be performed was typically > 10, especially for large muscle group exercises such as the leg press. The larger muscle group exercises appear to need much higher percentages of the 1 RM to keep them in the strength RM zone of the repetition continuum.

An example of how using the percentage of 1 RM can result in less than an optimal resistance to increase strength is the following: the strength coach puts a sign on a leg press machine that states 'use 80% of 1 RM for all sets'. An athlete uses 80% of 1 RM and performs 22 repetitions. The question now arises, 'Will performing 22 repetitions per set result in optimal strength increases?' Based on the RM continuum, a 22 RM is primarily related to development of local muscular endurance not optimal development for strength or power.

Charts are often used to predict the 1 RM from the number of repetitions performed with a submaximal load or to help determine an RM (e.g. from 1 to 10) from the 1-RM resistance that can be lifted. Unfortunately, most of these charts assume a linear relationship between these variables which is not the case. Thus, such charts and the resulting values should only be used as rough estimates of a particular resistance to use for an RM resistance or to predict an individual's 1 RM.

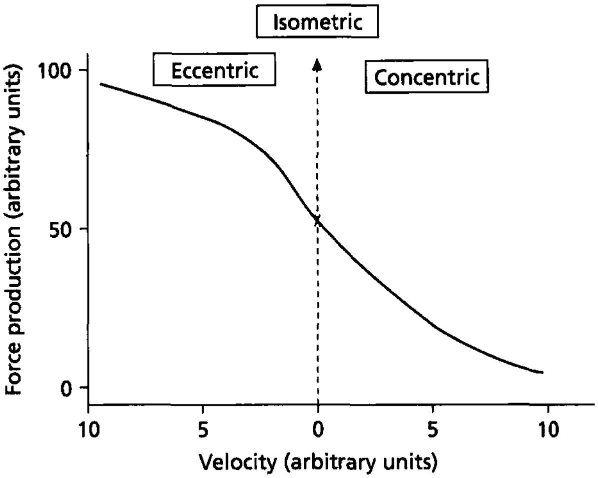


Fig. 3.12 Theoretical force–velocity curves for eccentric, isometric and concentric muscle actions.

Velocity of movement

The velocity of movement is a quality typically associated with the type of resistance used, the type of exercise choice and the modality of the exercise. Terms such as 'speed strength' and 'power' relate to the rapid development of force and high speeds of movement. A continuum of velocities are used in conventional resistance training from the very slow concentric movements, such as the 1-RM lift, to the higher speed power movements at about 30% of 1 RM. Training at different movement velocities is vital for optimal periodization of resistance training. The force–velocity curve represented in Fig. 3.12 represents the continuum of velocities from the concentric relationship of force and velocity to the eccentric relationship of force to velocity. Interestingly, as the velocity increases concentrically, force reduces and as the velocity increases eccentrically the force increases with isometric force at the centre of the force–velocity curve.

The principle of specificity is very important as it relates to specificity of training with about ± 20% carry-over above and below the training velocity used. In addition, all training adaptations are angle specific. Training slowly enhances slow speed development but has little carry-over to faster velocities and conversely high speed training has little carry-over to slower speed force development. This is a basic concept as a function of training (see Chapter 2). Periodization utilizes different loads and intensities which are performed at different velocities of movement and therefore training adaptations span a much larger continuum.

Summary of acute programme variables

A single resistance training workout can be described by the acute programme variables:

- choice of exercise;
- order of exercise;
- number of sets;
- rest periods;
- load or resistance used; and
- velocity of movement.

The choice and the final configuration of these variables results in the exercise stimulus for a particular workout. Workouts must be altered to meet changing training goals and to provide training variation. With this paradigm for the description of resistance exercise workouts, careful control of various components can be gained in manipulating variables to create new and optimal training session workout programmes. Because so many different combinations of these variables are possible, an almost unlimited number of workouts can be developed. Understanding the influence and importance of each of the acute programme variables in achieving a specific training goal is vital to creating the optimal exercise stimulus for the athlete at that point in a training cycle.

Recovery periods between training sessions

Recovery is vital to any athlete; however, too much recovery can initiate a detraining process. Herein lies the careful balance between rest and recovery vs. detraining. The amount of rest required between training sessions depends on the recovery ability of the individual. Older athletes may need more time to recover than younger athletes who have a greater physiological potential. Traditionally, three workouts per week, with 1 day of rest between sessions, have been used in most sports. It has been found to allow adequate recovery, especially for the novice, and fits into many different sport training schedules which are demanding in their practice alone (e.g. tennis). If the resistance training is not excessive, only moderate amounts of delayed muscular soreness should be experienced on the day after the session. The greatest amount of delayed muscular soreness results from heavy eccentric muscle actions and various drop jump types of actions used in plyometric programmes for supplementary power training as opposed to concentric isokinetic, dynamic concentric and isometric muscle actions. As the athlete advances in fitness levels and is better able to tolerate resistance exercise sessions, the frequency of training can be increased. One report in women volleyball players indicated that 4 days in succession per week may be superior to three alternate days in effecting increases in strength and performance. The onset of perceived discomfort may be masked during consecutive training sessions, and the 3-day recovery period may allow for a more complete recovery. This indicates that the interaction of stress and recovery may be more complex than previously thought.

Elite athletes may be capable of and need training frequencies of 4–5 days in a row in order to see significant improvement over short periods of training. It has been observed that competitive lifters train 5–7 consecutive days in order to achieve strength and power gains needed for competitive success. Training frequency per week is a function of the individual's need for the exercise stimulus to cause fitness gains. It is important that the individual can tolerate the physical stress so that overtraining does not develop. The development of periodized training cycles utilizes variations in training frequency to alter the exercise stimulus and provide for recovery and enhance the exercise stimulus. The individual's experience and physical condition as well as the amount of work performed in one training session will dictate his or her tolerance of more frequent weekly training sessions. In addition, athletes will train twice a day to reduce the volume within a workout so that the quality (intensity) of the workout can be maintained at the highest level. This usually comprises a morning and an afternoon workout, allowing 4–6 h rest between the two sessions.

Training frequencies greater than twice a week typically engage two different training programmes and do not simply repeat the same programme. A minimal frequency of at least two sessions a week for a given exercise is the core of every strength/power training programme. When training is carried out on consecutive days it often involves the use of a split routine (different body parts exercised each day) or a split programme (different exercises for the same body part performed each day). Some type of variation (periodization) needs to be employed when consecutive training days are used. The concept of using a 3-day a week training programme for all sports is far from the optimal training frequency. It is the individual's needs, sports schedule and, ultimately, the training goals of each period which will determine the amount of exercise required to increase a particular physiological or performance variable. Progression in frequency is also a key component to resistance training. Frequency of training will vary depending upon phase of the training cycle, the fitness level of the athlete, goals of the programme, and training history. Careful choices need to be made regarding the rest between training days. These choices are based upon the planned progress toward specific training goals and the tolerance of the individual of the programme changes made. If excessive soreness is present the next morning, this may indicate that the exercise stress is too demanding. If this is the case, the workout loads, sets and/or rest periods between sets and training frequency need to be evaluated and adjusted. Periodization of training will be vital to address such diverse needs over time.

Recommended reading

Gotshalk, L.A., Loebel, C.C., Nindl, B.C. *et al.* (1997) Hormonal responses of multiset versus single-set heavy resistance exercise protocols. *Canadian Journal of Applied Physiology* **22**, 244–255.

Kraemer, W.J. (1997) A series of studies: the physiological basis for strength training in American football—fact over philosophy. *Journal of Strength and Conditioning Research* **11**, 131–142.

Kraemer, W.J. & Fleck, S.J. (1988) Resistance training: exercise prescription. *The Physician and Sportsmedicine* **16** (6), 69–81.

Kraemer, W.J., Noble, B.J., Culver, B.W. & Clark, M.J. (1987) Physiologic responses to heavy-resistance exercise with very short rest periods. *International Journal of Sports Medicine* **8**, 247–252.

Kraemer, W.J., Fleck, S.J. & Deschenes, M. (1988) A review: factors in exercise prescription of resistance training. *National Strength and Conditioning Association Journal* **10**, 36–41.

Kraemer, W.J., Marchitelli, L., McCurry, D. *et al.* (1990) Hormonal and growth factor responses to heavy resistance exercise. *Journal of Applied Physiology* **69**, 1442–1450.

Kraemer, W.J., Gordon, S.E., Fleck, S.J. *et al.* (1991) Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *International Journal of Sports Medicine* **12** (2), 228–235.

Kraemer, W.J., Dziados, J.E., Marchitelli, L.J. *et al.* (1993a) Effects of different heavy-resistance exercise protocols on plasma β-endorphin concentrations. *Journal of Applied Physiology* **74**, 450–459.

Kraemer, W.J., Fleck, S.J., Dziados, J.E. *et al.* (1993b) Changes in hormonal concentrations following different heavy resistance exercise protocols in women. *Journal of Applied Physiology* **75**, 594–604.

Mulligan, S.E., Fleck, S.J., Gordon, S.E. *et al.* (1996) Influence of resistance exercise volume on serum growth hormone and cortisol concentrations in women. *Journal of Strength Conditioning Research* **10** (4), 256–262.

Chapter 4

Periodization of training

Introduction

Anecdotal evidence demonstrates that coaches and athletes, for at least the last several decades, have varied their training programmes on a yearly basis in an attempt to bring about the best possible performances during competition. Terms to describe this yearly variation in training include cycling, chronic programme manipulation, and periodization, with periodization being the most popular term. For a distance runner the variables that can be varied in a training programme include such things as: total kilometres run or the volume of training; running pace or intensity of training; terrain over which the running is performed; and the number of intervals performed at different distances (800 m, 1600 m, etc.). In a strength training programme the training variables that can be varied throughout a training year include all the acute programme variables discussed in Chapter 3. Thus, exercise order, exercise choice, number of sets, number of repetitions per set, rest periods between sets and exercises, exercise intensity and number of training sessions per day can all be manipulated and varied in a weight training programme.

Typically, sport scientists, coaches and athletes of the former Eastern Bloc countries are credited with developing and researching the concepts of periodization (Fig. 4.1). This type of training programme was developed to ensure adequate recovery between training sessions, optimal gains in strength and power in order to maximize strength and power performance at a certain time point (e.g. major competition). The goal was to peak for the best possible performance at a major competition, such as the Olympic Games or world championships. Anecdotally, part of the success of many of the former Eastern Bloc athletes indicates that periodized training does result in gains in strength and power over long training periods of years or an entire sporting career. Thus, the concept of periodization allows for the development of an athlete in a sport over the course of many years. It provides the necessary variation in the physical and psychological stress of conditioning and is used in order to maximize strength and power at specific time points. This allows the athlete to enter a competition at a physical and metal 'peak' and optimize their performance.

These former Eastern Bloc sport scientists and coaches carefully studied training volume and realized that the training intensity of their successful athletes followed a particular pattern over the course of a year. At the start of the training year, training volume was high and intensity was low compared to the end of the year. In addition, it was often observed that this volume dropped immediately prior to a major competition. Thus, training intensity was at its highest point and training volume was at its lowest point immediately prior to a major competition. In order to allow for adequate physical and psychological recovery prior to a major competition, training intensity was also reduced immediately prior to major competitions (Fig. 4.2). Skill training is also a major component in every sport. It was noted that skill training for a particular event or sport followed a similar pattern to that of training intensity, except skill training reached its peak slightly closer to a major competition than did training intensity. From this a general pattern of periodization of training was developed and highly individualized for each athlete (Fig. 4.1).

Anecdotal evidence from around the world indicates that if this training pattern of decreasing training volume and increasing training intensity was repeated three to four times per year, instead of only once per year, greater gains in fitness and sport performance were achieved. Repeating (e.g. three or four times per year) the training pattern of decreasing volume and increasing intensity also allowed for the possibility of several peak performances per year. This was especially important for sports with multiple major competitions. Thus, the sophistication of a periodized strength and power training programme became even more complex because of the needs of each sport and athlete. Nevertheless, the basic concept

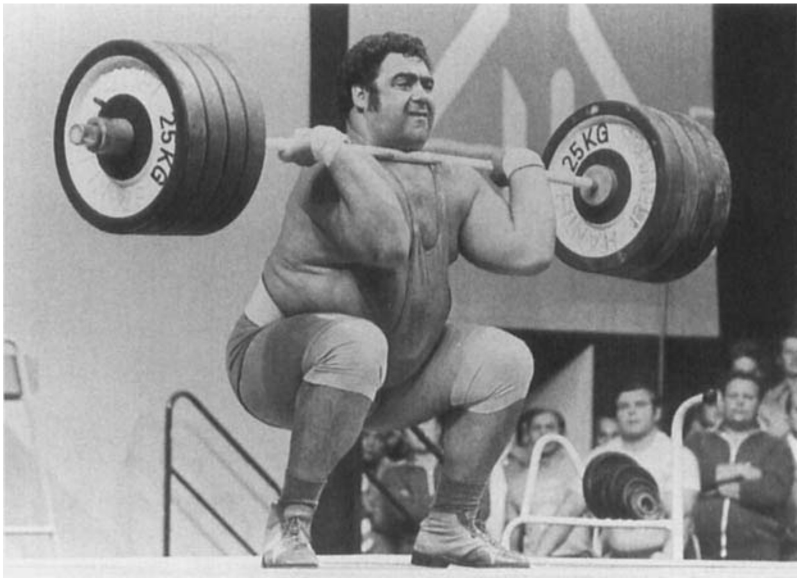
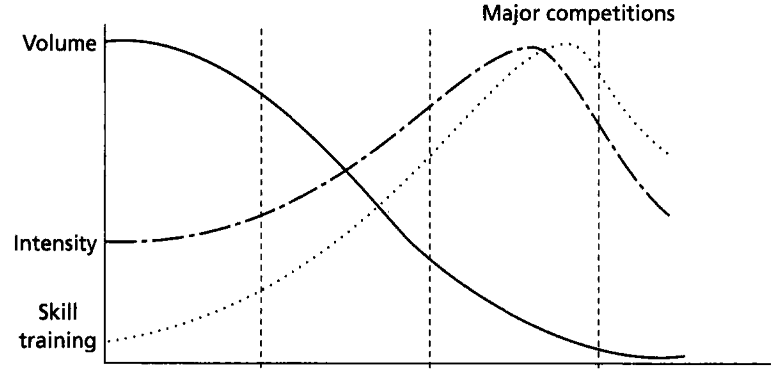


Fig. 4.1 Many attribute refining the concept of periodized training to the former Soviet Union and Eastern Bloc countries. Photo © IOC/Olympic Museum Collections.



European terminology	Preparation phase	First transition	Competition phase	Second transition (active recovery)
Traditional American terminology	Pre-season		In-season	Off-season
American power terminology	Strength/ hypertrophy	Strength/power	Peaking	Active recovery

Fig. 4.2 Periodization phase terminology.

of training periodization involved both variation, sports specificity and individualization of the training programmes. The basis of a training technology had been formed and was now being further examined in all of its permutations in both laboratories and conditioning programmes around the world.

Together with the concept of periodized training, a terminology was developed to describe various time periods within a periodized training plan. A macrocycle typically refers to 1 year of training and a mesocycle refers to 3–4 months of a macrocycle. An example of a mesocycle using classical periodization terminology is the preparation phase. A microcycle refers to 1–4 weeks within a mesocycle. Each of these time periods within a periodized training plan has specific training goals, such as maximizing muscle hypertrophy, increasing strength or increasing power. US terminology of pre-season, in-season and off-season can also be used to describe various time periods within a periodized training plan. Using this terminology, the time period being described can vary in length depending upon the sport or activity. For example, a sport with a long in-season, such as American professional baseball, must have a corresponding decrease in the off-season phase of training. A third type of terminology used to describe a typical periodized strength training programme is a variation of the classical European terminology and was developed by American strength/power athletes, such as Olympic weightlifters and shot putters. As with the previous two types of terminology, each training phase has particular training goals.

No matter which type of terminology is used to describe a periodized strength training programme, the two most important questions about the training programme should always be the same. Does the training programme achieve the target training goals specific to many strength training programmes (e.g. increased strength, power, local muscular endurance, total body weight and lean body mass, or decreased percentage of body fat, etc.)? Does the periodized programme result in greater changes in such variables than non-periodized training programmes? These are perhaps the most important questions when examining any periodized programme. The remainder of this chapter will examine some of the evidence concerning these questions.

Different acute programme variables result in different physiological responses

As discussed in Chapter 3, different combinations of acute programme variables, such as number of repetitions per set, number of sets performed and rest periods between sets, result in different acute physiological responses. Virtually all strength training programmes will result in some gain in strength, power and muscle hypertrophy. However, certain combinations of acute programme variables will emphasize these to a greater degree than other combinations. For example, three sets of 10 repetitions at 10 repetition maximum (RM) with 1-min rest periods between sets and exercises results in a significantly greater blood lactic acid and serum growth hormone response than three sets of five repetitions at 5 RM with 3-min rest periods between sets and exercises in both men (Kraemer *et al.* 1990) and women (Kraemer *et al.* 1993). Likewise, three sets of 10 repetitions at 10 RM with 1-min rest periods between sets and exercises results in a significantly greater blood lactic acid and serum growth hormone response than one set of 10 repetitions at 10 RM with a 1-min rest period between exercises in both men (Gotshalk *et al.* 1997) and women (Mulligan *et al.* 1996). So, if the goal of a training phase is to increase the ability to develop and tolerate high concentrations of blood lactic acid and so enhance short-term high-intensity local muscular endurance (e.g. freestyle wrestling or an 800-m race), training sessions of three sets of 10 repetitions at 10 RM with 1-min rest periods between sets of exercises would be most appropriate. Likewise, training sessions that result in a greater serum growth hormone response than other training programmes should be chosen when the goal of a training phase is to increase muscle hypertrophy, because the magnitude of the serum growth hormone response resulting from a training session is significantly correlated to both Type I (slow twitch) and Type II (fast twitch) muscle fibre hypertrophy (McCall *et al.* 1999). Thus, an understanding of the acute characteristics of the workout protocol can help develop an underlying theory for the component parts of a programme over a chronic period of time.

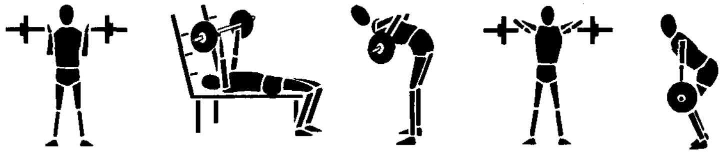
When performing training sessions of five sets of 10 repetitions for large muscle group exercises (e.g. back squat, push press, clean pulls) and three sets of 10 repetitions for small muscle group exercises (e.g. bent-over rows, crunches), the magnitude of the increase in 1-RM squat ability is dependent upon the length of the rest periods between sets and exercises (Robinson *et al.* 1995). Three-, 1.5- and 0.5-min rest periods result in a 7, 6 and 2% gain in 1-RM squat ability. The increase shown using 3-min rest periods is significantly greater than that shown using 0.5-min rest periods. Thus, when the major goal of a training phase is to increase 1-RM strength, longer rest periods are more appropriate.

Information gleaned from research provides a basis for how to utilize the acute programme weight training variables. It helps to support the different combinations of training variables in the design of workouts for each phase of a periodized resistance training programme. It also allows one to understand which variable to emphasize because of the physiological responses to a resistance training protocol. Such information shows that not all combinations of variables are the same and that changes made in a workout can have dramatic effects on the type of exercise stimuli that the body is receiving in that workout. With the many choices that can be made in the design of a resistance training programme, one can readily see the powerful set of tools available to the coach and athlete in resistance training programme design. This information also indirectly supports the theory that the training programme should be varied or 'periodized' to meet the changing goals and needs of athletes throughout the training year or throughout a sporting career.

Classic strength/power periodization model

One of the major goals of the classic strength/power periodization model is peaking of maximal force/power at a certain point in time, such as for a major competition (Fig. 4.3). The model follows a general pattern of decreasing training volume and increasing training intensity as a major competition approaches (Fig. 4.2). A classic strength/power periodization programme model is presented in Table 4.1. However, there are many variations of the classic strength/power periodization model, as no one periodization model can meet the specific needs of every athlete or sport. Nevertheless, it is the theoretical framework of periodization that allows for more training variability and recovery for the athlete. The training volume can be decreased and the intensity increased in this model by decreasing the number of repetitions per set from the hypertrophy to the peaking training phase. In the model presented, the training volume is also decreased from the power to the peaking phase by decreasing the number of sets performed. Active recovery phases are incorporated into this model. However, active recovery does not mean complete cessation of physical activity or training, nor is this phase typically long. This would result in deconditioning and the athlete would then have to spend training time to get back to their former physical condition, rather than improving it. Thus, active recovery phases normally consist of a reduction in training volume and intensity rather than cessation of all physical training. Longer periods of active recovery are dependent upon the individual sport and the athlete's requirements and often relate back to the level of training time and experience of the athlete within the context of the competitive requirements and schedule; for example, a few weeks of active recovery by a veteran athlete who has just won a gold medal at the Olympic Games and will now start to train for competitions next year—such a long active recovery period may not be detrimental to his or her competitive base. Conversely, a less experienced athlete who is trying to build his or her competitive status and is now getting ready for a world championship within months of the Olympic Games, may not want to take off that much time. One can develop all types of examples where the coach and trainer must

Table 4.1 Classic strength/power periodization model.



Training phase	Hypertrophy	Strength	Power	Peaking	Active recovery
Sets	3–5	3–5	3–5	1–3	Light physical activity
Repetitions/Set	8–12	2–6	2–3	1–3	
Intensity	Low	Moderate	High	Very high	
Volume	Very high	High	Moderate	Low	

carefully make decisions and use sound 'coaching judgements' (called clinical judgements in medicine) based on scientific facts to plan such training schedules. Therein resides the art of strength and conditioning programmes.

Variations of the classic strength/power periodization model are the most formally studied of the periodized strength training models (Table 4.2). It is important to remember that the goal of this model is to maximize strength/power at a certain time point. Thus, this model is not appropriate for athletes whose success does not depend upon maximal force/power, such as road cyclists and marathon runners. When examining any training model it is always important to consider what are the major goals of the particular training model? In other words 'What is the athlete trying to get good at?' It is important to keep this in mind because the programme must address some aspect of the athlete's performance goal(s).

Classic strength/power periodization studies

When examining any weight training study where comparisons between two different training programmes are performed, the length of the study and the training status of the subjects are of paramount importance. During the first 4–6 weeks of any realistic weight training programme, most strength/power increases occur because of neural factors (Sale 1992). In addition, one can see changes in the quality of the muscle proteins make a dramatic change in only a few workouts. The increase in strength/power as a result of neural factors can be quite large, especially in untrained subjects. For example, after only 2 days of isokinetic training (three sets of 10 repetitions) at 4.71 radian·s^{-1} male subjects demonstrated an increase in torque at 4.71 radian·s^{-1} of 22% (Prevost *et al.* 1999).

Another physiological change that occurs very quickly when weight training is performed is conversion of Type IIB to Type IIA muscle fibres. During 8 weeks of weight training twice per week Type IIB muscle fibres decreased from 21 to 7% of the total muscle fibre population in both men and women (Staron *et al.* 1994). In women a significant decrease in Type IIB fibres was noted after just 2 weeks of training, a total of just four training sessions, while in men a significant decrease in Type IIB fibres was noted after 4 weeks of training, a total of eight training sessions. For both the men and women in this study, strength significantly increased over 8 weeks of training without any significant change in muscle fibre size or lean body mass.

Thus, in short-term studies, any significant difference in strength/power or short-term high-intensity anaerobic endurance between two weight training programmes is difficult to achieve, because any and all realistic weight training programmes will result in the above two adaptations. This is especially true when untrained persons are used as subjects. If

Fig. 4.3 Classical periodization programmes were developed for strength/power athletes to peak for major world and Olympic competitions. Photo © Allsport/M. Powell.

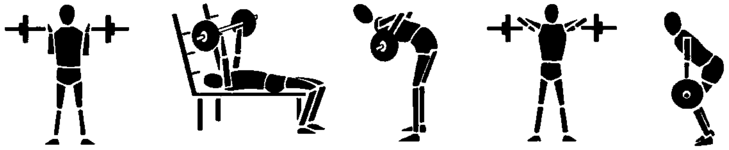


Table 4.2 Comparison of periodized studies.

Reference	Training length (week)	Frequency per week	Sets × Repetitions	Intensity	Exercises trained	Test(s)	Percentage increase
Stone *et al.* (1981)	6	3	Multiple sets 3 × 6	Progressed at own rate	Squats & 5 others	Squat Vertical jump	* *
			Classic periodization 1 wk 5 × 10 1 wk 5 × 5 1 wk 3 × 3 1 wk 3 × 2	Progressed at own rate	Squats & 5 others	Squat Vertical jump	*^{a} *^{a}
Stowers *et al.* (1983)	7	3	Single set 1 × 10	10 RM	Combination of 8	Bench press Squat Vertical jump	7* 14* 0
			Multiple sets 3 × 10	10 RM	Combination of 8	Bench press Squat Vertical jump	9* 20* 1
			Classic periodization 2 wk 5 × 10 3 wk 3 × 5 2 wk 2 × 3	10 RM		Bench press Squat Vertical jump	9* 27*^{b} 10*
O'Bryant *et al.* (1988)	11	3	Multiple sets 3 × 6	81–97% of pretraining 1 RM	Squat & 8 others	Squat Cycle power	32* 6*
			Classic periodization 4 wk 5 × 10 4 wk 3 × 5, 1 × 10 3 wk 3 × 2, 1 × 10	70–117% of pretraining 1 RM	Squat & 8 others	Squat Cycle power	38*^{a} 17*^{a}
McGee *et al.* (1992)	7	3	Single set 1 × 8–12	8–12 RM	Combination of 7	Cycling to exhaustion Squat reps to exhaustion	12 46

			Multiple sets				
			3 × 10	10 RM	Combination of 7	Cycling to exhaustion	15*
						Squat reps to exhaustion	71*
			Classic periodization				
			2 wk 3 × 10	10 RM	Combination of 7	Cycling to exhaustion	29*
			2 wk 3 × 5	5 RM		Squat reps to exhaustion	74*
			2 wk 3 × 3	3 RM			
			Multiple sets				
Willoughby *et al.*	12	2	3 × 10	Pretraining	Bench press	Bench press	8*
(1992)				10 RM	Squat	Squat	13*
			Multiple sets				
			3 × 6–8	6–8 RM	Bench press	Bench press	17*[c]
					Squat	Squat	26*[c]
			Classic periodization				
			4 wk 5 × 8–10	8–10 RM	Bench press	Bench press	28*[d]
			4 wk 4 × 5–7	5–7 RM	Squat	Squat	48*[d]
			4 wk 3 × 3–5	3–5 RM			
			Multiple sets				
Willoughby *et al.*	16	3	5 × 10	79% 1 RM	Bench press	Bench press	8*
(1993)					Squat	Squat	14*
			Multiple sets				
			6 × 8	83% 1 RM	Bench press	Bench press	10*
					Squat	Squat	22*[e]
			Classic periodization				
			4 wk 5 × 10	79% 1 RM	Bench press	Bench press	23*[f]
			4 wk 4 × 8	83% 1 RM	Squat	Squat	34*[f]
			4 wk 3 × 6	88% 1 RM			
			4 wk 3 × 4	92% 1 RM			
			Multiple sets				
Baker *et al.*	12	3	5 × 6 core ex	6 RM	Combination	Bench press	12*
(1994)			5 × 8 all others	8 RM	of 17	Squat	26*
						Vertical jump	9*
			Classic periodization				
			4 wk 5 × 10 core ex	10 RM	Combination	Bench press	11*
			3 × 10 all others	10 RM	of 17	Squat	18*
			4 wk 5 × 5 core ex	5 RM		Vertical jump	4*
			3 × 8 all others	8 RM			
			3 wk 3 × 3, 1 × 10	3,10 RM			

(*continued p. 62*)

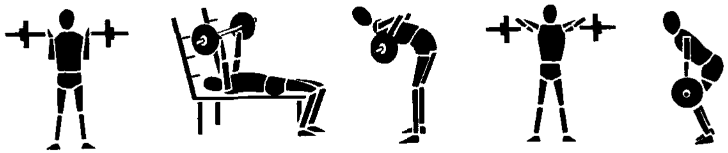


Table 4.2 *(cont'd)*

Reference	Training length (week)	Frequency per week	Sets × Repetitions	Intensity	Exercises trained	Test(s)	Percentage increase
			core ex				
			3 × 6 all others	6 RM			
			1 wk 3 × 3 core ex	3 RM			
			3 × 6 all others	6 RM			
			Undulating periodization				
			2 wk 5 × 10 core ex	10 RM	Combination	Bench press	16*
			3 × 10 all others	10 RM	of 17	Squat	28*
			2 wk 5 × 6 core ex	6 RM		Vertical jump	10*
			3 × 8 all others	8 RM			
			2 wk 5 × 8 core ex	6 RM			
			3 × 10 all other	10 RM			
			2 wk 5 × 4 core ex	4 RM			
			3 × 6 all others	6 RM			
			2 wk 5 × 6 core ex	6 RM			
			3 × 8 all others	8 RM			
			2 wk 4 × 3 core ex	3 RM			
			3 × 6 all others	6 RM			
			Multiple sets				
Herrick & Stone (1996)	15	2	3 × 6	6 RM	6 exercises	Bench press	25*
						Squat	46*
			Classic periodization				
			8 wk 3 × 10	10 RM	6 exercises	Bench press	31*
			1 wk off			Squat	54*
			2 wk 3 × 4	4 RM			
			1 wk off				
			2 wk 3 × 2	2 RM			
			Single set				
Kraemer (1997)	14	3	1 × 8–10, forced reps	8–10 RM	9 exercises	Bench press	3*
						Hang clean	4*
						Vertical jump	3*
						Wingate power	0

		3	Classic periodization 3 wk 2–3 × 8–10	50% 1 RM	12 exercises	Bench press	11*[g]
			2 wk 3–4 × 6	70–85% 1 RM		Hang clean	19*[g]
			2 wk 5 × 1–4	85–95% 1 RM		Vertical jump	17*[g]
			Repeat all weeks			Wingate power	14*[g]
Kraemer (1997)	24	3	Single set 1 × 8–10, forced reps	8–10 RM	20 exercises	Bench reps @ 80% 1 RM	37*
						Leg press reps @ 85% 1 RM	22*
						Bench press	13*
						Leg press	6*
						Wingate power	5*
						Vertical jump	7*
		4	Undulating periodization Strength session	2–4 × 12–15, 8–10, 3–5 RM	21 exercises	Bench reps @ 80%1 RM	56*[g]
			Hypertrophy session	2–4 × 8–10 RM		Leg press reps @ 85% 1 RM	41*[g]
						Bench press	29*[g]
						Leg press	20*[g]
						Wingate power	55*[g]
						Vertical jump	23*[g]
Schiotz *et al.* (1998)	10	4	Multiple sets 4 × 6 core ex	Initially 80% 1 RM	2 core, 5 assistance	Bench press	5
			3 × 8 all others			Squat	11*
			Classic periodization 2 wk 5 × 10 core ex 3 × 10 all others 1 wk 3 × 10, 1 × 8, 1 × 6 core ex, 3 × 10 all others 1 wk 2 × 8, 3 × 5 core ex, 3 × 8 all others 1 wk, 1 × 8, 1 × 6, 3 × 5 core ex, 3 × 8 all others 1 wk 1 × 8, 4 × 5 core ex, 3 × 8 all others 1 wk 1 × 8, 2 × 5, 1 × 3, 1 × 1 core ex, 3 × 6 all others 1 wk 2 × 5, 1 × 3, 1 × 2, 1 × 1, 3 × 6 all others 2 wk 2 × 3, 4 × 1 core ex, 3 × 4 all others	Initially 50% pretraining 1 RM	2 core, 5 assistance	Bench press	8*
						Squat	10*

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*Significant increase pre- to post-training.

Significant difference from: [a] 3 × 6 group; [b] 1 × 10 and 3 × 10 groups; [c] 3 × 10 group; [d] 3 × 10 and 3 × 6–8 groups; [e] 5 × 10 group; [f] 5 × 10 and 6 × 8 groups; [g] 1 × 8–10 group.

superiority of one training programme over another is shown in short-term studies, it may merely imply that the superior programme brings about quicker neural adaptations and/or Type IIB to Type IIA muscle fibre transformation. This may be especially true if no significant increase in muscle fibre cross-sectional area or lean body mass occurs.

Another factor that needs to be considered when examining weight training studies where comparisons between programmes are made is the limitation of applying results from studies using untrained subjects to the training of athletes or highly trained individuals. Strength/power increases occur at a much lower rate in highly trained compared to moderately trained subjects (Häkkinen *et al.* 1989). Assuming that the results of studies using untrained subjects are directly applicable to trained subjects in terms of magnitude of change and rate of change is tenuous. Unfortunately, the vast majority of studies comparing periodized models to non-periodized models have used untrained or moderately training subjects.

Studies comparing variations of the classic strength/power periodization model to multiple set and single set non-periodized programmes are presented in Table 4.2. Twelve of the 19 comparisons between the classic strength/power periodization model to multiple set programmes show significantly greater gains in 1-RM strength with periodized training. Only three of the strength comparisons demonstrate on a percentage basis a non-significant greater increase resulting from a multiple set programme compared to a strength/power periodization model. All of these studies, except for one, used men as subjects. The study that did use women (Herrick & Stone 1996) shows a non-significantly greater increase in strength on a percentage basis using periodized training. All four strength comparisons between single set programmes and a strength/power periodization model favour on a percentage basis the periodization model, with three of the four comparisons showing a significantly greater increase in strength using periodized training. One of the studies (Kraemer 1997) comparing a single set programme to a periodized programme during 14 weeks of training utilized only machines when performing the one-set programme. The periodized programme was performed using predominantly free weights. The use of machines for the one-set programme does limit the interpretation of the results to the comparison of a one-set machine programme to a periodized free-weight programme. The vast majority of these studies support the theory that the classic strength/power periodized training model is superior to both non-periodized multiset and single set strength training programmes.

Several of the studies do offer some insight into the reason periodized training results in greater strength gains than non-periodized training. A unique aspect of one of these studies (Willoughby 1993) was the use of trained subjects and that for the first 8 of 16 weeks of training there was no significant difference in total training volume between the periodization model and two multiset training programmes. After week 8 the periodized group's training volume significantly decreased compared to the multiset programmes. After 8 weeks of training all groups showed significant increases in 1-RM strength, but there was no significant difference between any of the groups. Only after week 8, when the periodized group's training volume was decreased, did significant differences in strength in favour of the periodized training become apparent. This indicates that the decrease in training volume present in the classic strength/power periodized model may in part explain the greater improvement in 1-RM strength. In addition, it may take up to at least 8 weeks of training in trained subjects for periodized training to show superior results compared to non-periodized programmes. This conclusion is supported by another study (Baker *et al.* 1994) where, for the entire 12 weeks of training, total training volume (total mass lifted) and relative training intensity (% 1 RM resistance) were equated between a multiset programme and a periodized programme. This allowed any difference in strength gains, if occurring, to be attributed to the manipulation of training volume and intensity and not to the total training volume or intensity used throughout the entire training programme. All groups significantly improved in strength, with no significant difference noted between groups. The results of both studies indicate the decrease in training volume and increase in training intensity present in the classic strength/power periodized training model is in part responsible for increases in strength greater than non-periodized programmes.

There are fewer comparisons of gains in motor performance between training programmes than strength comparisons. Of seven comparisons between classic strength/power periodized models and non-periodized single set and multiset training models, four comparisons show significantly greater gains in motor performance tasks (vertical jump and cycling power) with periodized training. Two of the comparisons on a percentage basis favour periodized training; however, the difference is non-significant. One of the comparisons favours on a percentage basis a non-periodized multiset programme over a periodized programme; however, the difference is non-significant. Because of the paucity of studies examining changes in motor performance, conclusions about motor performance must be viewed with some caution. However, comparisons to date do favour classic strength/power periodized models over non-periodized training.

Only one study (McGee *et al.* 1992) compared gains in measures of local muscle endurance (cycling to exhaustion and squat repetitions to exhaustion) between a classic periodization model, multiset programme and single set programme. The multiset programme and the periodization model both resulted in significantly greater gains of local muscular endurance than the single set programme. No significant difference between the multiset and periodization training was shown. However, the periodized model did show greater gains on a percentage basis in local muscular endurance than the multiset training. This study indicates that both multiset and periodized weight training result in greater gains of local muscle endurance than a single set programme.

Several studies have compared changes in total body weight and body composition between periodized and non-periodized training. No significant change in total body weight brought about by a single set programme and a classic strength/power periodized programme (McGee *et al.* 1992), and multiset programmes and a periodized programme (O'Bryant *et al.* 1988; McGee *et al.* 1992) have been reported. In a comparison of a periodized programme to a multiset programme, neither group showed a significant change in total body weight (Stone *et al.* 1981). While lean body mass and percentage body fat, determined by hydrostatic weighing, increased and decreased significantly, more related to the periodized training than to the multiset training programme. A 12-week study (Baker *et al.* 1994) using skinfolds to determine changes in body composition reports both a multiset and a periodized group showing significant but identical increases in lean body mass and total body weight, with neither group showing a change in total body fat. Using skinfolds to determine body composition it has also been reported that both multiset and periodized training result in no significant change in total body weight and non-significant increases in lean body mass (Schiotz *et al.* 1998), while the multiset group showed a small non-significant decrease in percentage body fat (12.8% to 12.2%) and the periodized group showed a significant decrease in percentage body fat (12.6% to 11.1%). A comparison of a single set programme and a periodized programme using skinfolds to determine body composition reports that the periodized training results in a significantly greater increase in total body weight and a significantly greater decrease in percentage fat (periodized training 18.1% to 13.8%; single set training 17.6% to 16.1%) than the single set programme (Kraemer 1997). Changes in lean body mass were not reported in this study. However, because of the significantly greater increase in total body weight and significantly greater decrease in percentage fat brought about by the periodized programme it is obvious that the periodized programme also resulted in a significantly greater increase in lean body mass than the single set programme.

Because of the paucity of studies examining changes in total body weight, lean body mass and body fat, conclusions concerning superiority of one type of training over another in bringing about changes in these variables must be viewed with caution. However, it is important to note that whenever a significant difference between training programmes has been reported it has always been in favour of the classic strength/power periodized training programme.

Undulating periodization model

Undulating periodization (also called non-linear periodization) is a more recent concept than the classic strength/power periodization model. One major goal of the strength/power periodization model is to peak strength and power at a certain point in time. However, for sports and activities with a long season, where success is dependent upon performance throughout the season, development and maintenance of physical fitness during the entire season is of prime importance. Peaking strength and power for major tournaments near the end of the season is important; however, without success during the season, qualification for major tournaments and competitions will not occur. Thus, the primary goal of a training model for sports and activities with a long season (e.g. basketball, baseball, soccer) is to develop physical fitness in such a way that success in a long season can occur.

Undulating periodization varies training volume and intensity in such a way that fitness gains occur over long training periods and treats peaking of physical fitness at a certain point in time as a minor training goal. This is accomplished by varying training using different RM training intensities or training zones such as 1–3 RM (very heavy), 4–6 RM (heavy), 8–10 RM (moderate) and 12–15 RM (light) training zones. In addition, a power training zone can be added in some programmes. These training zones are varied on a training session, weekly or biweekly manner. However, the training zones are not necessarily sequentially performed so that training intensity or volume follows a pattern of constantly increasing or decreasing over time. For example, a training session, weekly or biweekly sequential use of the three training stones might be 4–6, 12–15 and 8–10 RM on one occasion and 8–10, 4–6 and 12–15 RM on another occasion. The order of the training zones occurs randomly in this training model. The undulating periodization model is gaining popularity in sports and activities where strength/power is important for success during a long season, yet a planned workout sequence of weeks using the same intensity may not be conducive to the schedule, which makes application of the classic strength/power periodization model difficult to implement because of the pattern of high-volume training early in the model, resulting in a potential for residual fatigue and thus for poor performance (i.e. losing games) early in the season. An important key for the undulating or non-linear periodization model is the careful use of planned rest periods which usually occur after about every 12 weeks of the training cycle.

Although only limited study has taken place to date, it is also possible to combine various aspects of the classic strength/power and undulating periodization models. For example, using a classic strength/power model during the off-season and early pre-season of a sport, then switching to a undulating periodization model for the late pre-season and in-season weight training programme. One goal of such a programme would be to peak strength/power in the early pre-season and then continue to develop or maintain high levels of strength/power for the remainder of the pre-season and throughout the in-season weight training programme.

Undulating periodization studies

Only a few studies have compared the use of undulating periodization to other types of weight training programmes. However, these are quite promising concerning the positive effects of undulating periodization (Fig. 4.4). A comparison of the use of undulating periodization, with training zones varied on a biweekly basis, to a classic strength/power periodization model and a non-periodized multiset training programme show no significant differences in 1-RM strength or vertical jump ability (Baker *et al.* 1994). However, the undulating model did demonstrate slightly greater gains in these variables on a percentage basis over the 12-week training programme (Table 4.2). All three training programmes resulted in similar gains in lean body mass, determined using skinfolds measures, with no significant difference demonstrated between any of the training programmes.

A one-set programme has also been compared to a variation of an undulating programme (Kraemer 1997). The one-set training programme consisted of training 3 days per week using two different groups of exercises and forced repetitions. The two different groups of exercises were alternated on a training session basis. The undulating programme consisted of training 4 days per week using two different training sessions alternated on a training session basis. A strength/power session consisted of primarily multijoint exercises using either 3–5, 8–10 or 12–15 RM training zones, while a hypertrophy training session consisted of both single joint and multijoint exercises using a 8–10-RM training zone and 1–2-min rest periods between sets and exercises. The undulating training model resulted in significantly greater gains in measures of strength, local muscular

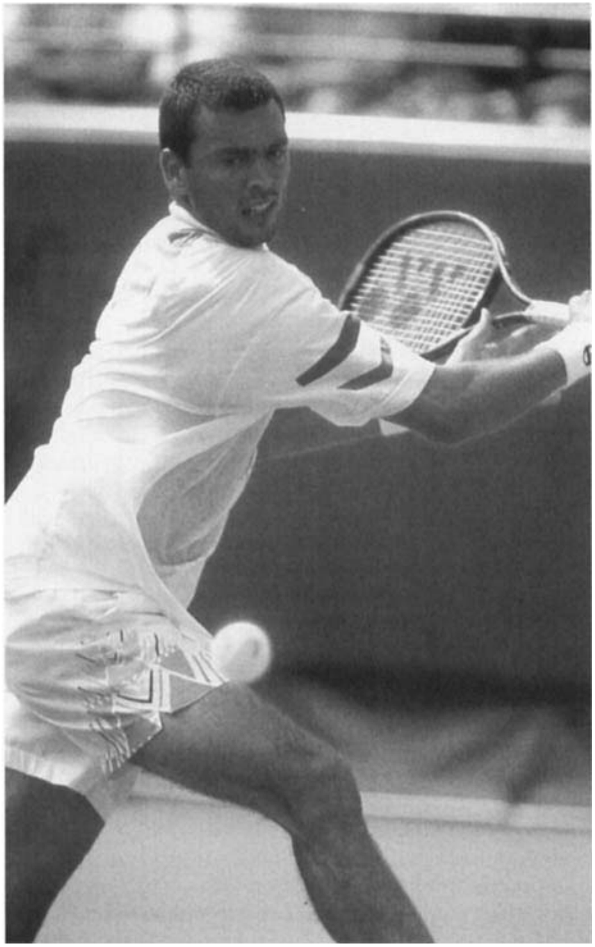

Fig. 4.4 Many sports training schedules are more conducive to using a new form of periodization called 'undulating' or non-linear as it allows more flexibility in schedule demands over a long competitive season. Photo © Allsport/G.M. Prior.

endurance and power (Table 4.2). Both training programmes resulted in a significant decrease in percentage body fat as determined using skinfold measurements. However, the undulating model resulted in a significantly greater decrease in percentage body fat (undulating 17.9% to 12.0%; single set 17.1% to 15.9%). Both programmes also resulted in a significant gain in total body mass. However, the undulating model demonstrated a significantly greater gain in total body mass than the single set programme (undulating 104 kg to 111 kg; single set 103 kg to 105 kg).

Because of the paucity of studies examining the results of undulating periodization, conclusions must be viewed with some caution. It does appear that undulating periodization can result in gains as great or greater in strength/power, lean body mass, total body mass, local muscular endurance and motor performance, and decreases in percentage body fat than other types of training programmes.

Conclusions

Although relatively few studies have compared different types of periodization models to other types of training programmes, some tentative conclusions can be made. Periodized programmes can result in greater strength/power gains than non-periodized multiset and single set programmes. Periodized programmes can also result in greater gains in motor performance, body composition and local muscular endurance than non-periodized programmes. Because of the relatively short training periods used in some studies comparing different training programmes, future studies need to examine changes in criteria over longer training periods. In addition, studies examining the response of women athletes, young athletes and older master athletes to periodized training are needed. Studies are also needed examining periodized models other than the traditional strength/power periodized model. A long-term goal of research examining periodized training should be to understand why periodized training may result in greater changes in criteria than non-periodized training. If this is understood, it will be substantially easier to design optimal strength training programmes to meet the needs and goals of athletes.

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Chapter 5

Periodized training programmes for athletes

Introduction

In this chapter various examples of periodized training programmes are presented. With each sport, different perspectives and teaching lessons related to programme development are offered. The development of extensive programme recommendations for every Olympic sport is beyond the scope of this handbook but demonstrating how to use the information in previous chapters is vital to proper implementation of the programme. The introduction for each sport should be carefully studied to elicit the perspective and teaching points being demonstrated in the example programme. As pointed out in the earlier chapters of this handbook, it is important to view these as examples, not as the sole type of programme that can be used for the sport presented. There are many variations in training to take into account when a programme is designed.

Each programme design for a sport and, more importantly, for the individual athlete will challenge the sports medicine professional and require a unique and specialized thought process using the type of information contained in this handbook. In order to familiarize the reader with different programme examples, this chapter starts off with basic information on periodization of training. We then provide example programmes for different sports to help the reader apply the knowledge base to the design of the training programme. Individual athlete considerations are not presented but must be included in any programme design.

Basics concepts in periodization of resistance training

Periodization was originally developed for athletes, usually strength/power athletes attempting to peak for a competition. The concept has now been expanded to include all types of physical development programmes. Many people credit the former Eastern Bloc countries with developing periodized training in the 1950s and 1960s. Interestingly, the idea was based on the work of Canadian endocrinologist, Hans Selye, who studied the adrenal gland and the effects of different types of stress in animals. He developed the concept of the General Adaptation Syndrome, in which a 'stressor' would first cause a dramatic decrease in physiological function but, if it did not kill the animal, an adaptation to the stress would occur over the next 6–8 weeks and then plateau off. If the stress was not removed or changed it would be come a 'distress' and the animal would die. Periodized training has now become an important corollary to the principle of 'progressive overload', as variation is key to optimal physical development with long-term strength training.

As pointed out in Chapter 4, several variations in terminology describing periodization have developed:

1 traditional American terminology;
2 traditional European terminology; and
3 American terminology that grew out of traditional European terminology (see Fleck & Kraemer 1997, 1998 for further review).

This can make it difficult to understand a periodized programme. In addition, there are dozens of models which have been proposed for use. However, all periodization terminology either describes a certain type of training, a certain portion of a training year, or a certain length of time within a training year. This makes it quite easy to understand all the various forms of periodization terminology. Europeans are normally credited with developing the original periodization terminology. Some Americans use this when describing a periodized training plan but others have developed their own terminology to describe a periodized training plan.

The adaptation of periodization concepts for use in the development of resistance training programmes for other non-strength and power athletes can be accomplished by adjusting classical concepts and manipulating the acute programme variables (e.g. periodize rest period lengths for lactic acid toleration).

Traditional European periodization terminology

Traditional European terminology consists of three general types of terms (see Chapter 4, Fig. 4.1):

1 the first describes the length of a particular training period;

2 the second, similar to off-season, pre-season and in-season, describes where, in the training year, a training phase is located; and

3 the third type of term describes a particular type of training.

All of these terms describe the length of a particular training phase. Different terms are used to describe a week, a month and a year of training.

Macrocycle

This term is normally used to describe one entire training year and is important for the personal trainer to have a yearly plan for use with each client. A macrocycle is typically 1 year in length (e.g. 1 January to 1 January of the next year). For athletes it is normally thought of as beginning and ending after the last competition of a season. Macrocycle is also sometimes used to describe a length of time longer than 1 year; it is sometimes used to describe the length of time between major competitions, such as the summer Olympics when it would refer to a 4-year period.

Mesocycle

This term was originally used to describe the major training phases of an entire training year so the preparation, first transition, competition and second transition phases were described as mesocycles. Thus, mesocycle originally referred to a time period of 2–3 months. However, with the advent of the idea that to ensure optimal gains in physical conditioning, changes in training should be made every 4–6 weeks, this term has changed to mean a training period lasting 4–6 weeks.

Microcycle

Microcycle refers to 1 week or 7 days of training but can also relate to a training cycle of up to 4 weeks in length, depending upon the programme design. No matter how many training sessions are performed per week, microcycle always refers to a set training period where a specific workout cycle is used for a specific loading and intensity range prior to moving to another distinct training stimulus or rest. This is the cycle that will specifically define what is being done for a particular training variable. Thus, the configuration of the exercise stimuli starts with the microcyle, moves to define the composite mesocycle which moves to define the composite macrocycle.

Identifying phases of training to define cycles

There are also terms to identify specific types of training. In this case, training phases refer to particular time periods within a total training year. Training phase originally referred to similar time periods within the training year as the American terminology of off-season, pre-season and in-season. Each training phase is made up of several mesocycles which are made up of microcycles defining the type of workouts used. The following are examples of phases commonly used in sport periodization of training.

Types of training terminology

These terms refer to broad types or categories of training and can be combined with other more specific aspects of a cycle (e.g. general training preparatory phase). The whole terminology process in periodization is to define what is being performed during a specific time frame in a training cycle.

General training

This term refers to training that develops all round fitness. This is often thought of as the general preparatory training needed to develop basic fitness. The concept also deals with the idea that many people are so unfit that they have to train to 'get in shape' so that they can then really start to train to make progress toward their goals. General strength training refers to weight training that develops all the major muscle groups of the body and overall strength capabilities. A general strength training programme would include at least one exercise for all the major muscle groups of the body.

Sport-specific training

This includes activities related to the specific sport the individual is preparing for. Thus, the type of training is related to the time spent on sport-specific training drill and activities related to the sport itself.

Competition-specific training

This refers to putting the athlete in a situation very similar to the actual sport or competition setting (e.g. tennis). Competition-specific training would be included predominately during the late pre-season, in-season or competition training phases.

American strength/power periodization

American coaches, after learning about periodization from the Eastern Europeans, developed their own terminology to describe a periodized training programme. The coaches developing this Americanized terminology were predominately from strength/power sports such as Olympic weight lifting and the throwing events in track and field. Therefore, it must be remembered that this terminology and type of programme was developed for a strength/power athlete and not a distant runner or any other type of non-strength/power athlete, although the ideas contained within this periodized programme can be applied to virtually any individual's training. In general, these terms include:

1 hypertrophy phase—the goal is to develop muscle mass to help in subsequent strength/power training;

2 strength phase—the goal of this phase is to develop maximal force and set up the body to be able to develop power;

3 power phase—the goal is to optimize the expression of maximal force and power;

4 peaking phase—the goal of the programme is to peak for competition; and

5 active recovery—the goal of this phase is to allow the individual time to recover both physically and psychologically from the training and competition cycles.

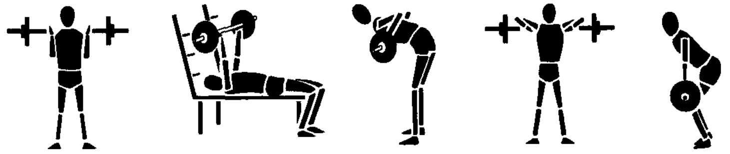
General preparatory conditioning phase

There is a distinct need to start an athlete off with a general training programme, which can be termed a 'base programme'. The base programme allows for a gradual entry into the process of physical conditioning and allows the personal trainer to learn more about the client without undue physical and psychological stresses. Making the proper progression is one of the fundamental elements of a periodized resistance training programme. Typical mistakes include programmes which 'undershoot' or 'overshoot' a client's physical abilities. Yet at the start of a programme too much too soon is the biggest problem. In periodization terms this base programme is often referred to as a 'general preparatory conditioning' phase of the training programme. The length of this type of training will be highly dependent upon the age, health and fitness of the athlete. The general preparatory conditioning phase may range from 4 to 12 weeks and improves the basic physical and mental toleration of resistance exercise stress. The more highly trained individual will need less time (e.g. 4 weeks) on this general conditioning phase in a periodization programme. Progress in physical abilities is not the primary goal in this phase of training but rather qualitative changes in how one feels and recovers from workouts.

During this phase, educational aspects of resistance training, aerobics and nutrition should be stressed. Teaching proper exercise techniques is also vital during this phase of training as loads are light and the ability to concentrate with little fatigue makes for an ideal teaching situation. It is essential not to overshoot an athlete's ability to recover from a workout or cope mentally with the required consistency of training. Rather than start a programme off too fast, the general preparatory conditioning phase of a periodized training programme allows the coach to prepare the athlete's mind and body for the challenges of a strength training programme.

With an almost unlimited number of programmes that could be developed for various sports and athletes, the key to developing the optimum programme is the scientific and theoretical aspects of the programme design. In this chapter, a number of programmes and background information is given to help the reader see the different options one can use from the previous chapter's background material. The classic model for periodization has been for strength/power athletes as seen in Chapter 4. In Table 5.1 a further description of this classic

Table 5.1 Periodization of training for the strength/power athlete.



	Hypertrophy	Strength	Power	Peaking
Volume	High	Moderate	Low to moderate	Low
Intensity	Low	High	High	Very high
Sets per exercise	3–6	3–6	3–6	1–4
Repetitions per set	8–20	1–5	1–5	1–4
Rest between sets	30–60 s	2–5 min	2–5 min	3–5 min
Exercises and exercise choice	General total body Emphasize weak areas	Muscle groups needed for success in the sport	Muscle groups needing power for success	Mostly power exercises
Exercise order	Weak areas first in training session	Muscle groups needed for success early in training session	Power exercises early in training session	Power exercises early in training session

Active recovery follows the peaking and competition phases of the training cycle and is used for restoration of the athlete both mentally and physically, while allowing his or her body to prepare for further training.

strength/power periodization model is overviewed. Key elements of the acute programme variables (see Chapter 3) can be distinguished and utilized to alter each element of the programme over time.

One must consider which type of periodized programme to use. In general there are two basic types which have developed: linear and non-linear periodized protocols for maximal force development. Let us now examine some of the basic differences between linear and non-linear periodization programme examples.

Linear periodized programmes

Classic periodization methods progressively increase in intensity with small variations in each 2–4 week microcycle. For example, a classic four-cycle linear periodized programme (4 weeks for each cycle) increasing in intensity might be:

Microcycle 1:
3–5 sets of 12–15 RM

Microcycle 2:
4–5 sets of 8–10 RM

Microcycle 3:
3–4 sets of 4–6 RM

Microcycle 4:
3–5 sets of 1–3 RM

It can be observed that there is some variation within each microcycle because of the repetition range of each cycle. Still, the general trend for the 16-week programme is a steady linear increase in the intensity of the training programme. Because of the approximately straight line increase in the intensity of the programme, it has been termed 'linear' periodized training.

The volume of the training programme will also vary, with the classic programme starting with a higher initial volume and, as the intensity of the programme increases, the volume gradually decreases. The drop-off between the intensity and volume of exercise can become less as the training status of the athlete advances. In other words, advanced athletes can tolerate higher volumes of exercise during the heavy and very heavy microcycles.

It is very important to point out here that one must be very careful not to progress too quickly to training with high volumes using very high intensities or heavy weights. Pushing the athlete too hard can lead to a serious overtraining syndrome which can compromise progress for months. While it takes a great deal of excessive work to produce such an overtraining effect, highly motivated athletes can easily make the mistake out of a desire to make gains and see progress in their training and sport performance. It is important to monitor the stress of the workouts. Remember, exercises within a programme (e.g. multiple chest exercises) can interact to compromise each other.

The purpose of the high-volume exercise in the early microcycles has been thought to promote the muscle hypertrophy necessary to enhance strength in the later phases of training. Thus, the late cycles of training are linked to the early cycles of training and enhance each other as strength gains are related to size changes in the muscle. Once maximal force has been developed, specialized power training programmes can allow for separate development of power capabilities in muscle. Programmes which attempt to gain strength without the necessary muscle tissue are limited in their potential.

The increases in the intensity of the periodized programme then start to develop the necessary nervous system adaptations for enhanced motor unit recruitment, as pointed out in earlier sections. This happens as the programme progresses and heavier resistances or higher velocities of movement are used. Heavier weights demand high threshold motor units to become involved in the force production process. Exercises with lighter power output but high training velocities also utilize specialized motor unit recruitment patterns. With the associated increase in muscle protein from the early cycle training, force production of the motor units are enhanced. Here again one sees an integration of the different parts of the 16-week training programme.

A 16-week programme is called a mesocycle and a 1-year training programme (macrocycle) is typically made up of several mesocycles. Each mesocycle attempts to progress the body's muscle hypertrophy, strength and power upward towards the theoretical genetic maximum. Thus, the theoretical basis for a linear method of periodization consists of developing hypertrophy followed by improved nerve function and strength/power. This is repeated with each mesocycle and progress is made in the training programme. Rest between the training cycles (active recovery phases) allows for the necessary recovery so that overtraining problems are reduced if not eliminated.

Undulating or non-linear periodized programmes

More recently, the concept of undulating or non-linear periodized training programmes have been developed to maintain variation in the training stimulus without holding to the strict phasing of training as discussed in Chapter 4. However, non-linear periodized training sometimes makes implementation of the programme easier when schedule or competitive demands over a long period of time limit the ability to vary the programme sequentially in a linear manner. The non-linear programme allows for variation in the intensity and volume within each 7–10-day cycle over the course of the training programme (e.g. 16 weeks). Typically, the change in the intensity and volume of training will vary (e.g. within a 7–14-day cycle. After, say, a 16-week programme, an active recovery phase of 1–2 weeks is then followed by another non-linear programme cycle or one can proceed to a linear programme if desired. A loading or intensity example for a non-linear periodized training programme over a 16-week mesocycle might be:

Monday:
2 sets of 12–15 RM

Wednesday:
6 sets of 1–3 RM

Friday:
3 sets of 4–6 RM

Monday:
4 sets of 8–10 RM

(This protocol uses a 4-day rotation with 1 day of rest between workouts.)

The variation in training is much greater within the 4-day cycle over 10 days. One can easily see that intensity spans over a maximum of a 15-RM range (possibly 1-RM sets vs. 15-RM sets in the cycle). This repetition intensity span in training variation appears to be as effective as linear programmes. The cycle of workouts can also include other types of training protocols, e.g. plyometric or six sets of three at 30% of 1 RM for power and velocity training. The key is the variation over the acute 1–2-week cycle over perhaps a 12–16-week mesocycle.

In comparison to the linear programmes, the athlete trains the different components of the muscle within the 7–14-day microcycle. Compared to the linear methods, non-linear programmes attempt to train the various components of the neuromuscular system within the same cycle. However, during a single workout only one feature is usually trained on that day. This appears achievable and may be more conducive to many individual's schedules, especially when competitions, travel or other schedule conflicts can make the traditional linear method difficult to adhere to.

In this programme the athlete rotates through the different protocols. The workout rotates between the different workout styles for each of the training sessions. If the athlete misses the Monday workout the rotation order is simply pushed forward so that he or she performs the next rotated workout scheduled. In this way no workout stimulus is missed in the training programme. It can also be dictated that a mesocycle will be completed when a certain number of workouts are completed (e.g. 48) rather than use training weeks to set the programme length of a particular cycle.

Again, the primary exercises are typically periodized. One can differentially periodize other supplementary exercise movements (e.g. hamstring curls, abdominal exercises) with care related to the type of movement capabilities; e.g. in the 'triceps push down' one could rotate between the moderate (8–10 RM) and the heavy (4–6 RM) cycle intensities. Assistance exercises or supplementary training must be carefully chosen so as not to interfere with the primary training stimulus being created for the specific non-linear workout.

Thus, two different approaches can be used to periodize the training programme: linear and non-linear programme schedules. The programmes appear to achieve the same effect and are superior to constant training programmes (see Chapter 4). The key to training programme success appears to be variation and different approaches can be used over the year to reach the training goals of the athlete.

Starting off strength training with a base programme

A base programme should be used by any athlete when beginning a weight training routine for the first time or when returning from an extended period of detraining. It has many similarities to a programme for general fitness or all round strength in workout frequency and muscle groups exercised. This may be a part of 'general training' for the preparatory period prior to more intense training. This is especially important for junior and master athletes. This type of programme allows the athlete to get used to the stress of resistance exercise. The frequency of training is at least two, but preferably, three times per week with at least 1 day separating workouts. Start out with one set and progress to three sets over a 6–8-week training period of at least 16 workouts. An example of a base programme for in the weight room is given below.

Example: base programme with equipment

Squat: 3 sets of 10–12 RM
Bench press: 3 sets of 10–12 RM
Single leg curls/stiff leg deadlifts: 3 sets of 10–12 RM
Single arm curls: 3 sets of 10–12 RM
Bent-leg sit ups: 3 sets of 15–20 repetitions
Shoulder (military) press (dumb-bells): 3 sets of 10–12 RM
Internal/external rotator cuff: 3 sets of 10–12 RM
Lateral pull downs: 3 sets of 10–12 RM

Rest: use 2 min rest between sets and exercises.

The base programme targets all the major muscle groups of the body (shoulders, chest, upper back, lower back, abdominals, front and back of upper arm, front and back of upper leg, calf, front and back of forearm and neck). The same body parts are trained each session and, initially, only one set is performed per exercise. In addition to multijoint exercises (e.g. squat, bench press), the programme also includes a number of single joint (isolation) exercises (e.g. arm curls, leg curls).

The first session should involve instruction of all the spotting and exercise techniques that will be used. The programme involves moderate loads (10–12 RM) and the emphasis is on perfecting exercise technique. Although a 10–12 RM refers to a loading that is heavy enough for only 10–12 repetitions to be performed, the first few workouts will often involve possible underloading as the athlete finds through trial and error how to select a load for a given RM zone range. It is not necessary to go to complete failure but the loading must be in a targeted range. It is preferable to underestimate rather than overestimate the weight and it will therefore take a few sessions for the athlete to discover a true 10–12 RM for each exercise. In the meantime, it should be realized that the athlete should only perform 10–12 repetitions, even though the weight is light enough to allow for more repetitions. There is nothing wrong with this and it is actually a desired training progression. A slightly lower intensity should be used for younger boys and girls (< 11 years) (12–15 RM) on this programme and the same guidelines apply.

The beginner should use a base programme for 6–8 weeks. Even though both the number of exercises per session and the repetition range are somewhat high, a base programme is characterized by a low weekly volume of training because of a relatively low total number of sets and sessions. Over the duration of this programme, the athlete experiences an increase in training volume by progressing from 1 to 3 sets for each exercise.

Initially, the metabolic stress is kept at a low level by rest periods of at least 2–3 min between sets. Additional time should be factored into the first session because of the extensive teaching and learning of the exercises. The athlete should shorten the rest intervals from workout to workout until the breaks are closer to 1–1.5 min. Shorter rest periods can be used with the circuit format compared to the other two because the muscle is allowed to recover for a longer period of time before beginning to exercise again. Thus, to provide more rest time for any particular muscle group, the athlete should first start using a circuit fashion when more than 1 set is involved for any of the exercises.

With this initial programme, rapid increases in strength and local muscular endurance will be observed in the primary movements as a result of dramatic learning effects. This programme allows for the athlete to gain maximal force and become accustomed to the physical effects of resistance training. Recovery should be monitored carefully and there should be no excessive soreness. If any soreness or pain result from the workout, further recovery should be allowed, loads for each set reduced in the next workout and, in extremely rare cases, medical evaluation sought.

Example: further manipulation of a base programme

Bench press*
Squat*
Front lateral pull downs*
Single leg curls*
Military press*
Single leg extension
Biceps curl
ALTERNATE†: wrist curl and reverse wrist curl
Standing heel raise*
Lying triceps extension
Bent-leg sit ups*
Seated row*
Back hyperextensions
Internal/external rotator cuff exercises.

*Start with these eight exercises in the first session.
†Do only one exercise in one workout and do the next exercise in the next workout.

Soccer

In this first sport-specific example for soccer (Figs 5.1 and 5.2), we provide an extensive background overview of the sport so that the reader can see the process of sport analysis prior to programme development. In addition, this example demonstrates how research findings can be used to make decisions and characterize the needs of players in a specific sport. In addition, the art of using the science to develop the aspects of the programme not directly supported by investigation should be looked for as you study the programme. The development of a solid programme to meet the needs of each player is vital to a sport where endurance, power, agility and speed must all be exhibited by athletes in their successful sport performance. In addition, this programme demonstrates how all players of a sport do not need the same type of training and position-specific decisions must be made for programme development.

Needs analysis of sport bioenergetics

Distance covered

Although there are some discrepancies in published data for the distance covered by soccer players in matches, most analyses indicate that a player should

Fig. 5.1 Soccer players require a vast array of physical capabilities for success in the sport including speed, agility, power and strength. Photo © Allsport/C. Brunskill.

Fig. 5.2 The sport of soccer requires strength training to prevent injury. Photo © Allsport/S. Dunn.

cover 9000–14 000 m, and the average distance covered by a player in a national or international soccer match is about 10 km.

It is interesting to note that the recreational player covers about the same distance as the top class players. If 10 km were covered by running at a steady pace in 90 min, oxygen uptake would be 35 $ml \cdot min^{-1} \cdot kg^{-1}$ or about 60% of the maximum value of the typical player. This is slow 9 $min \cdot km^{-1}$ jogging! What is the main difference between players of different levels?

Exercise pattern

Exercise pattern in soccer is intermittent and many different activities are alternating (e.g. walking, jogging, cruising, sprinting, backwards or sideways running). The total distance covered by outfield players consists of 25% walking, 38% jogging, 20% cruising and 7% backing. The sprinting distance at highest individual speed is only 10%. In time–motion research, players were found to stand still and walk for 57% of total playing time. One study reports that no more than 12% of the total time was spent in high intensity activities. Nevertheless, players need a relatively high oxygen uptake. Average oxygen uptake during a soccer match estimated from heart rate (HR) is around 70–80% of $\dot{V}O_{2max}$. Interestingly, this value is almost the same in players belonging to a national team and players of a low division or recreational players. Heart rate during a match for women and youth male players also show the same level and pattern of changes as observed for adult male players. Relative intensity of effort by individual players is the same regardless of the player's level.

This means that the main differences between players of different levels is not the total distance covered during a game, duration of low intensity activities or relative intensity, but the percentage and frequency of fast high intensity exercises during the game and the absolute value of maximal speed of play. This has been clarified from some studies comparing different competition level teams.

Exercise power output

Intermittent high intensity or variable speed activities typical in soccer elevate energy cost. These include frequent accelerating and decelerating, changing of direction, tackling, competing for the ball, jumping, rising after falling, etc. All these activities provide an extra physiological stress to the player. Running sideways and backwards elevate energy expenditure by 20–40% compared to normal running, depending on the speed of the running. Dribbling a ball also requires an extra energy expenditure above that of simple running at the same speed. It has been shown that there are 1000–1200 discrete movement changes in a game, with the mean duration being 4.5–6 s.

The mean duration of a sprint during top class matches is 2 s or 17 m. The average number of sprints is 19 and they occur once every 4–5 min. When high and moderate speed running are added the number of activities amount to 200, one per 30 s.

The interval nature of soccer is partly described by the high : low intensity activity ratio of 1 : 7. For every 4 s spent running hard, approximately 28 s are spent in activities of a more aerobic nature.

Maximal aerobic power and anaerobic threshold

Several studies have determined the $\dot{V}O_{2max}$ for elite male players; mean values between 56.5 and 69.2 ml·min^{-1}·kg^{-1} have been reported. For elite women players, mean values between 47.1 and 57.6 ml·min^{-1}·kg^{-1} have been reported. There is a positive relationship between $\dot{V}O_{2max}$ and the ability to resist deterioration in sprint speed during a simulated game test. $\dot{V}O_{2max}$ correlates well with the total distance covered in a game.

Studies show that soccer players have a high anaerobic threshold around 80% of $\dot{V}O_{2max}$, almost comparable to middle distance and distance runners. A significant negative correlation was found between deterioration in repetition sprint performance and anaerobic threshold for well-trained players. This suggests that not only improving the $\dot{V}O_{2max}$ but also pulling up the anaerobic threshold are important training goals for the soccer player.

Anaerobic lactacid system

The fact that the intermittent activities are more energy demanding than continuous exercise is supported by the observations of higher blood lactate concentrations during intermittent exercise. While most studies of blood lactate concentration at half time or at the end of a game have shown values of 4–10 mmol·l^{-1}, it is apparent that blood lactate values depend upon the intensity of activity in the few minutes prior to the sampling. Based on the findings of lactate concentrations in random interval sampling throughout the game, a single peak of lactate level during a match can at times be higher than 10 mmol·l^{-1}. Individual positions and the defence tactics adopted by the team significantly influence lactate concentrations. Therefore, improving the anaerobic energy production system should not be underestimated as it can provide more energy at a very high rate during intense exercise periods of the game.

It is known that muscle glycogen decreases rapidly during a soccer game. Low muscle glycogen impairs both aerobic endurance and anaerobic high intensity performance. The shorter average distance covered at high intensity running in low level players might be caused by low intramuscular glycogen concentrations.

Biomechanical analysis and muscle activity in soccer

Muscle strength

In most research measuring muscle strength of soccer players, data are obtained using an isokinetic apparatus and focused on concentric actions of the knee extensors. Mean values between 257–284 N at 0.0 $rad \cdot s^{-1}$, 214–300 N at 0.5 $rad \cdot s^{-1}$ and 126–182 N at 3.1 $rad \cdot s^{-1}$ have been observed.

In a study which compared knee extensor and flexor strengths in male players from national teams and four different divisions it was shown that the national team players were strongest. Recently, one study showed the strength of elite soccer players using free weights: 1-RM squat was 164.6 kg or 2.1 $kg \cdot body\ weight^{-1}$ and 1-RM bench press was 82.7 kg or 1.1 $kg \cdot body\ weight^{-1}$. These values were significantly higher than that for lower level team players.

The soccer kick

Most studies show that there is no relationship between kick performance and isokinetic knee extensor strength or isokinetic hip flexor strength for high level players. It appears that the strength of the knee extensors or hip flexors alone does not determine the final impact on the ball in a kick. Hip extensor muscles, hamstrings and lower leg muscles are also important components of the soccer kick.

Research findings indicate that the hip flexor in accelerating thigh towards the ball and eccentric contraction of hip extensor (e.g. the hamstrings) in decelerating or almost stopping the forward swing just prior to ball contact are dominant during a kick. Stabilizing the ankle also influences the impact of the foot with the ball to maximize the release velocity of the ball in kicking. A successful kick incorporates a complex series of synergistic and antagonistic muscles, including the muscle groups of trunk and upper extremity, rather than isolated muscle strength. The muscles of the non-kicking leg are also important as they provide an important support base for contact targeting of the kicking leg.

Some research showed that considerable changes in force from strength training did not improve peak ball velocity. In contrast, other studies showed that development in force from strength training improved kick performance. The subjects in the latter studies performed the strength training in addition to their ordinary training over a season. Another strength training programme, which built in plyometrics and ball exercise sessions, significantly improved kick performance. Strength training using special devices that allow functional (specific) muscle activities similar to the kicking motion with stretch-shortening cycle has also shown significant increase in peak ball velocity. Thus, it is important to combine basic strength training with soccer-specific strength training and skill training.

In contrast to the instep kick discussed above, in most kicks used in the game (e.g. push pass) the direction of the toes in the support leg and the kick leg are not always same. The direction of the toe in the support leg and the direction of the swing movement of the kick leg itself are often different in the higher level player at top level competition. In addition to an extension–flexion of hip and knee, hip adduction–abduction including diagonal plane, internal–external rotation of hip and knee and combinations of these movements should be trained.

It appears that a higher ability of explosive muscle action is advantageous in various game events in addition to kicking; these include rapidly changing direction, sudden acceleration and deceleration, heading, tackling, jumping, getting up from the ground and numerous goalkeeping skills. These explosive power performances are a multifaceted phenomenon that represents many training factors, such as maximal force, rate of force development, stretch-shortening cycle ability and intermuscular coordination specific to soccer skills. Therefore, all of these components of explosive strength should be included in a periodized training programme.

Sprinting

Comparing top German professional and amateur players at 30-m sprint tests, professional players were significantly faster than the amateurs even at 10 m. One study showed that average distance of sprinting during matches is 15–17 m. In another study, maximal sprinting distance was on average

20–30 m with an upper distance of around 40 m. Judging from these distances, quick acceleration at the start must be given more emphasis than the maintenance of top speed. A recent study of top professional soccer players from Brazil showed that the wingers and strikers have significantly greater total sprint distance than the other positions. Individual training programmes based on the positional role of the player should be carefully considered.

Agility and quickness

Most studies examine the agility of a professional soccer player using the Illinois agility run test which involves a combination of sprinting, changing direction and weaving in and out approximately 9 m (30 ft). Studies showed that the mean time of the test was less than the highest level of standardized score norms.

Any change of running direction is caused by an external impulse to the ground. The greater and quicker the direction change during desired high running speed, the greater force and shorter time of push off to the ground in the optimal direction is necessary. Any unnecessary extra step during turning should be avoided. Based upon the results of a study showing that an 8-week eccentric strength training programme decreased contact time on the force platform when changing direction, it was concluded that agility performance could be improved through eccentric strength training.

The amortization phase of foot contact with the ground in changing of running direction or turning can be considered the eccentric phase. The muscle must contract concentrically to execute the take off in the desired direction. If change from eccentric muscle action to concentric action is performed quickly, the resultant concentric action is more powerful than if no eccentric action was performed or if there was a pause between the eccentric and concentric muscle contraction phases.

To shorten the time to switch from eccentric to concentric muscle action and develop maximal contraction in the shortest time of foot–ground contact for quick changing of running direction, various stretch-shortening cycle exercises or 'shock' method (plyometric training) is effective.

Ball control and fake

In receiving and controlling the ball, flexibility of the hip joint, muscle strength and balance of the supporting leg are necessary to control the ball and to keep the player's body between the opponent and the ball. Combining a body fake or step fake with fast acceleration to rid him or herself of the opponent(s) is impossible without well-developed strength, power, flexibility and total body balance. Pull back and step over ball fake, shooting and passing fake, change of tempo and direction fake (quick change of acceleration and deceleration) are often used. A player can execute these fakes or pivots only if he or she has unilateral and multidirectional strength and flexibility of the hip, knee and ankle joint. Pendulum-like movement of the upper body during a fake requires good flexibility and strong trunk muscles.

Heading

Heading is a unique and an important skill in soccer. Usually the player jumps into the air and contacts the ball. While trying to head the ball there is often forceful body contact with surrounding players in the air. The trunk flexion and rotation mainly determine the force applied to the ball by the player. The neck should be isometrically fixed at the moment of impact. For successful heading, strengthening abdominal and trunk muscle is necessary. Shoulder and arm strength are also necessary in aggressive aerial duels.

Tackling

Data obtained from various players of different levels have showed that the total number of tackles averaged 14 per player per game and this value increased in higher levels of competition. For successful slide tackling at right angles from a low position in a safe manner, the hip joint must be flexible and strengthened. Getting up from the ground quickly straight after the slide tackle and starting the next play rapidly requires total body explosive strength.

Throw-in

Little attention has been paid to the ability of field players to throw the ball in a throw-in style but being able to throw the ball further will be advantageous in many situations of the game. Explosive strength and flexibility of trunk and shoulder should be trained for the long throws.

Goalkeeping

The goalkeeper occupies a special position in soccer. He or she needs to have specific physical abilities different from field players. Goalkeeping consists of more than receiving the ball with the hands and throwing; a high degree of quickness in reactions, agility in all different directions from various body positions, speed of getting up from the ground and diving, and throwing the body in another direction, height of jumping and starting velocity of sprinting forward and backward are all required.

The more skilled goalkeepers were found to dive faster and more directly at the ball using a countermovement jump, whereas the less skilled goalkeepers failed to perform a countermovement. Development of explosive strength and flexibility of upper extremities, trunk and lower body are necessary.

The modern goalkeeper is more than just a shot-stopper. He or she has to receive the ball and pass with either foot; at times heading is also essential. To improve the ability to throw the ball as fast and far as possible, strength and power in the shoulders, chest and back muscle groups are necessary. Well-developed upper body explosiveness is needed to fist punch the high ball as far as possible.

Body composition and size

Increasing lean body mass to some extent is an important training aspect in soccer players, as superfluous body fat decreases performance, such as acceleration, jumping, sudden turning and changing of direction in which body mass is lifted against gravity. A high percentage of body fat is the cause of fatigue in the early phase of the game. The average percentage of body fat for top level male players is approximately 10% or below. Mean body fat percentage of between 19.7 and 22.0% has been reported for elite women players. As a general trend, the goalkeepers, centre backs and forwards used as 'target players' tend to be taller and heavier players. However, data show that body size is not necessarily a determinant of sport success.

Primary sites of injury and its prevention

Common injuries

Eighty-eight per cent of all soccer injuries are localized to the lower extremities and 90% of all injuries are sprains, overuse, contusion and strains. Injury types and localization in both men and women are similar but women are observed to have a greater incidence of knee injuries than men, and are more prone to suffer dislocations of the patella or anterior cruciate ligament (ACL) injuries. This may result from different muscle activation patterns for cutting or deceleration movement between men and women.

Ankle sprains are the most common injuries for both men and women, constituting about 20% of all soccer injuries. Twisted ankles can occur not only when the player contacts another player competing for the ball and the player's foot touches the ground at an undesirable angle, but also when the player lands with their foot on another player's foot or lose their balance after a jump for heading and goalkeeping.

The other most common types of injury in soccer are musculotendinous injuries or strains of the lower extremity, especially the quadriceps, hamstrings, adductors and gastrocnemius. Groin pain is becoming increasingly recognized as a common symptom of injuries in soccer players. Adductor longus, rectus abdominis, iliopsoas and rectus femoris are included in this region. Compression as a result of direct impact and distraction as a result of overstretching or overload are two major causes of muscle ruptures.

Meniscal injuries, medial collateral ligament (MCL) and ACL injuries are common. Injury to the ACL has been estimated to occur in one out of 100 senior players every year. These injuries occur not only in contact, such as being tackled by another player, but also in non-contact situations, such as a quick change of direction or pivot turn when a player's foot is fixed to the ground. It is important to note that 40% of ACL injuries occur in non-contact situations.

Mechanism of injury and prevention

Players who have muscular weaknesses and strength imbalances are likely to experience situations where the muscle fails to sustain the joint. Muscle tightness, misalignment, muscle weakness and joint instability are also related to many soccer injuries. A recent study, which monitored a men's college soccer team over a 4-year period, clearly demonstrated a significant decrease in team injuries during the years in which strength training was employed.

Data from the World Cup final stage showed that more than 70% of injuries to players occurred where no foul play was adjudged; 50% of injuries in this category were associated with contact with another player, such as a tackle, collision and heading, while 20% did not involve another player. Players sustaining knee sprains not caused by collision had reduced knee extension strength in the injured leg compared to non-injured players.

In soccer, those situations where high force is needed are likely uses only a single legs in various angles and planes of joint movements. In evaluation and prescription of strength training of soccer players, angle specificity should be considered as well as lateral specificity.

It has recently been proposed that not only the conventional index for muscle balance of the hamstrings and quadriceps (H : Q ratio) but also the ratio of eccentric hamstring strength to concentric quadriceps strength ($H_{ecc} : Q_{con}$) is important for evaluation and to design training programmes aimed at increasing the muscle stabilization at the knee joint. It is worthy of note that the incidence of injury was three times higher during off-season practice compared with in-season practice sessions.

A rehabilitation programme in the pre-season is necessary to improve joint flexibility and stability, muscular strength and endurance, coordination and balance. The exercises should be chosen to activate proprioceptive or kinaesthetic feedback systems and movement coordination similar to soccer-specific movement.

Traditionally, quadriceps strength training used to be employed for injury prevention and rehabilitation of soccer players. However, isolated quadriceps muscle activity increases the strain within the ACL fivefold. For the knee and hip joint, it is important to emphasize structural exercises in which coactivity of hamstrings and quadriceps occurs instead of single joint exercises. For the ankle joint, coordination training with an ankle disc has been found to reduce the incidence of ankle sprains in soccer players significantly.

Goalkeeper injuries

The goalkeeper has a specific injury pattern different from field players of the team. Sixty per cent of all upper extremity injuries in professional soccer players were sustained by goalkeepers. In addition to the head injuries acquired in collision with other players or the goal posts, and abrasions or bruises acquired in landing directly on the body, the common upper extremity injuries sustained by goalkeepers are shoulder dislocation, fractures to the wrist, and fractures, dislocations and distortions of the fingers. These injuries occur after the goalkeeper throws him- or herself on to the ground or lands straight on his or her arm. Typical throwing injuries, such as rotator cuff tears or labrum tears in the joint, may also occur. Lower extremity injuries in goalkeepers almost always occur in the same way as in field players.

Components of training for soccer conditioning

The goals of conditioning training in soccer are first to improve the ability to perform explosive movements and the capacity to execute higher intensity exercises repeatedly without decreases induced by fatigue throughout the game and, secondly, to prevent injuries during games and training. To achieve this goal, a conditioning programme has to be multifaceted and should cover all the different aspects of the physical abilities required for high performance soccer discussed above. Conditioning training for soccer players is divided into five components and their subcomponents (Fig. 5.3). There is some overlap between the training categories as they are so closely related to each other. Some training categories can be performed in combination (e.g. speed training, quickness and agility training, and plyometric training can be performed together in a single series of exercise movements).

Strength and power training

There are four types of strength training. The exercise, intensity, volume (sets and repetitions), speed, angle

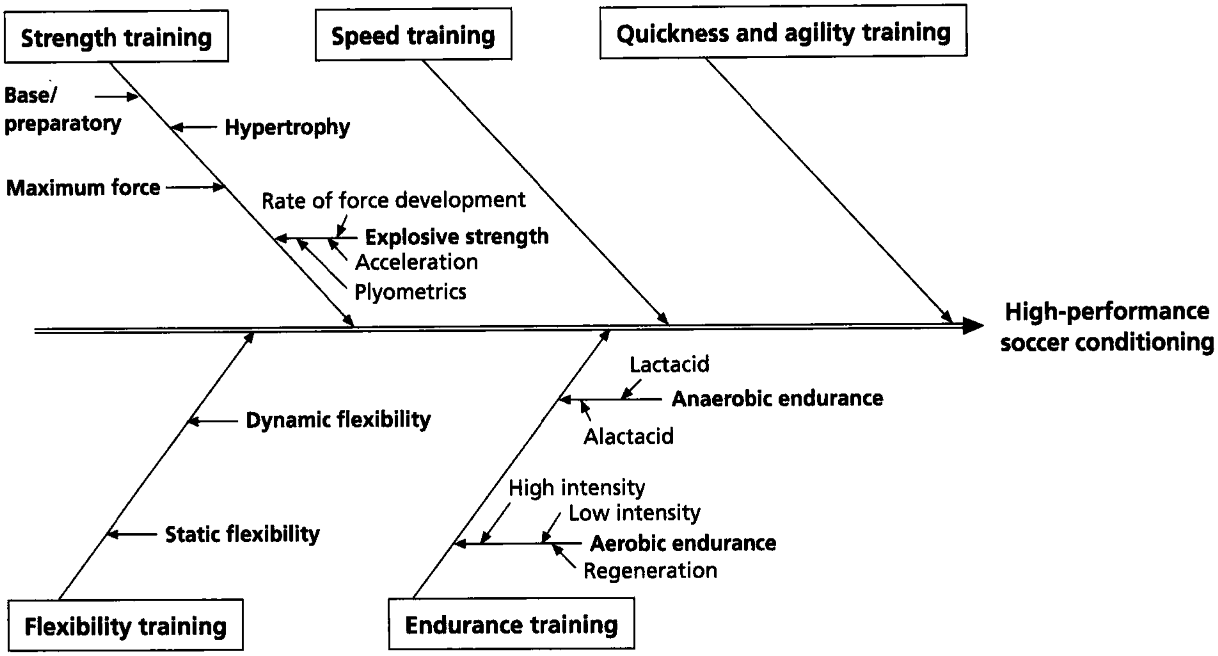


Fig. 5.3 Components of periodized soccer-specific strength and conditioning training.

of performing exercise movement, exercise mode and rest periods used in each of the categories differ.

Base/preparatory training

The goal of base/preparatory training is to increase range of motion, to improve flexibility and to facilitate the function of various proprioceptive reflexes and body balance control. The training involves a relatively high volume at low to moderate intensity (2–4 sets of 13–20 RM). Between sets and exercises, 1–2 min rest is taken. Performing exercises in a full range of motion and moderate velocity in a controlled manner is important in this training. For players who have functional instability of the ankle joint, ankle disk (or balance board) training is recommended. This base/preparatory training allows the player's muscles and connective tissues to adapt subsequent strength and conditioning training and to prevent injuries in the beginning phase of skill or tactics training in the field or artificial turf.

All the major muscle groups of the body should be included in the training programme. Training the abdominal and back muscles is also important to stabilize movement and to transfer the power generated in a part of the body to the whole body effectively.

Hypertrophy training

It is clear both from observations and anthropometric studies of elite soccer players that an exaggerated muscle hypertrophy is not essential to being an exceptional soccer player; however, increasing lean body mass is necessary to develop strength and power in subsequent training phases. Preventing injury and facilitating strength recovery after an injury also requires some degree of muscle hypertrophy.

Hypertrophy exercises consist of at least one multijoint and/or single joint exercise for all the major muscle groups of the body. For lower extremities, exercises at different joint angles and movement planes should be adopted. Upper body hypertrophy is needed to some extent in order to prevent injury and to allow players—in particular goalkeepers—to withstand contact with other players. Hypertrophy training consists of a relatively high volume and moderate intensity (e.g. 3–4 sets of 8–10 RM). Rest periods are 1–2 min.

Development of maximal force capabilities

The major goal of strength training is to develop the body's ability for maximal force. To improve and develop intra- and intermuscular coordination for the major muscle groups used for movements in soccer, exercises are predominantly of the multijoint strength type.

Soccer players should also concentrate on various multijoint strength exercises, especially ones using a single leg, such as the single leg squat, a variety of lunges and step ups. These single leg exercises are performed at several depths of knee bent position, internal and external rotated hip angles, and abducted and adducted hip joint positions, similar to the various playing positions during soccer matches.

To achieve maximum benefit from these exercises, free weights are superior to machines. When performing the single leg exercises with a barbell or dumb-bell, body position and motion must be controlled in all three planes. This allows proprioceptive and kinaesthetic feedback to occur in a manner similar to that in soccer performance. This phase of strength training mainly consists of moderate to high intensity and moderate to low volume (3–4 sets of 6–8 RM). Rest periods are relatively longer than hypertrophy training (2–3 min).

Explosive strength (power) training

Explosive strength (power) training improves limiting performance factors for soccer players in the strength domain. There are three training subcategories: rate of force development training; acceleration training; and plyometric training.

RATE OF FORCE DEVELOPMENT TRAINING

Rate of force development (RFD) training allows the player to exert as much force as possible in a very short period of time. The key to this type of training is maximal effort in a rested state. The loads typically range from 30% to 60% of 1 RM but can be as high as 85% of 1 RM. However, the key is maximal exertion in the appropriate lifting movements. The rest periods should be 3–4 min to allow sufficient recovery in order to exert maximal effort in lifting movements. With this type of training, the ability to produce force quickly is the primary goal of training.

ACCELERATION (BALLISTIC) TRAINING

The goal of acceleration or ballistic training is to exert force ballistically in an accelerating manner. When lifting the lighter resistances more quickly to train at a faster velocity more specific to soccer, the bar decelerates during the later phase of the lift. To prevent this undesirable deceleration, actual projection of the medicine balls or players' bodies into free space like jumping with or without resistance is used. Some Olympic-style lifts and related lifts are also used, as such lifts have an explosive and accelerative velocity profile.

PLYOMETRIC (STRETCH-SHORTENING CYCLE) TRAINING

With plyometric exercises the muscles are rapidly loaded with an eccentric action immediately before concentric action. Plyometric training is designed for developing maximal force production in a very short ground contact time and reducing the inhibitory Golgi tendon organ reflex. In addition to vertical and horizontal forward jumps and hops, single leg lateral jumps and hops with quickly changing directions and turns should be adopted for soccer players.

Speed training

Speed training concentrates on starting and accelerating abilities in short distance running; the maintainance of top speed is not emphasized. Various drills to improve the initial velocities from standing start and acceleration techniques are used for speed training. Resistance running drills with harnesses, sleds and parachutes are also helpful to develop explosive starting and high acceleration for soccer players. Assisted or overspeed running drills can be used so that the neuromuscular system can learn the high stride frequencies the player has never experienced.

Speed training should be designed to approximate game situations such as free running into open space to receive the ball, racing to the ball in one-to-one, and cover running. Players are more highly motivated by exercises using balls in competitive situations. The recommended distance to be used in speed training is in the range of 10–40 m. At least 30 s should be taken for the rest periods. The stance and the leg used to push the ground first should be changed at every sprint.

Quickness and agility training

Soccer players need to start their movements rapidly from both the right and left foot equally. Players who can react quickly in every direction from different body positions often have decisive roles as defenders and attackers especially in front of goals. Quickness training is defined as a series of training to improve a first step explosion from a stationary position or slow movement. The purpose of agility training is to increase the frequency of change of movement pattern and direction in a restricted time and area. Both are closely connected with reaction training and decision making. In combining quickness and agility training, the ability to vary body position or action quickly and to change direction suddenly is improved effectively.

Endurance training

There are two types of endurance training based upon the systems of energy supply: aerobic and anaerobic training.

Aerobic endurance training

Aerobic endurance training is divided into regeneration, low intensity and high intensity training, according to the physiological functions improved by the training.

REGENERATION TRAINING

Exercises with below 65% of HR_{max} (approximately below 130 b.p.m. for 20-year-old players), such as light jogging, are included in this category. If this type of training was carried out on the day after a match or hard training, recovery from fatigue would be facilitated. It also can be used to avoid overtraining and to stabilize the immune system, which can be suppressed because of intensive and extensive mental and physical exercise during a heavy schedule of tournaments.

If regenerative type training such as an over distance running lasted over 60 min, the training purpose would be to develop a state of physical conditioning to support low and high intensity training and anaerobic training in later training stages.

LOW INTENSITY AEROBIC ENDURANCE TRAINING

The purpose of low intensity aerobic endurance training is to improve peripheral factors of aerobic endurance (the proliferation of capillaries and the oxidative capacity in the muscle). Intensity of this training should be between 65 and 80% of HR_{max} (approximately 130 and 160 b.p.m. for elite 20-year-old players). The upper border corresponds to the anaerobic threshold. For an average soccer player, a relatively lower heart rate should be used for the upper border (e.g. 140–150 b.p.m.). When continuous methods are used for this training intensity, the duration of training varies from 30 to 60 min. However, care must be taken so that aerobic endurance training does not compromise speed and power development.

Intermittent training games with special rules are strongly recommended for this training. In this case, the active period should be from 5 to 10 min. Active recovery, such as jogging or ball juggling with a partner, should be adopted to maintain the HR at approximately 130 b.p.m. The rest periods are 2–3 min.

HIGH INTENSITY AEROBIC ENDURANCE TRAINING

High intensity training allows the player to improve central factors such as cardiac output and, as a result, to increase $\dot{V}o_{2max}$. The range of training intensity corresponds approximately to 80–100% of HR_{max}.

Intermittent training games using special rules should mainly be used for this training. In practice, 170–180 b.p.m. are used for target HR by the end of the activity for 20-year-old soccer players. Too high an intensity can inhibit the increasing of stroke volume and further activate a larger portion of energy coming from glycolysis. As a result, aerobic processes are inhibited and the concentration or creativity necessary for tactical decision making could theoretically be disturbed.

The duration of this exercise is 1–2 min. The rest interval should not be longer than 3 min. The number of repetitions might be 3–8 times.

Anaerobic endurance training

The purpose of anaerobic endurance training is to improve the capacity to produce power and energy continuously via the anaerobic pathways. This training is further subdivided into two types of training according to exercise duration, by which energy supply system is used.

LACTACID ENDURANCE TRAINING

The purpose of this training is to improve glycolytic energy pathways and increase tolerance to unfavourable internal changes, such as accumulation of lactic acid and hydrogen ions (buffer capacity). This process usually takes about 8 weeks. The intensity should be almost maximum. The exercise duration is 30–90 s and the rest period is equal to the exercise duration (about 1 : 1 exercise : rest ratio progression). The number of repetitions is usually 3–4. The number of sets is 2–3 at most, with 10–20 min active recovery intervals between the sets. This highly intensive lactacid endurance training creates considerable physiological stress. It is recommended only for advanced or elite players.

ALACTACID ENDURANCE TRAINING

The aim of alactacid endurance training is to improve creatine phosphate energy supply reactions. The duration of the exercise should be 5–8 s (running 40–70 m) with maximal intensity, and the rest period is about 1–2 min. In order to avoid blood lactate accumulation, the training should be divided into 3–5 sets consisting of 4–5 repetitions. Rest periods with light exercise, such as walking or slow jogging, should be 5–10 min. This training should be distinct from sprint speed training. Usually there is no opportunity in the game to run straight over 40 m, reaching and maintaining top speed. Exercise patterns can be designed to approximate game situations so that acceleration, deceleration, stopping, changes of direction and playing the ball are involved repeatedly in a single exercise training bout.

Flexibility training

Flexibility training mainly consists of static and dynamic stretching. In addition to a warm-up routine at the beginning of every training session and game, stretching can be performed as a special training task, theoretically to help prevent injury during the season.

Static stretching

Static stretching improves the range of motion of isolated joints and muscles. Special attention is needed for hips, thighs, hamstrings, ankles and spin region. Besides stretching in a team training session, regular stretching programmes should be undertaken by the player at home every day. Static stretching after activities helps the muscles recover from exercise stress and is part of most 'cool downs'.

Dynamic stretching

The purpose of dynamic stretching is to increase the joint mobility in the active full body dynamic movements specific to soccer. Usually a series of rhythmical calisthenics type movements are used but it is useful to perform dynamic stretching with soccer-specific movements such as slide tackle and hip turn kick with or without balls.

Periodization training programme for soccer

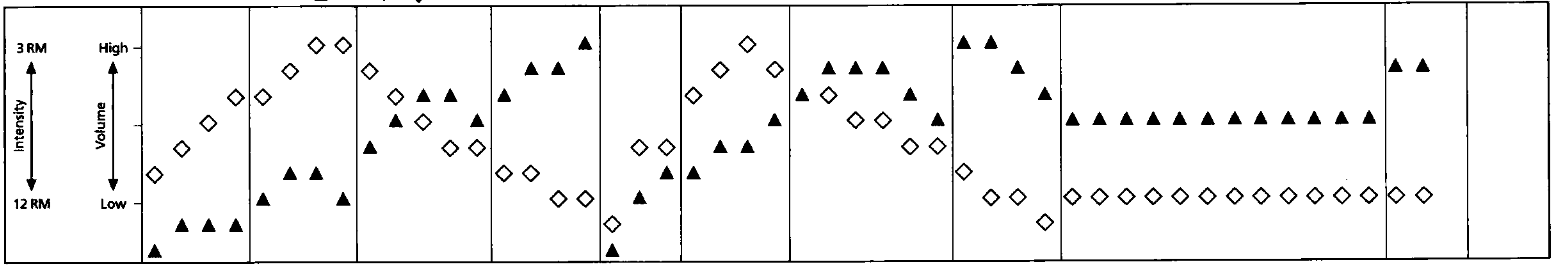
There are many different kinds of physical abilities that must be developed in the training of soccer players as shown above. However, the human body cannot adapt to so many different physiological requirements at the same time. One method that can induce beneficial adaptation in one motor ability or physiological system necessary for soccer discussed above may produce negative effects on another ability or system. Not only strength and conditioning training, but also tactical and technical training are important and often take long training periods inducing overtraining. Thus, periodization of an entire training programme is important to offset this potential for overtraining while peaking the team for competitions, especially championship tournaments at the end of most seasons.

Therefore, in order to increase the training effect of the targeted abilities, to avoid overtraining and to overcome accommodation to the same kinds of training for long periods of time, some selected training targets (prioritized training) should be distributed over several mesocycles in sequence, depending on their relationships to each other. Variation in a training programme is vital to its success.

We examine two examples of a 1-year periodized strength and conditioning training programme for soccer players: a model for a intercollegiate team (Fig. 5.4) and a model for a professional team (Fig. 5.5). Both programmes are based on the basic principles

		JAN				FEB				MAR					APR					MAY				JUN					JUL				AUG				SEP					OCT				NOV					DEC	
Microcycles (weeks)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Mesocycles	Preparation 1																	Transition 1			Preparation 2														Competition															Transition 2		
STRENGTH TRAINING																																																				
Phase	Base				Hypertrophy				Max force					Explosive				Recovery			Hypertrophy				Max force						Explosive				Maintenance												Conc.			Recovery		
Intensity	Low				Low				Moderate					High				Low			Low–Moderate				Moderate–High						High				Moderate–High												High			Low		
Volume	Moderate				High				Moderate					Low				Low			High				Moderate						Low				Low												Low			Low		
Rep (RM)	13–20				10–12				6–8					3–6				10–12			10–12				6–8						3–6				6–8 Rep												3–6					
Set	2–4				3–4				3–4					3–4				1–3			3–4				3–4						3–4				2–3 Set												3–4					
Rest period (min)	1–2				1–2				2–3					3–4				1–2			1–2				2–3						3–4				2–4												3–4					
Sessions per week	2–3				3				3					2–3				0–2			3				3						2–3				1–2												2–3					
PLYOMETRICS																																																				
Intensity												Low		Mod		High												Low		Mod		High			Moderate																	
Volume												High		Mod		Low												High		Mod		Low			Moderate																	
Sessions per week												2		2		2												2		2		2			1																	

INTENSITY & VOLUME OF STRENGTH TRAINING ▲ Intensity ◇ Volume



SPEED																																																				
Sessions per week	0								1		2			3				0							1				2			3			1–2															0		
QUICKNESS & AGILITY																																																				
Sessions per week	0								1		2			3				0					1						2			3			1–2															0		
ENDURANCE (AEROBIC) Sessions per week																																																				
Regeneration	3–4				2				1									3–4			3				1–2										1															2–3		
Low intensity	1										2			1				0			1								2			1			1–2															0		
High intensity	0											2		1		2		0											2			1		3	1–2															0		
ENDURANCE (ANAEROBIC) Sessions per week																																																				
Lactacid	0											1		2		1		0													1	3		1	1–2															0		
Alactacid	0											1				2		0													1			2	1–2															0		

Fig. 5.4 Periodization plan for intercollegiate soccer.

	JAN				FEB				MAR					APR				MAY					JUN				JUL				AUG					SEP				OCT					NOV				DEC			
Microcycles (weeks)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Macrocycles	Preparation													Competition (1st stage)																Transition 1				Competition (2nd stage)																Transition 2		

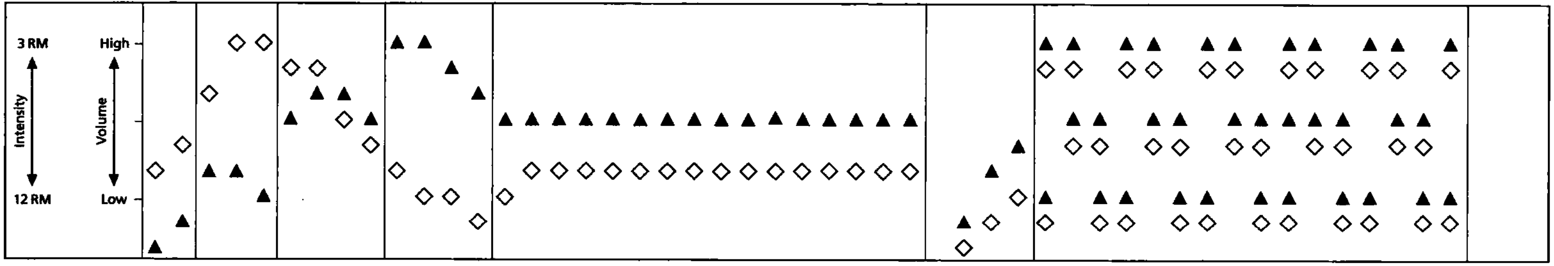
STRENGTH TRAINING

Phase	Base		Hyper			Max force				Explosive				Maintenance																Recovery				Maintenance (non-linear model)																Recovery		
Intensity	Low		Low			Moderate				High				Moderate–High																Low				Low–Moderate–High																Low		
Volume	Moderate–High					Moderate				Low				Low–Moderate																Low				Low–Moderate–High																Low		
Rep (RM)	13–20		10–12			6–8				3–6				6–10																10–12				3–15																		
Set	2–4		3–4			3–4				3–4				2–3																1–3				2–5																		
Rest period (min)	1–2		1–2			2–3				3–4				2–4																1–2				1–4																		
Sessions per week	3		3			3				2–3				1–3																0–2				1–3																		

PLYOMETRICS

Intensity						Low		Mod		High				Moderate																		Mod		Moderate																		
Volume						High		Mod		Low		Low		Low																		Low		Low																		
Sessions per week						2		2		2		1		1–2																		2		1–2																		

INTENSITY & VOLUME OF STRENGTH TRAINING ▲ Intensity ◇ Volume



SPEED

Sessions per week	0						2				3			1–2																0		2		1–2																0		

QUICKNESS & AGILITY

Sessions per week	0						2				3			1–2																0		2		1–2																0		

ENDURANCE (AEROBIC) Sessions per week

Regeneration	3		2							1				1–2																1–3				1–2																1–3		
Low intensity	2		1					3		1		2		0–2																1		2		0–2																0		
High intensity	0							2		1		3		0–2																1		2		0–2																0		

ENDURANCE (ANAEROBIC) Sessions per week

Lactacid	0							1		2		1		0–1																0		2		0–1																0		
Alactacid	0							1				2		0–1																0		2		0–1																0		

Fig. 5.5 Periodization plan for professional soccer.

described above. The major differences between the two models are the length of the preparation and the competition phases. There is only one competition phase of 15 weeks in the collegiate model, whereas in professional model there is a 7-month competition phase divided in half by a break of 4 weeks. These examples are only a guideline and it should be emphasized that there may be many different periodized training programmes based upon the specific conditions of a particular programme and according to the specific demands of a given team and athletes.

The North American intercollegiate model

The competition phase of this model team starts at the end of August and they have two games each week thereafter until the beginning of November. Tournaments start at the end of the competition phase until the middle of December, depending on the results of the games. The plan consists of two preparation phases divided by a 4-week transition phase for recovery.

Each preparation phase consists of hypertrophy, maximum force and explosive phase. The first half of the preparation phase, starting in January, has a base/preparatory phase prior to the hypertrophy phase. In this model, it is assumed that players have not engaged in any formal strength training before, so base/preparatory and hypertrophy phases are emphasized to stimulate their adaptation to a higher level of strength training and for the morphological changes of the body.

Plyometric training is started in the latter half of the maximum force phase. Speed training and quickness and agility training are emphasized at the explosive strength phase. Aerobic endurance training proceeds to anaerobic training. High intensity aerobic training is avoided with hypertrophy training and is not emphasized in the first half of the maximum force phase and in the explosive strength phase.

A normal in-season training programme will be used, consisting primarily of small numbers and low volume of moderate intensity multijoint exercises to maintain strength and explosiveness. When the team are picked to go to the national championship, and if there were 2–3 weeks prior to the start of the tournament, a concentrated load training session would be utilized, accentuating explosive type multijoint strength exercises to regain and peak strength and explosiveness.

Following a competition and before the next preparation phase, there is a second transition phase lasting 3 weeks to recover from the physical and mental stress of the competition phase.

The professional model

In most countries the professional soccer league has an official competition schedule lasting 7–8 months, divided in half by a midseason break. Usually only 3–4 months can be used for the training or preparation phase. This period could be much shorter according to the team's success level.

In our model, the relative length of the base/preparatory and hypertrophy phases is shorter than the intercollegiate model, because professional players usually have well-developed morphological strength bases. Plyometric training is started at low intensity from the beginning of maximum force phase.

The organization of strength, speed, quickness and agility, and endurance (aerobic and anaerobic) training are almost the same as the intercollegiate model, but using a greater number of sessions per week.

During the first half of the competition phase, a normal in-season maintenance training programme is used. However, during a long-lasting competition phase, some types of muscle fibres and connective tissue are possibly lost, and catabolic responses may deteriorate over the season. These factors may result in injury and decreased performance in the most important games which are usually scheduled at the end of the season. Furthermore, it is difficult to prepare strength and explosiveness for the forthcoming second half of the competition phase in such a short recovery period. Therefore, the non-linear periodization programme is used instead of the normal in-season maintenance training programme during the second competition phase.

Varying intensity drastically within 1 or 2 weeks, this programme induces optimal physiological responses to muscle mass maintenance, stimulates

Table 5.2 Sample training programme of base phase.
Repetitions (RM): 13–20
Sets: 2–4
Rest periods (min): 1–2
Sessions per week: 2–3

Days 1 and 3	Day 2
Lower extremities	
Back squat	Leg press
Front lunge	45° lunge
Side lunge	Knee extension
Leg curl	Cross over lunge
Standing calf raise	Seated calf raise
Toe raise	Toe raise
Ankle disc*	Ankle disc*
Upper extremities	
Field player	
Dumb-bell bench press	Dumb-bell fly
Dumb-bell shoulder press	Side shoulder raise
Dumb-bell raw	Lateral pull down
Goalkeeper (in addition to above exercises)	
External/internal rotation†	External/internal rotation†
Wrist curl†	Wrist curl†
Reverse wrist curl†	Reverse wrist curl†
Trunk and abdominals	
Crossed leg twist crunch‡	Crossed leg twist crunch‡
Reverse crunch‡	Reverse crunch‡
Crunch‡	Crunch‡
Back crunch§	Back crunch§

* 5 min each leg.
† 2–3 sets × 20 RM.
‡ 2–3 sets × 20–30 repetitions.
§ 2–3 sets × 10 repetitions.

Table 5.3 Sample training programme of hypertrophy phase.
Repetitions (RM): 10–12
Sets: 3–4
Rest periods (min): 1–2
Sessions per week: 3

Days 1 and 3	Day 2
Lower extremities	
Back squat	Front lunge
Side lunge	Knee extension
Cross over lunge	Standing leg curl
45° lunge	Hip abduction/adduction
Calf raise	Calf raise
Toe raise	Toe raise
Ankle disc*	Ankle disc*
Upper extremities	
Field player	
Bench press	Upright row
Shoulder press	Lateral pull down
Dumb-bell raw	Dumb-bell bench press
Goalkeeper (in addition to above exercise)	
Incline bench press	Incline bench press
External/Internal rotation†	External/internal rotation†
Wrist curl†	Wrist curl†
Reverse wrist curl†	Reverse wrist curl†
Trunk and abdominals	
Roman chair side raise‡	Roman chair side raise‡
Flat bench knee pull-in‡	Flat bench knee pull-in‡
Leg raise crunch‡	Leg raise crunch‡
Roman chair back extension§	

* 5 min each leg.
† 2–3 sets × 20 RM.
‡ 2–3 sets × 20–30 repetitions.
§ 2–3 sets × 10 repetitions.

neuronal factors to maximal force generation and explosiveness, and allows players to recover from the game and training.

Strength training programme and its variations

Typical one session programmes for strength training of each phase are developed in Tables 5.2–5.7. The exercises should not be changed during one training phase but intensity, volume and rest periods between sets and exercises need to be changed regularly every 1–2 weeks within the phase. The ranges of variations within each phase are also shown in Figs 5.4 and 5.5. The changing plans in each mesocycle of our models are as follows.

In the base/preparatory and hypertrophy phases in the professional model and those of the first preparation phase in the intercollegiate model, volume should be increased gradually and intensity is also increased. In the last week of hypertrophy training, intensity should be decreased in order to allow recovery from accumulated fatigue. The rest periods are decreased gradually.

Table 5.4 Sample training programme of maximum force phase.
Repetitions (RM): 6–8
Sets: 3–4
Rest periods (min): 2–3
Sessions per week: 3

Days 1 and 3	Day 2
Lower extremities	
Power clean	Push jerk
Back squat	Deadlift
Step up	Front lunge
Side lunge	Cross over lunge
Upper extremities	
Field player	
Bench press	Upright row
Shoulder press	Lateral pull down
Dumb-bell raw	Dumb-bell bench press
Pull over	Pull over
Goalkeeper (in addition to above exercise)	
Biceps curl	Biceps curl
Wrist curl*	Wrist curl*
Reverse wrist curl*	Reverse wrist curl*
Trunk and abdominals	
Pull down twist*	Pull down twist*
Slant broad leg thrust†	Slant broad leg thrust†
Pull down crunch*	Pull down crunch*
Roman chair back twist†	

* 2–3 sets × 8–10 RM.
† 2–3 sets × 10 repetitions.

Table 5.5 Sample training programme of explosive strength phase.
Repetitions (RM): 3–6
Sets: 3–4
Rest periods (min): 3–4
Sessions per week: 2–3

Days 1 and 3	Day 2
Lower extremities	
Hang clean	Push jerk
Push press	Half squat
Split squat jump	Dumb-bell split snatch
Upper extremities	
Field player	
Dumb-bell bench press	Bench press
Dumb-bell raw	Seated row
Pull over	Pull over
Goalkeeper (in addition to above exercise)	
Wrist curl*	Wrist curl*
Reverse wrist curl*	Reverse wrist curl*
Trunk and abdominals	
Medicine ball Russian twist†	Medicine ball Russian twist†
Medicine ball overhead throw	Medicine ball overhead throw†
Medicine ball crunch throw†	Medicine ball crunch throw†
Medicine ball back toss†	Medicine ball back toss†

* 2–3 sets × 6–8 RM.
† 2–3 sets × 10 repetitions.

In the hypertrophy phase of the second preparation phase in the intercollegiate model, intensity needs to be increased and volume is decreased to prepare for the next maximum force phase. The rest periods are decreased.

In the explosive strength phase in the professional model and that of the second preparation phase in the intercollegiate model, the first 2 weeks' training begins with high intensity which should be decreased towards the last week. The rest periods are increased. This allows the player to enter the first game of the season without fatigue. In the explosive strength phase of the first preparation phase in the intercollegiate model, intensity is increased and volume is decreased towards the last week. The intensity level is at its highest in the last week, because a recovery week may not be necessary just before a recovery phase. The rest periods are increased.

In the maximum force phase of both models, intensity is increased and maintained in the middle of the phase for 2–3 weeks and decreased at the end of the phase. Volume is decreased. The rest periods are maintained.

In the maintenance phase, there are no regular changes of these training variables. According to a team schedule, the training programme itself and number of sessions should be varied.

Table 5.6 Sample training programme of in-season (normal type).
Repetitions (RM): 6–8
Sets: 2–3
Rest periods (min): 2–4
Sessions per week: 1–2

Days 1 and 2

Lower extremities
Hang clean
Single leg press
Side lunge

Upper extremities
Field player
  Bench press
  Lateral pull down
Goalkeeper (in addition to above exercise)
  External/internal rotation*
  Biceps curl
  Wrist curl
  Reverse wrist curl

Trunk and abdominals
Crossed leg twist crunch†
Reverse crunch†
Crunch†
Roman chair back extension‡

* 2–3 sets × 20 repetitions.
† 2–3 sets × 20–30 repetitions.
‡ 2–3 sets × 10 repetitions.

Plyometrics training programme

An example of gradual progression for plyometrics training over 6 weeks for the first preparation phase of the intercollegiate model is presented in Table 5.8. The higher volume programme for the professional player can be developed by increasing the number of sets and repetitions. Using more single leg exercises can increase the intensity of plyometric training and increasing the height of obstacles such as hurdles used as a target of jumping or hopping.

Weekly training distribution

Table 5.9 shows a sample weekly training distribution plan of each training mesocycle. Performing heavy strength training and plyometrics on the same day is not to be recommended. However, this does not apply to high-level soccer players, because recovery from various skills training, tactics training and other conditioning training, such as endurance training, is also necessary. It is not uncommon to have two or three training games scheduled in a week at the late preparation phase.

The fatigue effect of strength training and plyometrics training are similar and several training sessions of this type executed every day may lead to severe exhaustion of the player. In order to avoid the superimposition of fatigue traces and increase the effectiveness of training, performing strength training and plyometrics on one day and concentrating on endurance training on a different day are recommended. The player's ability to perform exercises of another type is restored more quickly than the ability to repeat the same type of exercise.

Distance running

In this programme, distance running is used as the sport example because such runners bracket the metabolic continuum for lower force production needs and higher aerobic metabolism as being the predominant performance requirement. Typically, distance runners do not like to spend much time in the weight room as it takes time away from their run training. Furthermore, studies in the 1970s showing mitochondrial and capillary reductions with resistance training made many runners fear resistance training as a potential risk to their performance. Research in the 1980s showed that resistance training specifically designed to meet the needs of an endurance runner enhanced performance and injury prevention. Today, distance runners have come to rely on strength and power training to enhance hill running capabilities, maximal running velocity, to improve economy of running and to help prevent injury (Fig. 5.6). In this programme example, it is demonstrated how simple it is to add a fundamental programme into the training programme for a distance runner. A supplementary strength training programme can easily be incorporated into the sport which appears to have few direct needs for high force production yet can benefit from its inclusion.

Table 5.7 Sample training programme of in-season (non-linear type).

Light	Moderate	Heavy
Repetitions (RM): 8–12 Sets: 3–4 Rest periods (min): 1–2 Sessions per week: 1	Repetitions (RM): 6–8 Sets: 3–4 Rest periods (min): 2–3 Sessions per week: 1	Repetitions (RM): 3–6 Sets: 2–3 Rest periods (min): 3–4 Sessions per week: 1
Lower extremities		
Single leg press	Hang clean	Hang clean
Side lunge	Single leg press	Dumb-bell split snatch
Step up	Side lunge	Push press
Upper extremities		
Field player		
Dumb-bell bench press	Bench press	Lateral pull down
Dumb-bell row	Lateral pull down	
Goalkeeper (in addition to above exercises)		
Triceps extension	Biceps curl	Pull over
Wrist curl	Wrist curl	Wrist curl
Reverse wrist curl	Reverse wrist curl	Reverse wrist curl
Trunk and abdominals		
Crossed leg twist crunch*	Pull down twist†	Medicine ball Russian twist‡
Reverse crunch*	Slant boad leg thrust‡	Medicine ball overhead throw‡
Crunch*	Pull down crunch†	Medicine ball crunch throw‡
Roman chair back extension‡	Roman chair back twist‡	Medicine ball back toss‡

Note: Two of three programmes are performed a week in turn.
* 2–3 sets × 20–30 repetitions.
† 2–3 sets × 10–12 repetitions.
‡ 2–3 sets × 10 repetitions.

Periodization is the variation of acute programme variables (intensity, volume, frequency and rest) over time. Classically, periodization uses cycles that coincide with the preparation and the competitive season(s) of athletes. Thus, a simple periodization programme may include four 3-month periods (mesocycles) within a year (macrocycle) consisting of the competitive, active recovery, strength (build-up) and power cycles, respectively (Table 5.10). Microcycles can be created within mesocycles to define and create the specific type of workouts used during these different training periods.

Following the rigours of the competitive cycle, a period of active recovery is usually prescribed in which the athlete is active, but engaged in activities for pleasure and in a non-intensive relaxed manner. This period is obviously tempered by the level of competition involved. Active recovery in higher level Olympic athletes is much shorter than for more novice runners because of the need to keep a high level competitive edge for year round competitions. Nevertheless, peak training for major competitions (e.g. the Olympic Games) requires careful planning of race, training and recovery cycles in order to peak at the proper time. The active recovery cycle is followed by preparation for the following competitive season which begins with the strength (build-up) cycle, during which the athlete slowly increases the volume and intensity of training to prepare for the more intense power cycle that follows. The power cycle

Table 5.8 Sample training programme of plyometrics.

	Week	1	2	3	4	5	6
Drills	Day	1/2	3/4	5/6	7/8	9/10	11/12
Double leg hurdle jump		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg hurdle lateral jump (R)		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg hurdle lateral jump (L)		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg 180° hurdle jump		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg forward zigzag jump		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg lateral zigzag jump (R)		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Double leg lateral zigzag jump (L)		3 × 8 (low)	4 × 6 (middle)	3 × 6 (high)	2 × 6 (high)		
Single arm bounding		2 × 8	2 × 10	3 × 10	2 × 12	3 × 12	3 × 12
Lateral bounding		2 × 8	2 × 10	3 × 10	2 × 12	3 × 12	3 × 12
Single leg hurdle jump (right leg)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg hurdle jump (left leg)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg hurdle lateral jump (right leg—L)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg hurdle lateral jump (left leg—R)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg hurdle lateral jump (right leg—R)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg hurdle lateral jump (left leg—L)			2 × 6 (low)	2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	2 × 6 (high)
Single leg zigzag jump (right leg)				2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	
Single leg zigzag jump (left leg)				2 × 6 (low)	2 × 6 (low)	2 × 6 (middle)	
Single leg lateral zigzag jump (right leg—L)						2 × 6 (low)	2 × 6 (middle)
Single leg lateral zigzag jump (left leg—R)						2 × 6 (low)	2 × 6 (middle)
Single leg lateral zigzag jump (right leg—R)						2 × 6 (low)	2 × 6 (middle)
Single leg lateral zigzag jump (left leg—L)						2 × 6 (low)	2 × 6 (middle)
Total number of jumps		200	280	274	228	216	216

Note: Numbers show jumps × sets; R and L are direction of movement; low/middle/high show relative height of the hurdles.

Table 5.9 Sample weekly training distribution plan.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Base/hypertrophy phase						
Weight		Weight		Weight		
	Regeneration		Regeneration		Low intensity	Regeneration
Maximum force phase (1)						
Speed, Q&A				Speed, Q&A		
Weight		Weight		Weight		
	Low intensity		Regeneration		Low intensity	
Maximum force phase (2)						
Speed, Q&A				Speed, Q&A		
Plyometrics				Plyometrics		
Weight		Weight		Weight		
	Low intensity		Regeneration		Low intensity	
Maximum force phase (3)						
Q&A		Speed		Speed, Q&A		
Plyometrics		Anaerobic		Plyometrics	Anaerobic	
Weight	Low intensity	Weight	High intensity	Weight	High intensity	
		Regeneration			Regeneration	
Explosive phase (1)						
Speed, Q&A	Anaerobic	Speed, Q&A	Anaerobic	Speed, Q&A	Anaerobic	
plyometrics	Low intensity	Anaerobic		Plyometrics	Low intensity	
Weight		Weight	High intensity	Weight		
					Regeneration	
Explosive phase (2)						
Speed, Q&A		Speed, Q&A	Anaerobic	Speed, Q&A	Anaerobic	
Plyometrics	Low intensity	Anaerobic	Low intensity	Plyometrics	Low intensity	
Weight	High intensity	Weight	High intensity	Weight	High intensity	
						Regeneration
In-season						
	Anaerobic	Speed, Q&A				
Weight	Low intensity	Weight	High intensity		GAME	
Regeneration				Regeneration		

* The order of exercises in a day should be from top to bottom as shown.
Q&A, Quickness and agility drills.

usually finds the athlete reducing volume of training in order to focus on increasing intensity, which will ultimately prepare him or her for the competitive cycle to follow.

The rationale for periodized programmes is simple: systematic variation allows greater performance gains than a programme that is not varied. It makes intuitive sense to rest the body's physiological systems (e.g. nervous system and peripheral tissues) to allow for recovery following a period of intense training or competition. This is then followed with a cycle of relative rest during which the athlete recovers both

Fig. 5.6 Strength training for distance runners is vital to help tolerate the high intensity endurance training, promote quicker recovery and prevent injury. Photo © Allsport/G.M. Prior.

physiologically and psychologically before beginning another cycle of demanding training. This is accomplished by progressing from the build-up through the power phase to the next season's competition—a scenario which can be repeated indefinitely with different microcycle decisions being made, based upon the fitness level and needs of the athlete who is now becoming a more seasoned competitor. Ultimately, the goal of the programme with each successive training–recovery period cycle is to improve the athlete's performance over time.

Interestingly, while beyond the scope of this text, research supports the use of periodization of training for cardiovascular or endurance training too. The most compelling evidence is empirical, and is found in the training logs of world class athletes. However, the mechanisms by which periodization may work, its efficacy at different ages and ability groups (young vs. old, untrained vs. trained) and the optimal way to combine endurance and strength periodization programmes simultaneously for runners are not completely understood scientifically.

Table 5.10 A theoretical linear cycle for training in distance runners.

	Cycle 3 *Power*	Cycle 4 *Competition*	Cycle 1 *Rest*	Cycle 2 *Endurance*
Run	LT training Cruise or tempo intervals	Race	Jog	Initially, increase length of usual runs. During second half, increase length of long runs, and begin hill bounds
Lift	Plyometrics 2–3 sets highest intensity, lower volume	In-season programme Maintain strength, power, enhance injury prevention	One set Low volume, low intensity	2–3 sets higher intensity, highest volume

Compatibility of cardiovascular and strength programmes

Surprising to some coaches and athletes, research over the past decade has emerged which indicates that resistance training may actually contribute to improvements in aerobic performance. This is not entirely surprising when it is viewed in context of earlier studies, which attempted to determine incompatibilities with concurrent strength and endurance training. The concept of exercise compatibility is covered in greater detail in Chapter 6.

The late Dr Robert Hickson, for the University of Illinois–Chicago Circle was one of the first scientists to study the use of strength training with concurrent endurance training. His investigative team found that concurrent high intensity resistance and endurance training tended to hinder strength development in the long term. However, concurrent strength and endurance training did not appear to hinder development of endurance. In another study he examined high level 10-km runners and initiated a heavy (5-RM) squat training programme to see if it depressed their 10-km road run times. To everyone's surprise all the runners clocked faster times. Subsequent studies have verified this point and the fear that strength training would decrease aerobic performance has now been dismissed by most coaches, especially when designed as a runner-specific strength training programme.

Prior to the work of Hickson and colleagues, it was hypothesized that concurrent strength training might hinder the acquisition of endurance or actually reduce existing aerobic capacity ($\dot{V}O_{2max}$) through the dilution of capillary and mitochondrial densities in the active muscles.

Strength training may improve running performance

Contrary to loss of aerobic capacity, subsequent studies have shown that for many runners, strength training—especially explosive strength training—actually improves lactate threshold and improves running economy. These are two of the most important determinants of endurance success in addition to $\dot{V}O_{2max}$ which appears to reach a training capacity more quickly than other variables.

Lactate threshold (LT) is the running intensity (pace) beyond which the accumulation of lactate in the bloodstream continues to increase sharply (geometrically), and indicates that the exercise intensity has become increasingly anaerobic rather than aerobic. It is distinctly advantageous to improve LT, as sustainable aerobic pace will correspondingly increase.

Running economy (efficiency) is the inverse of the proportion created by the amount of oxygen consumed ($\dot{V}O_2$) to maintain a given pace (e.g. 55 ml $O_2 \cdot min^{-1}$ at 16 $km \cdot h^{-1}$). Running economy is high when a smaller $\dot{V}O_2$ is required to maintain a pace (e.g. 50 ml at 16 $km \cdot h^{-1}$ or 0.20), and low when a larger $\dot{V}O_2$ is required to maintain the same running pace (e.g. 60 ml at 16 $km \cdot h^{-1}$ or 0.16).

Strength training can apparently increase LT by > 10% in previously non-strength trained endurance athletes. The mechanism by which LT is increased is not completely understood, but could result from increases in contraction force among slow twitch fibres (Type I), thus decreasing the relative intensity required of these fibres and delaying the need to recruit higher threshold fast twitch fibres (Type II) which, if activated, would result in increased lactate production.

The mechanism(s) involved with improvements in running economy brought about by strength and power training are likewise unclear, but could include a similar mechanism to that bringing about an improvement in LT (muscle fibre recruitment patterns), as well as effects on running style and biomechanical efficiency. In addition, time on the ground may be reduced (ground reaction forces may be lower) with explosive strength training. This may be because of increases in the force–time curve at the lower time points of the curve (e.g. 0.1 s).

It appears that the judicious inclusion of strength/power training in an otherwise exclusively aerobic conditioning programme is beneficial. The theoretical reduction of injuries, because tissues are stronger through strength training, is a compelling argument for the performance of strength training for endurance athletes. Injury reduction alone from high intensity and at times high-volume training of endurance runners, combined with LT and running economy considerations, makes a sports-specific supplementary strength training programme for runners a requirement for the competitive athlete.

Periodizing combined running and strength programmes

A needs analysis should first be conducted for the sport. In addition to time, resources and goals/objectives, it is important to ascertain the short- and long-term requirements of the individual athlete. Maximal performance objectives may conflict with health objectives and the relative value of these parameters for the individual athlete must be kept in mind when periodization of the programme is carried out.

Mesocycles and microcycles within a periodized programme should be individualized according to the fitness level of the athlete and their seasonal objectives. For example, for a traditional high school or college track athlete beginning a competitive track season in March in the northern hemisphere and lasting approximately 3 months, four mesocycles may be created, with microcycles within mesocycles added (Table 5.10). If the competitive mesocycle comprises the 3 months from March to June (Cycle 4), then June to September would comprise the active recovery mesocycle (Cycle 1), September to December would comprise the endurance build-up mesocycle (Cycle 2), and January to April would be the power acquisition cycle (Cycle 3). Although a distance runner could use cross-training aerobic modalities other than running during this training, most highly competitive runners need to use running as their training modality. Resistance training should be performed on the major muscle groups of the body and target the joints that are most susceptible to injury (e.g. ankle, leg, lower back).

The example given may be modified in any manner that suits the needs analysis of the specific athlete for a given distance specialty. In fact, the runner may wish to modify the developed mesocycles and microcycles according to the results achieved and the requirements identified by an on-going iterative assessment. This highlights the fact that training programmes are 'dynamic' in nature and must be responsive to the different needs and conditions that exist. It is in fact very difficult to give specific recommendations for all types of distance runners when the individual requirements of an athlete are not known. The risk of a cookbook approach is that the individualized needs of the athlete may be ignored and therefore programme design potential is limited. Therefore we give an example only as a starting point to help you develop your own programmes for distance runners which meet each athlete's needs.

Theoretical basis for aerobic training recommendations

If $\dot{V}O_{2max}$, LT and economy are the principal determinants of distance running success, then training should be specifically aimed at improvements in these parameters. Maximal oxygen consumption will be improved by aerobic training associated with a well-rounded specially designed distance running programme. This involves various types of training, including the performance of 'cruise' intervals or 'tempo' runs which generally train LT (also known as 'anaerobic' training). Cruise intervals, a term coined by the exercise physiologist Jack T. Daniels, are long periods of running interrupted by short periods of rest. Tempo intervals are continuous race pace runs of shorter than race distance. The key to LT training, whether performing cruise intervals or tempo runs, is to maintain a pace near the LT threshold—that complies with intensity and functional specificity—which for most runners is approximately 85–90% of heart rate maximum.

As a general rule, LT training should not total more than 10–15% of the entire weekly mileage. LT training is initiated in Cycle 3, following the Cycle 2 preparation that includes progressively longer runs and initial power training in the form of hill bounding. In a sense, the LT workouts, which are high intensity in nature, comprise the quality workouts. All the other runs of varying distances performed during the week serve as additional 'junk miles', primarily to build endurance, burn calories and permit enough recovery so that the quality workouts can be performed on a recurrent weekly basis.

The hill bounding of Cycle 2 is preparatory for the more intense power workouts of LT training in Cycle 3. They were popularized by the New Zealand coach, Arthur Lydiard, and are performed by using a hill with a gradual slope rising at least 400 m in length. Following a warm-up, the runner should bound up the hill with high knee lift while pushing strongly off the toes, with high kickback of the heels. Forward speed is actually minimized in favour of accentuating the knee lift, pushing off the toes, and high kickback which results in bounding rather than running up the hill.

Weekly (or every week and a half) long runs should be gradually increased during Cycle 2 according to the requirements of the distance of the event being trained for. Generally, neither the distance run nor the total weekly mileage should be increased by more than 10% per week during this build-up phase in order to avoid overtraining and potential injury.

Theoretical basis for strength training recommendations

The purpose of strength training for the distance runner is not to develop muscle mass, but to reduce the chance of injury, reduce the time on the ground with each foot strike, and strengthen tissue so that greater volume and intensity of run training may be tolerated, especially at high levels of competition and with longer distance races (e.g. marathon). It is this training process that will allow improvement in LT and running economy to be achieved. Upper body strength exercises can help postural support of the upper body, arm movement and symmetrical development of the body. For example, it has been shown that during a marathon, runners drop their centre of mass which affects stride length; this is attributed to loss of postural muscle support in the upper body. Thus, postural support muscles need to be strengthened and their isometric endurance improved to help reduce this effect.

During Cycle 1, lower intensity and a lower volume is used (1 set of 12–15 RM). The athlete performs systematic exercises which conform to 'push and pull' exercise pairs, trunk exercises and other lower extremity exercises. In Cycle 2, the athlete increases the intensity to 10 RM and performs 2–3 sets of the same exercises. In addition, exercises are varied to change the angle of the exercise. In Cycle 3, both strength and running are power orientated. Therefore, strength training should be kept at 2–3 sets, but the intensity of the exercises should be raised to the range of 6–8 RM. In addition, explosive strength training exercises should be included. Recent studies have shown that this improves the foot strike time on the ground which is dependent upon explosive strength. High quality power exercises using about 1–3 repetitions in a set to maintain maximal power output (plyometrics, pulls with 30% of 1 RM, etc.) are needed to achieve this. During the competitive running season, the runner needs to maintain strength and power and a maintenance programme should be used 1–2 times per week (see in-season workout example).

It is not possible to be specific with recommendations for different athletes racing a variety of distances, especially given the differences in training tolerance. Individualizing the programme for the specific athlete, based on their response to the training, is mandatory. In some cases a non-linear undulating periodization model, discussed above, which varies the volume and intensity more frequently within a 7–14-day cycle may be appropriate where training and competition schedules are more demanding.

Example of periodization for a 10-km runner

Resistance training periodization

The choice of exercises for a runner includes alternating squats and lunges for the lower body, alternating bench press, overhead push press, and press downs for the 'push' component exercise. This is combined with alternating seated rows, lateral pull downs, and upright rows or hang pulls for the 'pull' exercise and alternating crunches and L-seats for the abdominal exercises, alternating roman chair back extensions, lower back machine and 'good mornings' for the back and, finally, alternating roman chair lateral raises and dumb-bell lateral flexion for the obliques.

These exercises are performed during Cycles 1–3 and a maintenance programme developed from these exercises for Cycle 4, which should also include explosive power training—a key to maintaining functional abilities. During Cycle 3, plyometric exercises (depth jumps, bounds, jumps, etc.) can be added as a strength base will have been achieved. Incorporation of these exercises is accomplished using the same acute variable selection as used for the conventional resistance training exercises.

Let us arbitrarily decide that the order of the above exercises will be rotated so that pushes, pulls, torso and leg exercises change order with every workout. The number of sets of each of these exercises is 1 during Cycle 4, 1 during Cycle 1, 3 during Cycle 2 and 2–3 during Cycle 3, with several sets of plyometric drills and exercises increased progressively during Cycle 3. The rest periods during Cycle 1 are 2 min, during Cycle 2, 1–1.5 min, and 3–4 min during Cycle 3. The intensity or load is 12–15 RM during Cycle 1, 10 RM during Cycle 2 and 6–8 RM during Cycle 3 and power intensities (e.g. 30% of 1 RM) exercises for Cycle 4 along with injury prevention exercises (e.g. calf raises, 8–10 RM).

A basic 'in-season' programme is used by distance runners in season. Loads, sets and exercises may be altered using a non-linear progression which allows more flexibility to the in-season or competitive phase schedule. This programme is performed 2 days per week. From this starting point a 'non-linear periodization model' for loading and number of sets can be utilized, with complementary exercises to vary the programme over long training periods. Optimal programmes will contain closed kinetic chain exercise choices (e.g. squats, lunges).

An example of a 2 day a week in-season training programme for an endurance runner is as follows:

Day 1
Warm-up
Squat—2 sets of 12–15
Leg curls/stiff leg deadlift—2 sets of 12–15
Bent-leg sit ups—2 sets of 25
Low back machine—2 sets of 12–15
Standing calf raises—2 sets of 12–15
Upright rows—2 sets of 8–10

Day 2
Warm-up
Hang pulls from the knees—4 sets of 3 at 30–60% of 1 RM
Leg curls/stiff leg deadlift—3 sets of 12–15
Bent-leg sit ups—3 sets of 15
Standing calf raises—2 sets of 6–8 RM
Dumb-bell chest press—2 sets of 10–12

Swimming

In this programme we give specific examples of the general composition and then show how the programmes for specific high level athletes might look. This allows the reader to see how the general programme might be translated to a particular athlete.

Rationale

High levels of strength and power are necessary for successful performance in swimming. In recent years there has been an increasing emphasis on including an injury prevention role for resistance training. This enables the swimmer to undertake higher volume training sessions as well as limiting the impact of overuse injuries on time out of the water.

Beyond the size changes that occur with the basic adaptation to a strength training programme, massive size increases are typically not the goal of a swimming training programme. Although there are some instances where swimmers require a programme that emphasizes increase of muscle size (short sprints) in certain body areas (e.g. shoulders, back), this is generally not a primary programme goal as excessive size (e.g. body builder type) may impact negatively on other aspects of swim performance, such as hydrodynamics and aerobic capacity. A major aim is to increase the power output of the muscles which act as prime movers in the target swimming style. This is perhaps more important for swimmers who specialize in the shorter distance events, as increased muscle strength and power output can be translated into increased swimming speed when combined with practice in the pool. In addition, when muscle strength and power are increased through appropriate resistance training, the muscles can perform the swimming stroke at a lower percentage of their maximal capacity and therefore efficiency should be improved and fatigue reduced.

To increase power as well as strength, the athlete should attempt to complete some of the exercises at a faster velocity. As the swimming stroke requires rapid acceleration of the limbs through the water, particularly in sprint events, the speed of muscle actions during resistance training is important. To swim faster, the power output must be increased to overcome the hydrodynamic drag force, which increases with the square of the velocity of the swimmer through the water.

Programmes are generally similar for men and women swimmers, although individual variation occurs when an injury is identified or musculoskeletal screening has identified a high risk of injury.

The aims of the programme change throughout the year as the athlete gets closer to major competitions. The focus of mesocycles shifts from strength to more endurance as the competition draws closer. This translates to a decrease in intensity and increase in volume.

Exercise selection

Exercises are programmed on the basis that they:

- are specific to the swimmer's competitive stroke in terms of muscles involved and joint movement;
- prevent muscle imbalances developing between agonists and antagonists;
- prevent injury to prone areas, such as the shoulder;
- provide variety; and
- suit the skill level of the athlete.

Injury prevention

Shoulder girdle injuries are the most common injuries for swimmers. The main cause of shoulder injury is overuse. Tendinitis mainly occurs in the swimmer's rotator cuff muscles and can usually be addressed by increasing the strength of the external rotator muscles and stabilizing the muscles around the scapular.

The constant repetition of training can cause inflammation or tenderness around the rotator cuff. On some days over 14 km are swum by the athlete and this usually causes the muscles producing shoulder internal rotation to develop considerable strength, resulting in an agonist–antagonist imbalance.

The following programme is designed as an introductory programme for the start of the swimming year. The aim of this programme is to increase strength and power output specifically in the muscles around the shoulders while also trying to increase the athlete's general strength level.

Introductory resistance programme
Warm-up: 5 min on bike, stretch.

Days 1 and 3

Set	1	2	3	4
Bench press	6	6	4	4
Lateral pull downs	6	6	4	4
Squats	5	5	3	3
Standing circles	6	6	6	6
Single arm seated row	8	8	6	6
Forward raise	6	6	6	6

Abdominals: see below

Day 2

Set	1	2	3	4
Clean pulls	5	5	3	3
Chin ups	6	6	6	6
Single leg squats on incline block	6	6	6	6
Trunk rotation machine	6	6	6	6
Forward raises	8	8	6	6
Swiss ball reverse flys	6	6	4	4

Abdominals: see below.

Abdominal workout
Select 200 repetitions from the following:
Swiss ball
  crunches (2 × 20)
  leg tucks (2 × 20)
  lateral roll (2 × 20)
Medicine ball
  side pass (2 × 10 each side)
  45° sit (2 × 30)
  overhead throws (2 × 20)
  twists (2 × 20)
Week 1: do all sets and repetitions.
Week 2: do all sets and repetitions and add another smaller repetition set.
Week 3: do only first two sets—higher repetitions sets only.
Week 4: do as much weight as possible on last lower repetition set.

Sample individual programmes

This first programme was designed for Daniel Kowalski, an Australian Olympic medallist. The emphasis is to provide the swimmer with enough strength to enable him to complete the volume of training that is required of a swimmer in the 1500 m freestyle event. A key requirement is also to increase the power output of the muscles so as to increase swimming velocity and improve efficiency. Increasing strength in the shoulder girdle and muscles stabilizing the pelvic trunk area are also primary aims. Kowalski had suffered from chronic rotator cuff tendonitis before coming to the Australian Institute of Sport programme and therefore injury rehabilitation and prevention exercises constitute a considerable part of his initial programme.

Daniel Kowalski: Olympic silver medallist 1996, 1500 m freestyle

Weights programme

Day 1 and 3

Set	1	2	3	4
Single arm dumb-bell bench press	6	6	6	6
Lateral pull downs	8	8	6	6
Single arm seated row	6	6	6	6
Leg press	5	5	5	3
Pull overs	6	6	6	6

Abdominal workout

Medicine ball, varied (50)
Crunches (50)
Leg raises (50)
Body hold on arms (3 × 30 s)

Day 2

Set	1	2	3	4
Incline press	6	6	6	6
Reverse flys	6	6	4	4
Squats	5	5	3	3
Lateral raises	6	6	6	6
Tricep press	6	6	6	6 (super set)
Curls	6	6	6	6 (super set)

Abdominal workout

Side crunches (50)
Crunches (50)
Leg raises (50)
Twists (30)

The following programme was designed for Petria Thomas, a sprint butterfly swimmer and Olympic medallist. The emphasis of this programme is twofold. Petria has very mobile joints and as such needs to be made more stable in her shoulders, while also emphasizing the development of strength. Power development is important and it is expected that the increases in performance in the training room will translate to improved maximal swimming velocity as well as increased efficiency at submaximal swim velocities. Again, a further goal is injury prevention and rehabilitation.

Petria Thomas: Olympic silver medallist 1996, 200 m butterfly

Strength programme

Day 1 and 3

Set	1	2	3	4
Incline dumb-bell press	8	8	6	6
Chin ups (wide grip)	6	6	6	6
Squats and rebound jumps	5–6	5–6	5–6	5–6
Standing circles	6	6	6	6
Single arm row	8	8	6	6
Calf raises (+ weight)	10	10	10	10
Abdominals: as below				

Day 2

Set	1	2	3	4
Standing dumb-bell press	8	8	6	6
Dumb-bell bench pulls	6	6	6	6
45° flys	6	6	6	6
Leg press	5	5	5	5
Split jumps	6	6	6	6
Rotator cuff	6	6	6	6
Shrugs	5	5	5	5
Abdominals: as below				

Day 4

Set	1	2	3	4
Close grip bench press	6	6	6	6
Dumb-bell bench pulls	6	6	6	6
Lunge walks	5	5	5	5
Lateral raises	8	8	6	6
Rotator cuff	6	6	6	6
Curls	10	10	8	8

Abdominal workout

Swiss ball
  one leg tucks (3 × 15)
  crunches + weight (3 × 20)
  twists (2 × 10 each side)
  bridge (3 × 30 s)

Wrestling

Wrestling, like other anaerobic sports, places a tremendous stress on the metabolic system as well as being a weight class sport. The sport of wrestling is one of the most demanding competitive sports of today from a metabolic perspective. This section looks at the very important concept of bioenergetics as it relates to the success of the athlete in this sport. Conditioning must reflect a need to cope with the acid–base disruption aspect of this sport, as with other combative sports (e.g. boxing, judo). In general, the wrestler needs muscular strength and power, together with local muscular endurance, to meet the demands of the match. Weight management also presents a special challenge to the wrestler in both the off-season and in-season phases of the year. If not carried out properly, weight loss can have dramatically detrimental effects on physical performance capabilities. Because the competitive season is so long, injury prevention also has a vital role in wrestling success.

Physical demands

The physical demands of wrestling are affected by the amount of weight lost prior to a match and the number of matches wrestled; this is the essence of the physical demands in wrestling. The physical demands will be related to the weight loss and the match schedule for a tournament. The ability of the wrestler to meet the physical and psychological demands of tournament wrestling will ultimately determine a champion. Therefore, strength and conditioning programmes must be centred on developing the physical conditioning weight management programmes, and skills needed to cope with the demands of tournament wrestling.

In order to understand such physical demands we start by examining the acute physiological stresses associated with a single wrestling match. This will help to understand the demands placed on the wrestler's body while helping to establish the physiological basis for principles of strength and conditioning specific to wrestling.

Sources of energy for wrestling

It is apparent that the sport of wrestling taxes both the aerobic and anaerobic energy systems. During the match the sport demands are maximal or near maximal muscular activity. In order to sustain such physical exertion, energy must be made available to the muscles involved with each of the wrestling moves. Adenosine triphosphate (ATP) provides the necessary energy for muscular activity. A limited amount is stored in the muscle but most ATP comes from energy substrates (primarily carbohydrates, protein and some fat). The body processes these substrates through aerobic and anaerobic metabolic cycles to produce ATP, the energy-producing molecule for the body.

The anaerobic system is divided into the ATP-phosphocreatine (PC) and the lactic acid system. A limited supply of ATP and PC is readily available in the muscles for use without any metabolic processing of energy substrates (carbohydrates, fats or proteins). Splitting of PC will also produce energy to put together ATP molecules from adenosine diphosphate (ADP), which needs another phosphate molecule to become ATP. Glycolysis (also called the lactic acid energy system) is a series of biochemical reactions which take place within the muscle cell and contributes energy when higher power output demands continue for longer periods of time (> 10–20 s). Compared to the aerobic energy system, which can use and process all three energy substrates (carbohydrates, fats and proteins), the lactic acid system can only use carbohydrates (glucose) to produce ATP energy. This is important, as wrestling calls upon the lactic acid system to contribute a significant proportion of the energy needed for a wrestling match. Therefore, lactic acid accumulates during a wrestling match. Carbohydrates are stored as glycogen in the muscles and liver and broken down into glucose. Furthermore, food restriction during the weight phases can dramatically compromise the amount of stored glycogen in the body.

When producing ATP energy from glycolysis (the lactic acid system), a byproduct of the energy-producing reaction, lactic acid or lactate, is formed. Higher concentrations are seen in the muscle where it is formed and increases in the blood are observed as soon as 5 s after maximal exercise activity, as the body attempts to expel it from the muscle or clear it. If intense muscular activity continues, concentrations in the muscle as well as in the blood will continue to increase well above resting levels. If metabolic demands are excessive, the power output of the body will drop. In other words, the body's musculature will not be able to keep up the intensity of exercise without sufficient energy availability. This is one reason why a wrestler may not be able to complete a move in the last minute of the match. This is where the energy-producing ability of the wrestler is not equal to the

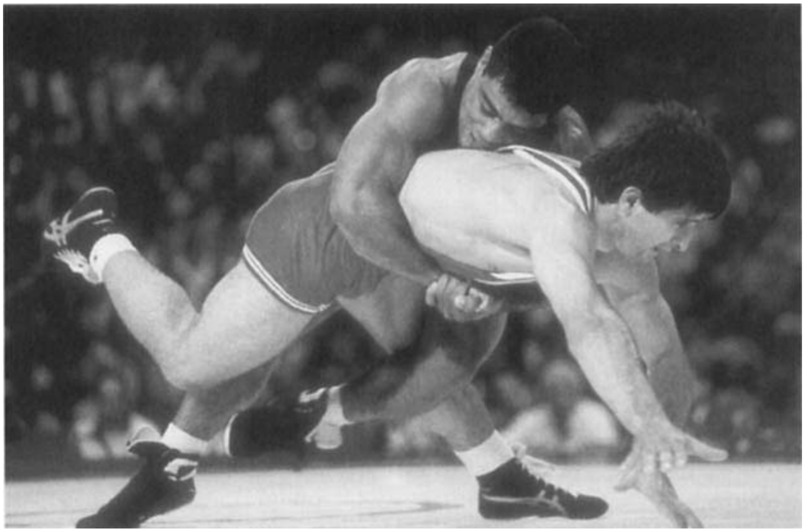


Fig. 5.7 The sport of wrestling is unique in that it requires powerful movement within the context of extreme fatigue as a result of metabolic acidosis. Photo © Allsport/J. Jacobsohn.

demands of the sport. Proper conditioning can help this (Fig. 5.7).

While the ability to produce energy via the lactic acid energy system allows the body to maintain activity of high power output, it cannot be maintained for extended periods of time. Even with the support of aerobic metabolism for total energy output, the lactic acid system can only be maintained at maximal or near maximal power outputs for approximately 2–5 min. At some point power capabilities decline. The build-up of lactic acid in part contributes to and is associated with metabolic acidosis (decreasing of the body's pH balance to more acidic conditions) and continued reduction in the pH of the muscles adversely affects the body in many different ways. Metabolic acidosis tends to reduce the power output of muscular activity by reducing enzyme effectiveness in the biochemical energy reactions. Reduced pH also affects muscular force by interfering with the essential contraction coupling events in the contractile unit of the muscle. This indicates that one of the goals of a strength and conditioning programme for wrestling is to improve the tolerance of metabolic conditions encountered during wrestling.

The aerobic energy system helps to support all of the energy demands for muscular activity during a wrestling match. It is also involved in the recovery process during exercise when muscle fibres are not being recruited and after exercise when the muscles are attempting to recover from the exercise stress.

Once muscular activity is initiated, all the metabolic energy systems simultaneously 'kick in' to meet the requirement for energy. The magnitude of the contribution or the percentage coming from each energy source is related to the power output required by the muscle and the duration of the effort. It is important to consider the energy demands of muscles during a match as being dynamic. There is a shifting of the magnitude of the energy source percentage within each muscle between the three energy components in response to the intensity of the match. Remember, there are two energy systems—aerobic and anaerobic—but three components, as the anaerobic system is broken into two energy components—ATP-PC and lactic acid. The energy demands vary for each specific muscle, depending upon the demands placed on that muscle at any point in the wrestling match.

Energy demand changes during wrestling

Now let us take an example and see if we can put into practice some of the concepts we have learned concerning the bioenergetics of wrestling. As the wrestler starts the first period of wrestling, the majority of energy originates from aerobic sources. Then he ties up with the opponent using a head lock and right away the anaerobic demands in the arms and upper back dramatically shifts to more anaerobic sources, while the legs and much of the rest of the body may still be getting most of their energy from aerobic sources. He then decides to make his first 'shoot' and attempts a single leg takedown. The energy demands in the legs now make a dramatic shift to primarily ATP-PC in order to produce the speed and power needed to penetrate the opponent's defences. The opponent counters and thus starts to provide resistance to the wrestler's upper body. Still, our wrestler gets in on the opponent's legs. If the wrestler gets in cleanly before the opponent counters, the upper body may use primarily the ATP-PC system. If there is an extended struggle to gain the leg and takedown, a dramatic increase in anaerobic energy demands occurs in the wrestler's upper body. The legs will also require a high anaerobic component if the wrestler attempts to get to his feet with the opponent's single leg or moves into an active ride position using the legs to force pressure on the opponent. Conversely, the anaerobic demands will reduce if he just goes to an upper body ride position and does not utilize his legs for any significant force production. A takedown and finish off of the move takes anywhere from 5 to 30 s and sometimes longer. When the opponent counters the takedown (or any other move), this initiates the resistance beyond body weight that must be moved and controlled. This sets up another volley of energy sequence demands for both wrestlers, and this type of interplay goes on the entire match, move by move.

Energy availability and performance

The demands for energy continue and what cannot be obtained from one component demands more from another. When the ATP-PC energy stores are significantly depleted, in about 5–10 s, the lactic acid source starts to become the primary component for energy as the wrestler continues to wrestle at high power production levels. The lactic acid in the muscle and the blood will continue to rise while activity requiring such high power output continues in the various muscles. Each of the various muscles used during the wrestling match will attempt to get rid of the lactic acid and will clear some of it into the blood, thus contributing to the lactic acid levels in the blood. Thus, in order to perform a constant series of moves associated with repetitive offensive and defensive changeovers, the energy must be available for the power to be maintained in takedowns, escapes, reversals and rides. If the optimal energy needed for the move is not available, the quality of the move will be dramatically affected. For example, this could be translated into a reduction of power from the bottom position to the feet in an escape or a lack of strength and power to finish off a takedown.

Thus, reasons for missing a move change over the course of a match as fatigue plays a greater part. Energy depletion may play a greater part in fatigue in the later minutes of a match when energy availability can be very low. Thus, conditioning to offset the fatigue becomes a vital contribution to successful wrestling performance. Here is where a wrestler in top condition can force the match and expend the opponent's energy reserves in order to build up a lead or wear down the opponent. If a wrestler is not conditioned to tolerate the metabolic acidosis of a match, the ability to utilize his or her body's muscular strength and power will be compromised.

While short breaks in the action happen, when a wrestler goes off the mat and injury time outs are allowed when a wrestler is hurt, this does not provide the necessary time for complete recovery. Thus, rest periods which address this type of stress are needed. Rest periods of 1 min or less performed in a circuit style are important in the pre-season part of a programme.

While ATP-PC stores are partially restored, the majority of lactic acid is not cleared when only short recovery periods are observed. This begins to pose a real demand on the wrestler's physical ability to tolerate the acidic conditions associated with high levels of blood lactate. The physiological need to buffer the factors which contribute to the shift in the acid–base balance in the body is vital, as reduced muscle and blood pH will adversely affect muscular actions (especially concentric movements) and therefore wrestling performance.

Lactic acid responses to wrestling

During the sustained muscular activity in a match, the muscles used to perform specific moves can produce large amounts of lactic acid. The upper body musculature appears to be most involved with sustained muscular contractions, but the legs and hips are highly involved with the power moves of the match involving takedowns, throws, stand ups and when leg rides are used. Thus, it is quite possible that the upper and lower body musculature function differently because of the nature of the moves used and the different metabolic demands of various offensive and defensive moves. Blood lactic acid will partially reflect the clearance of lactic acid from the muscle into the blood. Thus, muscle lactate is significantly higher but follows a similar pattern to blood lactate.

The blood lactic acid concentrations in response to a freestyle wrestling match can be over 19 mmol·l^{-1} as seen in Fig. 5.8. In addition, the blood pH is also significantly reduced following a single wrestling match. The lactic acid and hydrogen ions must be buffered for as long as possible in both the muscle and the blood if optimal function is to be maintained. The reduction in energy production is partly caused by reductions in the pH of the cellular environment which starts to shut down metabolic reactions. Blood lactate moves out of the muscle and circulates through the body and signals a variety of physiological responses in various parts of the body, including the brain, lungs and kidneys.

Understanding the metabolic demands of the match is essential to help develop a strength and conditioning programme which prepares the wrestler for the match. It is important to remember that many power movements must be produced when the body is in a state of metabolic acidosis.

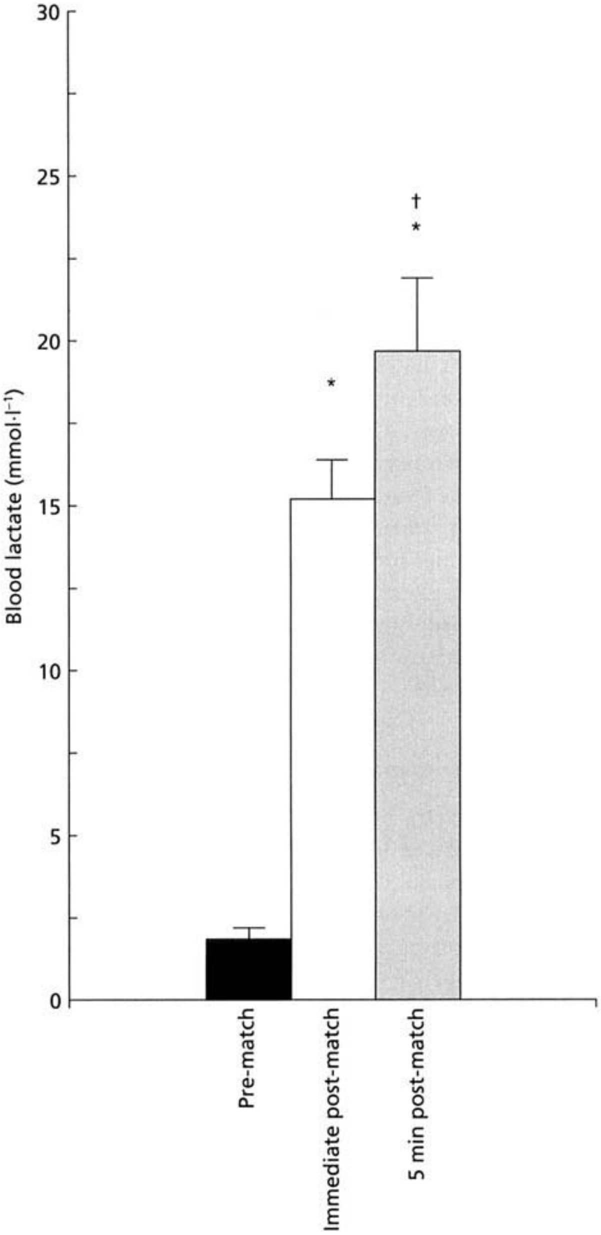


Fig. 5.8 Blood lactate levels in a wrestler. *$P < 0.05$ from pre-match; † from immediate post-match.

Training implications

Theoretical aerobic base

For many years wrestlers have tried to train the aerobic energy system with long slow distance typically referred to as 'road work'. This has been performed to help body weight management and develop a basic level of conditioning. How much aerobic fitness is needed for anaerobic sports is still unknown but it has been shown that interval sprint training can improve maximal aerobic capacity. Long distance running may compromise power production, especially in the absence of any heavy resistance training for those muscles. This appears to indicate that running alone could be detrimental to power development when no compensatory heavy resistance exercise training is performed with the muscles involved. Thus, care must be taken when using aerobic conditioning for weight loss purposes, as excessive amounts may well affect the power performance that is especially important for throws and quick countermovements.

As a weight class sport, increases and strength and power are more important to many wrestlers at the elite levels of competition than gains in muscle mass, which would potentially move them up in their weight class. Younger novice wrestlers should be advised to find a weight class for their optimal strength, power and size rather than intentionally reduce weight, because repeated dieting—weight loss followed by repletion back to a higher weight—has now been shown to have health implications for wrestlers. Programmes for wrestlers are focused on development of the strength, power and endurance necessary to perform the various moves on the mat against a competitor. In addition, isometric training is beneficial for certain moves in wrestling (e.g. hand locks, bear hugs) and specialized isometric supplementary training programmes can be added to the programme.

Wrestling programme

The resistance training programme is an important component of a conditioning programme for wrestling. Development of strength and power along with the ability to tolerate high levels of lactic acid production during a match are important to the wrestler's physical capabilities. In addition, programmes are typically not directed at excessive hypertrophy if the wrestler is solid for his or her fat-free body mass in a weight class. Other components of the wrestling programme include plyometrics, wrestling practice and drills, cardiovascular cross-training with limitations on running due to negative effects on strength and power development in the lower body musculature. Proper and stable weight loss and hydration practices also need to be undertaken in order to minimize fatigue and provide the necessary nutrients for building and maintenance of muscle mass and energetic function. An important part of the whole programme is rest and recovery from conditioning and practice along with suitable recovery nutrition. Lengths of each of the segments can be adjusted to address any year cycle of a wrestling season. Individualized programme progressions need to be used and exercises specific to the individual on injury rehabilitation and prevention exercises also need to be individualized. An example programme is given below.

Phase 1 (8 weeks)

(Monday, Wednesday, Friday)
This part of the programme will be directed at general conditioning in the weight room with the development of the ability to tolerate the high lactic acid production that occurs with wrestling to be developed in the weight room prior to practices on the mat. For wrestlers that wrestle year around this will also provide a change up in exercise selections.

Circuit rotation

Bench press
Seated row

Single knee extensions
Single leg curls

Low back exercise
Sit ups (variety)

Upright rows
Lateral pull owns

4-way neck exercise
Calf raisers

Bicep curls
Tricep extensions

Internal rotator cuff exercise
External rotator cuff exercise
Medicine ball push ups (alternate one hand on ball one hand on ground, right, both left)

12–15 RM zone loading
Progress from one circuit to three circuits
90 s progressing to 30 s rest between sets; super set pairs when down to 60 s rest

Phase 2 (8 weeks)

The development of strength is important to the further development of sports-specific power. This programme is dedicated to development of strength and power and then further enhancing the local muscular endurance needed. Changes in the circuit programme can be made and even placing a power exercise (e.g. hang cleans) at the end of the circuit can be implemented after several weeks.

Monday and Thursday	**Tuesday and Friday**
Power cleans	3 circuit training protocol
Push press	
Bench press	
Hang pulls from knees	
Squats	
Medicine ball chest toss (30% of 1 RM bench press)	
3–5-RM zone	Circuit: 8–10-RM zone
2–3-min rest between sets	60 s rest between sets (super set exercise pairs)

Phase 3 (8 weeks)

This phase of the resistance training programme is directed at continued development of the strength power base needed for a wrestler on an individualized level. Circuit training continues to taper off into 'on mat' practices where the metabolism during wrestling will address the metabolic maintenance of the acid–base buffering systems needed to offset acidosis and its negative effects on muscle function.

Monday and Thursday	**Tuesday**	**Friday**
Hang/power cleans	Deadlift	3 circuits
Push press	Bench press	
Squat jumps	Split squat	
Lunges	Front pull downs	
Cable twists	Knee ups/twists	
Stiff leg deadlifts	Neck exercises	
3–5 RM		Same as phase 2
2–4 sets	Hang cleans from knees at end of circuit	
2–3-min rest between sets		

Phase 4 (8 weeks)

This phase is a pure strength power phase with training days reduced for recovery purposes.

Monday	**Wednesday**	**Friday**
Bench press	Incline press	Bench press
Squat	Hang cleans	Squat
Seated rows	Side squats	Seated rows
Deadlift	Jump squats	Deadlift
Push press	Cable twists	Push press
Sit-up versions	Hanging knee ups	Sit-up versions
4 way neck	Medicine ball	4 way neck

Monday/Friday	**Wednesday**
2–4 RM zone strength exercises	Power exercises 2–4 repetitions
3 min rest between sets	2–3 min rest between sets
3–4 sets	3–4 sets
15–20 repetitions for non-primary exercises	

Phase 5 (8 weeks)

Pre-season

Non-linear periodized days with different types of workouts getting ready for formal 'on mat' practices and the season.

Monday

Squats
Medicine ball chest throws
Rotator cuff exercises*
Sit-up variations
Calf raises*
Neck exercises
Biceps/triceps super sets*
Bench press
Seated rows
Push press

2–3 sets
3–5-RM zone
2–3-min rest between sets
*8–10 repetitions for assistance exercises

Wednesday

Circuits
2 or 3 circuits with hang cleans from the knees at the end of the circuit

Friday

Jump squats
Hang cleans for the knees
Bench throws (medicine ball at about 30% of 1 RM)
Lunges
Medicine ball exercises emphasizing twisting and overhead movements

2–3 sets
Quality repetitions from 2 to 4 repetitions per set
2–3 min rest between sets
Loading specific to power development 30–60% of 1 RM

In-season

The goals of an in-season programme are the maintenance of the wrestler's strength base and then the continued development of power. Stabilizing the body mass that the wrestler will be wrestling at is vital to optimal physical status. Large body weight swings during the season to 'make weight' is negative in the current understanding of optimal and safe wrestling practices. Many variations can be used with a non-linear periodization programme to meet the multiple match demands during a week.

Volleyball

The sport of competitive volleyball is considered by many to be one of the most explosive and fast paced sports being contested today. Since its inception, it has evolved into an activity requiring tremendous strength, power, agility and speed, not to mention elaborate competitive strategies. As with many sports requiring these physical traits, off-court training and conditioning currently receive much greater attention and effort. Although on-court volleyball training is undoubtedly the most critical aspect of preparation for this sport, supplementary training can make the subtle difference between two comparably talented teams.

Off-court training and conditioning can take many forms, but this section will focus on integrating volleyball-specific resistance exercise into a year-long training cycle (macrocycle). Before such a resistance exercise programme can be properly designed, a needs analysis must be performed for the sport of volleyball. Such an analysis includes:

1 the anatomical and kinesiological characteristics;
2 the energy requirements; and
3 injury considerations for the sport.

Performance and physiological characteristics of volleyball

To understand the role that a resistance exercise programme can have for volleyball preparation, let us examine what goes on during a typical match. Volleyball is a very fast paced, high power sport. Elite male volleyball players have been reported to perform 250–300 high power activities during a five game match. Of these activities, over 50% are jumps of various types, 30% are short sprints and 12–16% are dives for balls. Jumps constitute the majority of power events (Fig. 5.9), and elite females have been reported to average 12 jumps per game, with values reaching as high as 35 jumps per game. Players at different positions naturally exhibit different jump frequencies

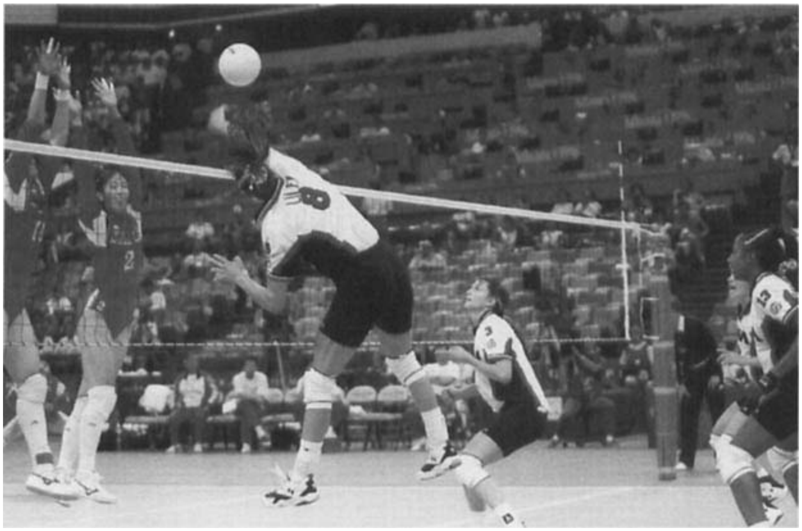


Fig. 5.9 Vertical jump power is a vital attribute needed by volleyball athletes which can be specifically developed with a properly designed strength training programme. Photo © IOC/Olympic Museum Collections.

and types. Although front line players all jump frequently during a game, middle blockers perform 50% of all jumps on the front line. A majority of the jumps performed by middle blockers and right outside hitters are defensive in nature (blocking jumps), while almost 60% of the jumps by left outside hitters are offensive in nature.

The ability to change direction is termed agility, and is a critical component of volleyball fitness. During a typical point of approximately 10 s, a player will change direction four times. High levels of agility require tremendou eccentric strength and a short amortization phase (transition from eccentric to concentric muscle action). The longer the rally, the greater the number of direction changes. Although over 50% of all points or rallies are 5–7 s in duration, almost 20% are 3 s long, while 15% are 9–10 s long, and 10% are > 15 s in duration. Although not typical, rallies of 20–45 s duration have been reported, and can affect the physiological nature of the game tremendously. Overall, approximately 50 rallies occur during a typical game, or 250 during a five game match.

It has been estimated that 90% of the energy required for successful volleyball play is derived from anaerobic energy sources, with only 10% coming from aerobic sources. A quick examination of a typical game clearly illustrates that volleyball is a 'burst' type of sport. The action occurs in short bursts of high power and speed activities. Although typical rest intervals between points may be very short (12–14 s), the duration of activity is even shorter. Aerobic capacity is most important for the recovery periods between rallies, but is not the primary energy source during the actual points. In support of these metabolic characteristics, volleyball players do not typically develop large levels of lactate accumulation. Likewise, although heart rates can be quite elevated at times, the frequent rest intervals result in considerably lower heart rates than during typical endurance type activities (e.g. long-distance running, swimming, cycling). Despite the strong emphasis on anaerobic metabolism, setters have exhibited the highest lactate accumulation and heart rates when compared to other positions on court. Considering that the setter is directly involved in almost every rally and covers much ground, such a metabolic and physiological response is to be expected.

In general, volleyball requires many high powered actions, such as jumps, sprints, dives and changes of direction. Front row players jump the most, and players in different positions must perform different types of jumps. While the duration of a point or rally can be quite short, these bursts of activity must be performed repeatedly throughout a match. Anaerobic energy sources are primarily required for volleyball, with most energy coming from the ATP-PC system, with somewhat less emphasis on anaerobic glycolysis (lactic acid system).

Anatomical and kinesiological characteristics

To determine which resistance exercises should be incorporated into a volleyball-specific programme, let us examine the typical movements that occur during a game. Table 5.11 lists common volleyball activities, the kinesiological descriptions of these anatomical movements, and exercises that can be used to train these motions. It should be kept in mind that there are literally tens of thousands of possible resistance exercises, so this table does not consist of the only possibilities. Despite the abundance of resistance exercises available, many experts feel that multijoint exercises should constitute the most important exercises (core exercises). As volleyball is typically played with both feet on the ground, it has been suggested that closed kinetic chain exercises are preferred to open kinetic chain exercises. In addition, as many volleyball actions require high levels of power, it is important to incorporate high power exercises into the resistance exercise programme.

Sport-specific injuries

Volleyball is typified by certain types of injuries which must be considered when designing a long-term resistance exercise programme. Accommodation must be made for pre-existing injuries, or preventive exercises must be incorporated in an attempt to minimize the risk of injuries. Commonly injured areas include the shoulder musculature, because of the repetitive nature of high velocity spiking motions, and the knees and ankles, because of the repetitive nature of jumping and landing on a hard court. As such, considerable effort must be spent on developing the muscles of the shoulder girdle as well as those surrounding the joints of the lower limbs.

Table 5.11 Resistance exercise selection for volleyball.

Volleyball activity	Anatomical actions	Resistance exercises
Set	Shoulder abduction to overhead position, elbow extension	Military press, push press, push jerk, incline press, bench press
Bump	Shoulder flexion, elbow stabilization	Dumb-bell bump raise, upright row, incline press, arm curl
Dig	Shoulder flexion, shoulder abduction, elbow stabilization	Lateral 45° raise, incline press, arm curl
Step into dig/block	Single leg strength (i.e. hip extension, knee extension, ankle extension, hip abduction, lateral stabilization)	Split squat, lunge, side squat
Spike	Shoulder extension, internal shoulder rotation (concentric), external shoulder rotation (eccentric)	Pull over, dumb-bell internal and external rotation, seated row, lateral pull down, incline press, bench press
Block	Shoulder abduction to overhead position, shoulder extension to resist force of ball	Military press, push press, push jerk, pull over, seated row, lateral pull down, upright row
Ready position and jumps	Hip extension, knee extension, ankle extension	Front and back squat, calf raise, hang clean and snatch, push jerk
Arm swing for jumps	Shoulder extension, shoulder flexion	Pull over, dumb-bell bump raise, upright row, seated row, lateral pull down, military press, push
Torso stability	Vertebral flexion and extension, lateral vertebral flexion and reduction	Abdominal exercises, front and back squat, hang clean and snatch, seated row

Design of the macrocycle

Figure 5.10 illustrates how the year-long resistance exercise programme (macrocycle) for volleyball is divided into four 12-week mesocycles. The duration of each mesocycle can be modified to fit the requirements of different training scenarios. The macrocycle in Fig. 5.10 fits a typical collegiate programme in the USA where there is a primary season (mesocycle 4, in-season) and a less important secondary season. This secondary season often occurs during mesocycle 2. Off-court training is not altered much during this mesocycle even though there is some competition during this phase. Each mesocycle is separated by at least a week of active recovery (no lifting) to provide appropriate recovery for each mesocycle. Although it is often tempting to skip these phases, the long-term improvement of the athlete is greatly facilitated when such recovery is routinely provided. Performance testing for the core exercises

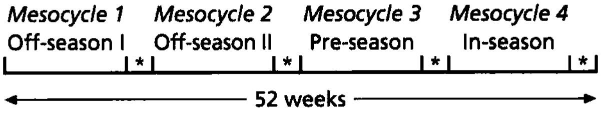


Fig. 5.10 Example of a volleyball resistance exercise macrocycle. *Active recovery (1 week). Mesocycles are based on 12-week periods, although they can be longer or shorter depending on characteristics of the competitive and off-season calendars.

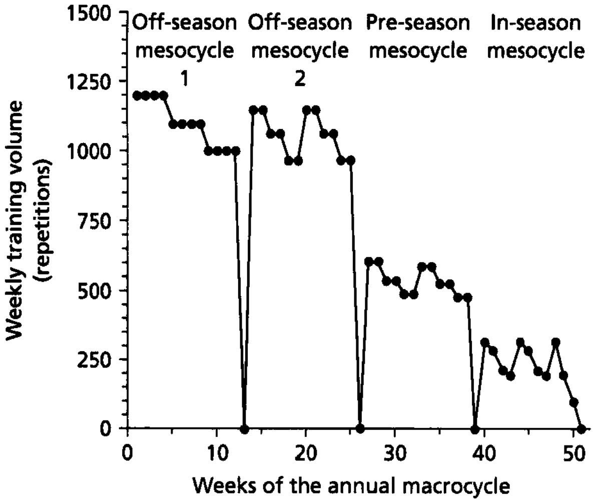


Fig. 5.11 Resistance exercise training volume (total repetitions) for the volleyball resistance exercise macrocycle.

can be performed prior to each active recovery phase to establish training loads for the following mesocycle.

Examination of Figs 5.11–5.13 will clarify the relationship of resistance exercise training volume and relative training intensity throughout the macrocycle. The greatest volume of resistance exercise training occurs in the off-season when more time can be devoted to off-court conditioning. As the primary season approaches, less training volume is prescribed in the weight room to accommodate the increased training demands of on-court volleyball practices. Eventually, the in-season training volume is very low, thus permitting maintenance of the gains developed during the off- and pre-season mesocycles. In an inversely related fashion, relative training intensity across each mesocycle moves in a gradually increasing fashion. The lone exception to this is the in-season mesocycle where the relative intensity is kept moderately high to help maintain the strength and power developed during the off- and pre-seasons. To minimize unnecessary training stress from in-season resistance exercise, each week of the in-season

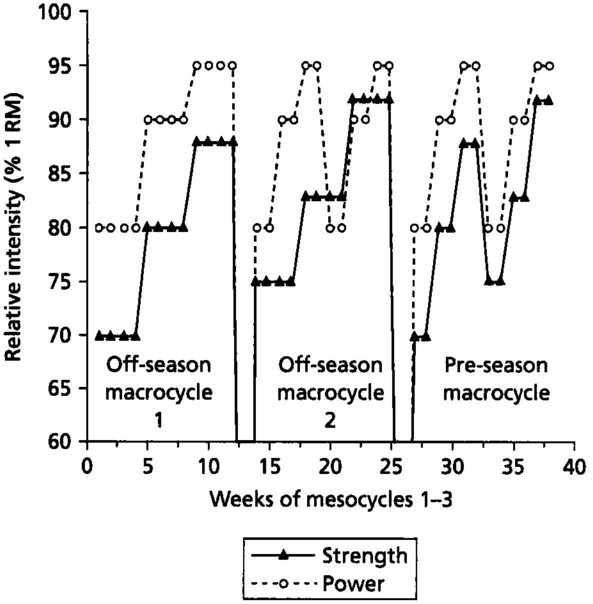


Fig. 5.12 Relative training intensity (percentage of 1 RM) for the first three mesocycles (off-season 1, off-season 2, pre-season) of the volleyball resistance exercise programme. Percentage of 1 RM has been estimated from the RM loads described in the text.

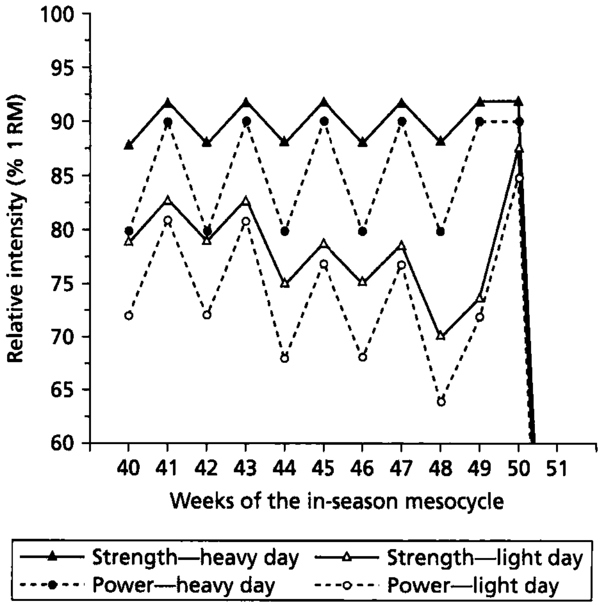


Fig. 5.13 Relative training intensity (percentage of 1 RM) for the in-season mesocycles of the volleyball resistance exercise programme. Percentage of 1 RM has been estimated from the RM loads described in the text.

programme utilizes a light day as indicated by the open symbols in Fig. 5.13. The following will describe some of the considerations for selecting the numerous choices for the five acute resistance exercise training variables: choice of exercise; order of exercise; training volume; training intensity or load; and interset rest.

Off-season 1 mesocycle (Table 5.12)

This mesocycle is the initial training phase of the entire competitive year. The volume is high, with weekly total repetition starting at 1200 repetitions week^{-1}. Every 4 weeks this value decreases during this 12-week period. Likewise, the relative intensity increases every 4 weeks. Figure 5.13 illustrates the different loading for the strength exercises (high force development) and the power exercises (high power development). Despite the different loading, the progression for intensity is similar for all exercises. The high power exercises utilize lower repetition ranges because of the possibility of technique breakdown with fatigue from high repetitions. The core exercises for this macrocycle are the military press, bench press, back squat and hang power clean exercises. These constitute the most important exercises for this training cycle. If time constraints limit the number of exercises that can be performed, these exercises should be prioritized. As illustrated in Table 5.12, the exercise groups can be performed in any order, but the exercises within any group must be performed in the order listed. This arrangement was developed because of equipment limitations at many facilities. Rather than have athletes lined up at various exercise stations as they wait to get on a piece of equipment, the order of performing the exercise groups could be determined by equipment availability and athlete preference. Ideally, high power exercises (e.g. cleans, snatches, push jerks) are performed early in the training session, followed by the core exercises, concluding with the supplementary exercises.

Table 5.12 Off-season 1 mesocycle resistance exercise programme for volleyball.

Group	Monday and Thursday	Tuesday and Friday
1	**Military press*** Dumb-bell bump raise	Lateral 45° raise Upright row
2	Lateral pull down **Seated row**	**Hang power clean†** (from midthigh)
3	**Bench press***	**Split squat** Side squat
4	Single leg extension Single leg curl	Dumb-bell internal rotation Dumb-bell external rotation
5	**Squat***	Dumb-bell pull over
6	Reverse arm curl Regular arm curl	Calf raise
7	Abdominals	Abdominals

Three sets of each exercise. 10-RM loads unless otherwise noted. Interset rest periods 1–2 min. Heavier loads use longer rest intervals. Core exercises listed in bold.

*Periodized exercises: weeks 1–4, light, 15 RM; weeks 5–8, medium, 10 RM; weeks 9–12, heavy, 5 RM.

†Periodized exercise: weeks 1–4, light, 5 RM; weeks 5–8, medium, 3 RM; weeks 9–12, heavy, 2 RM.

Exercise selection for mesocycle 1 includes split squats rather than lunges. Split squats are simply lunges without the forward stride, the lead foot is placed in proper position and the lunge motion is executed without moving the lead foot. This motion is easier to master than the lunge exercise which incorporates a step forward and back with the lead leg. Side squats are performed in a similar manner although the lead leg is placed 60° to the side. Such a motion is designed to mimic striding for a dig, although the torso remains upright during the side squat. Leg extensions and leg curls are performed unilaterally to emphasize the work performed by each individual leg. This further reinforces the concept of single leg strength. Dumb-bell bump raises are performed by grasping the dumb-bell handle in a vertical position with both hands. Keeping the elbows only slightly bent, the weight is raised in front of the body (shoulder flexion) to an overhead position. Lateral 45° raises are also performed with dumb-bells by raising the weight from the sides to the top of the head level. The elbows should remain slightly bent, and the arms are raised 45° to the side. The hands may be held in a thumbs up position if so desired. As so many abdominal exercises are available these have not been described in detail. In actuality, many coaches incorporate abdominal exercises into on-court practices.

Off-season 2 mesocycle (Table 5.13)

This off-season mesocycle adds variety to the previous mesocycle by changing training volume every 2 weeks. Relative training intensity is slightly increased and follows a pattern similar to mesocycle 1. Several exercises have been changed to accommodate a training–learning progression. Hang power snatches have replaced hang power cleans, thus increasing the velocity of movement. Lunges have replaced split squats because the basic lunging motion should have been mastered by now. It should be noted that this exercise is not what is commonly referred to as 'walking' lunges where the athlete moves across the training hall in an exaggerated walk. While this can be a good exercise, it is different from the classical lunge as prescribed here. Push presses have replaced military presses. This exercise introduces the athlete to use of the 'power zone' muscles (musculature from the knees to the low back) while performing overhead work. This is particularly important for volleyball where the entire body is used for many motions (e.g. setting, bumps), not just the upper body musculature. Finally, incline presses have replaced the standard bench press. This change begins to incorporate a more sports-specific motion into the training.

Table 5.13 Off-season 2 mesocycle resistance exercise programme for volleyball.

Group	Monday and Thursday	Tuesday and Friday
1	**Push press*** Dumb-bell bump raise	Lateral 45° raise Upright row
2	Lateral pull down **Seated row**	**Hang power snatch†** (from midthigh)
3	**Incline bench press***	**Lunge** Side squat
4	Single leg extension Single leg curl	Dumb-bell internal rotation Dumb-bell external rotation
5	**Squat***	Dumb-bell pull over
6	Reverse arm curl Regular arm curl	Calf raise
7	Abdominals	Abdominals

Three sets of each exercise. 10 RM loads unless otherwise noted. Interset rest periods 1–2 min. Heavier loads use longer rest intervals. Core exercises listed in bold.

*Periodized exercises: weeks 1–2, light, 12 RM; weeks 3–4, medium, 8 RM; weeks 5–6, heavy, 3 RM; weeks 7–8, light, 12 RM; weeks 9–10, medium, 8 RM; weeks 11–12, heavy, 3 RM.

†Periodized exercise: weeks 1–2, light, 5 RM; weeks 3–4, medium, 3 RM; weeks 5–6, heavy, 2 RM; weeks 7–8, light, 5 RM; weeks 9–10, medium, 3 RM; weeks 11–12, heavy, 2 RM.

Pre-season mesocycle (Table 5.14)

Training volume for this mesocycle decreases considerably, as can be seen in Fig. 5.11. This change is necessary because of the increasing amount of on-court training during this phase. To achieve the decreased volume, training frequency is decreased from four sessions per week to three. Additionally, fewer exercises are performed. Relative training intensity for the strength and power core exercises now changes every 2 weeks, and rotates between light, medium and heavy loads. The last 2 weeks of this mesocycle culminates in the heaviest loads to help 'peak' the athletes for the impending season. Front squats are now alternated with back squats in an attempt to continue to develop lower body musculature while decreasing the work performed by the lower back. Leg curls are now performed bilaterally to minimize training time, while leg extensions have been dropped because of the large amount of knee extension work performed during the squat and lunge exercises. Both hang cleans and hang snatches are now performed, but from knee height rather than midthigh height. Although this difference in starting height may appear to be slight, it can be critical for the athlete learning to use their hip musculature properly during these powerful movements. Push jerks have also been added to develop the use of the 'power zone' muscles in overhead work.

In-season mesocycle (Table 5.15)

Careful prescription of the resistance exercise protocol is most critical during this mesocycle. Although some coaches do not prescribe any resistance exercise

Table 5.14 Pre-season mesocycle resistance exercise programme for volleyball.

Group	Monday	Wednesday	Friday
1	**Push jerk†** Dumb-bell bump raise	**Push press†**	**Push jerk†** Lateral 45° raise
2	**Hang power clean†** (from knee height) Lateral pull down	**Hang power snatch†** (from knee height) Seated row	**Hang power clean†** (from knee height)
3	**Front squat*** Bilateral leg curl	**Lunge** Side squat	**Back squat*** Bilateral leg curl
4	Dumb-bell pull over	Dumb-bell internal rotation Dumb-bell external rotation	Dumb-bell pull over Dumb-bell internal rotation Dumb-bell external rotation
5	Abdominals	Abdominals	Abdominals

Three sets of each exercise. 10-RM loads unless otherwise noted. Interset rest periods 1–2 min. Heavier loads use longer rest intervals. Core exercises listed in bold.

*Periodized exercises: weeks 1–2, light, 15 RM; weeks 3–4, medium, 10 RM; weeks 5–6, heavy, 5 RM; weeks 7–8, light, 12 RM; weeks 9–10, medium, 8 RM; weeks 11–12, heavy, 3 RM.

†Periodized exercise: weeks 1–2, light, 5 RM; weeks 3–4, medium, 3 RM; weeks 5–6, heavy, 2 RM; weeks 7–8, light, 5 RM; weeks 9–10, medium, 3 RM; weeks 11–12, heavy, 2 RM.

during the competitive period, it is much too long a time to go without any resistance exercise training. However, every attempt must be made to accommodate the extreme stresses inherent with a competitive season. Resistance exercise volume is further decreased during this mesocycle by training only twice per week and decreasing the number of exercises. In order to maintain the strength and power developed during the previous three mesocycles, the relative training intensity is kept fairly high. All too often coaches opt for performing high numbers of repetitions with light weights during this phase. Unfortunately, this type of training does not optimize maintenance of the strength and power critical for elite volleyball performance. It is also important to continue to provide variety to the resistance exercise training because it is easy for an athlete to become stagnant in the weight room when the stimulus does not change. To combat this, light and heavy days have been incorporated (Fig. 5.13). This is easily accomplished by deducting a set percentage from the typical training load. The light and heavy days are alternated throughout this mesocycle for further variety. Each week utilizes a different relative intensity (3 or 5 RM) resulting in an undulating pattern as seen in Fig. 5.13. The sets, repetitions per set, and the relative intensity all interact to provide considerable variety during this phase. Exercise selection also provides variety as several exercises are alternated on successive weeks. As the competitive season is the time for optimizing power capabilities, cleans, snatches and push jerks are all routinely incorporated during this period. The duration of the resistance exercise training sessions during the in-season period should be very short, 30–45 min in length. The light training days get progressively lighter as the season progresses to accommodate fatigue. However, week 11 utilizes relatively heavy loads while volume is very low. In this manner, the athletes may be in peak strength and power condition immediately prior to the most important contests of the season.

Table 5.15 In-season resistance exercise programme for volleyball.

Session 1	Session 2
Hang clean*	**Hang snatch***
Push jerk*	**Push press***
Bench press	Incline press
Dumb-bell bump raise	Dumb-bell internal and external rotation
Front or back squat* (alternate each week)	Lunge or side squat (alternate each week)
Bilateral leg curl	Bilateral leg curl
Abdominals	Abdominals

Two to three sets of each exercise at 10-RM loads unless otherwise noted. Interset rest periods of 1–2 min. Heavier loads use longer rest intervals.
*Core exercises listed in bold use the following protocols:

Week	Sets	Repetitions	Load: Session 1	Load: Session 2
1	3	5	5 RM	90% 5 RM
2	3	3	90% 3 RM	3 RM
3	2	5	90% 5 RM	5 RM
4	2	3	3 RM	90% 5 RM
5	3	5	5 RM	85% 5 RM
6	3	3	85% 3 RM	3 RM
7	2	5	85% 5 RM	5 RM
8	2	3	3 RM	85% 3 RM
9	3	5	5 RM	80% 5 RM
10	2	3	80% 3 RM	3 RM
11	1	3	85–95% 3 RM	85–95% 3 RM
12	–	–	–	–

Note: Training days scheduled around the competition schedule. Do not lift the day before or the day of a competition if possible.

Conclusions

The potential variety of a resistance exercise programme is both a blessing and a curse. One can become very confused while attempting to manipulate all the acute training variables and their possible combinations. On the other hand, it is also possible to design a resistance exercise programme customized for the unique demands of almost any situation. The programme depicted for volleyball is meant to be an example based on numerous previously used programmes. As the demands of each situation differ, so can the resistance exercise programme be modified to provide the optimal stimulus.

Gymnastics

The sport of gymnastics is one of few in which winning is qualitative rather than quantitative. In this programme example a conventional college season construct for anchoring the terms and the season of periodization is used. Collegiate and international level gymnasts may sacrifice strength and conditioning training to devote more time to training specific skills and routines. However, skill training alone will not yield the desired results and supplementary training can address aspects of physical development which cannot be effected by gymnastics training alone. An effective strength training programme can be integrated with regular sport practices, ultimately improving physical development and performance (e.g. vertical jump) which contribute to enhanced performance and success. It is vital that the strength and conditioning coach strives to educate gymnasts on how strength and power training can be an integral part of preparatory training and successful performance.

Needs analysis

Sports-specific training refers to a certain training style that complements a specific sport. With that in mind, recall the concept of not only sports-specific training, but take it even one step further to *skill-specific* training within gymnastics. Here the specific skill is broken down and analysed for specific performance variables and movements and then categorized for training (Table 5.16).

Gymnastics requires individual skills to be performed sequentially to comprise a routine. In order to develop an effective training programme for gymnasts, each event must be individually analysed to assess the predominant skills utilized, and therefore to determine the modes of training and appropriate exercises.

Exercises and skills

As an example, let us examine the women's vault, which is a very short event in which the objective is to propel the body over the horse, covering as much height and distance as possible. Completion time for

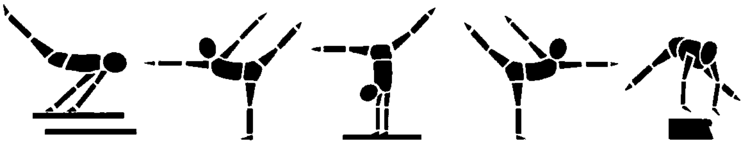


Table 5.16 Analysis of gymnastic events.

		Performance variables					
			Rate of force development				
Event	Skill	Power	High	Low	High force development	Local muscular endurance	Isometric strength
Vault	Any skill	×	×		×		×
Bars	Cast handstand	×	×		×	×	×
	Giant swing	×	×		×	×	×
	Release move	×	×		×	×	×
Beam	Jump/leap	×	×		×		×
	Press handstand		×			×	×
	Dance moves			×			
	Handspring	×	×		×		
	Saltos	×	×				
Floor	Tumbling/saltos	×	×		×	×	×
	Jump/leap	×	×		×		
	Dance moves			×			
	Press handstand			×	×	×	×

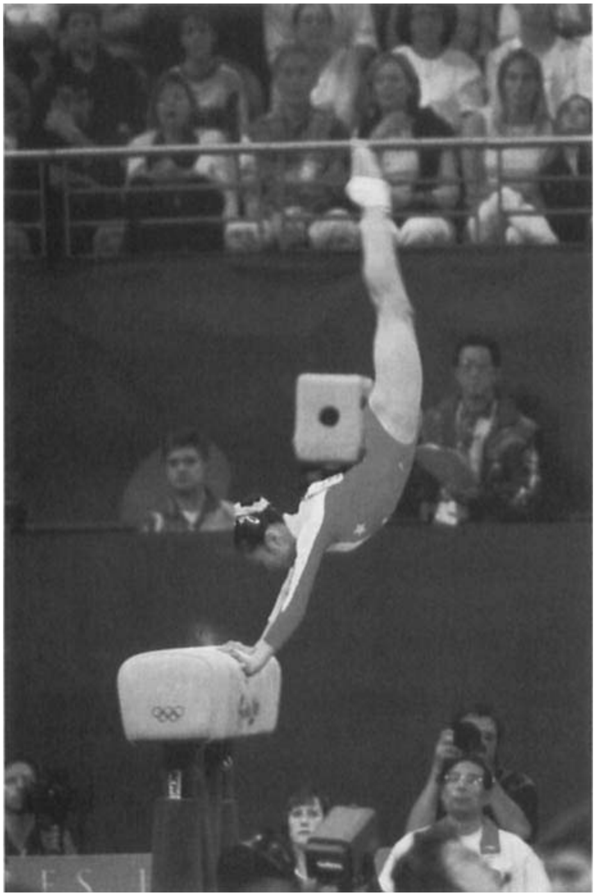


Fig. 5.14 Power development is vital to many events in gymnastics. Photo © Allsport/E. Shaw.

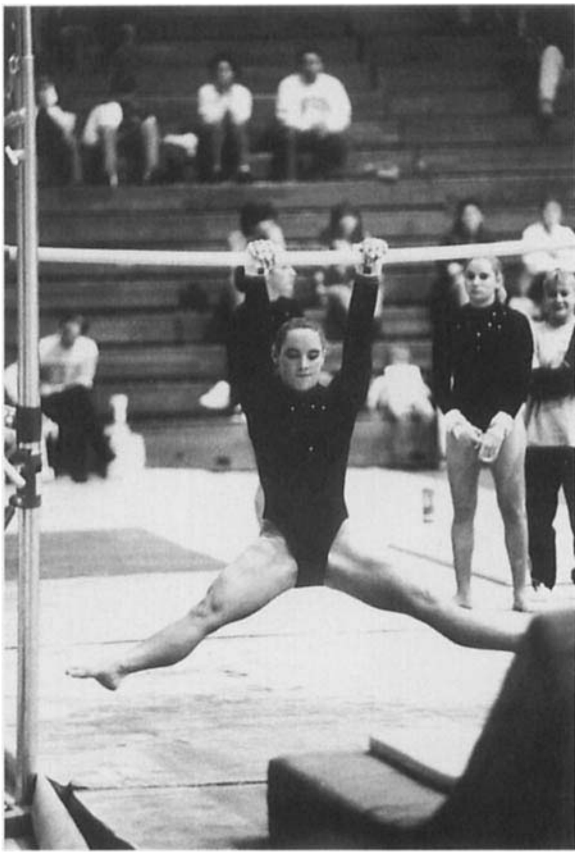


Fig. 5.15 Success in gymnastics depends on power development by arms, legs and trunk. Photo courtesy of Ball State University Photo Services.

an entire vault event with run-up is approximately 20 s. In order to perform a successful vault, the gymnast requires a significant amount of power both to sprint and to propel the body from the horse (Fig. 5.14). Landing requires a great amount of eccentric strength to offset the great amount of force produced. One study showed that vertical ground reaction forces can be as great as 11.4 times body weight upon landing from a vault, indicating that eccentric strength must be present in order to absorb the shock and maintain form and balance.

The skills required for the performance of the uneven parallel bars are unique (Fig. 5.15). The most important component of this routine is the swing, which requires isometric (static) strength for proper alignment of body positions and gripping of the bar. The event lasts approximately 1.5 min and therefore demands local muscular endurance. Eccentric strength for landing is also an important factor for the uneven bars.

The balance beam and floor exercise routines consist of dance, acrobatics and tumbling moves (Figs 5.16 and 5.17). These routines are subject to a time limit and last approximately 1.5 min. These two exercises require a significant amount of eccentric strength for the impact of landings. Such moves as handstands and planches require isometric strength for holding these positions.

Although power, rate of force development and strength comprise much of a gymnast's repertoire, local muscular endurance is also required for an award winning performance. Local muscular endurance is required for three of the four events: bars, balance beam and floor exercises. For example, near the end of a routine, the body is already fatigued and must be able to perform one or two skills that require explosive power. Gymnasts not conditioned for this type of endurance will encounter extreme difficulty upon completing the skills of the routine.

Systemic (aerobic) endurance is not directly involved with each event but is considered a performance aid in practice. A gymnast becomes aerobically conditioned as he or she completes multiple skills and several routines progressively of each event during a practice session. Therefore, during competition, when there is time to complete only one routine of each event, the gymnast can perform it with ease. Supplementary aerobic training with running must be carefully prescribed (< 40 km·week^{-1}) as it can compromise muscular power.

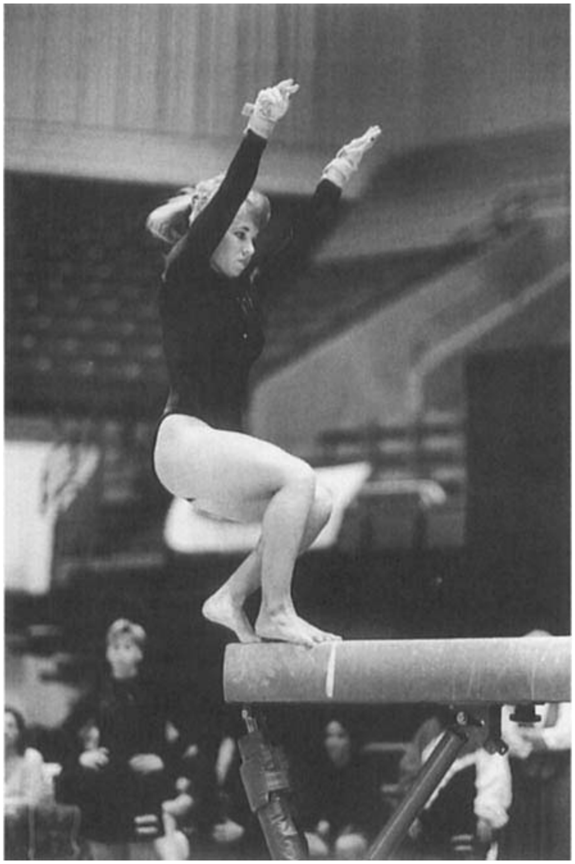


Fig. 5.16 Eccentric strength contributes to the ability to balance. Photo courtesy of Ball State University Photo Services.

Physiology

The intense nature of gymnastics requires predominantly fast twitch muscle fibres energized by the anaerobic system. Type II muscle fibres are used when the activity is of high intensity and short duration, such as the exercises in women's gymnastics. These fibres possess high contraction speed

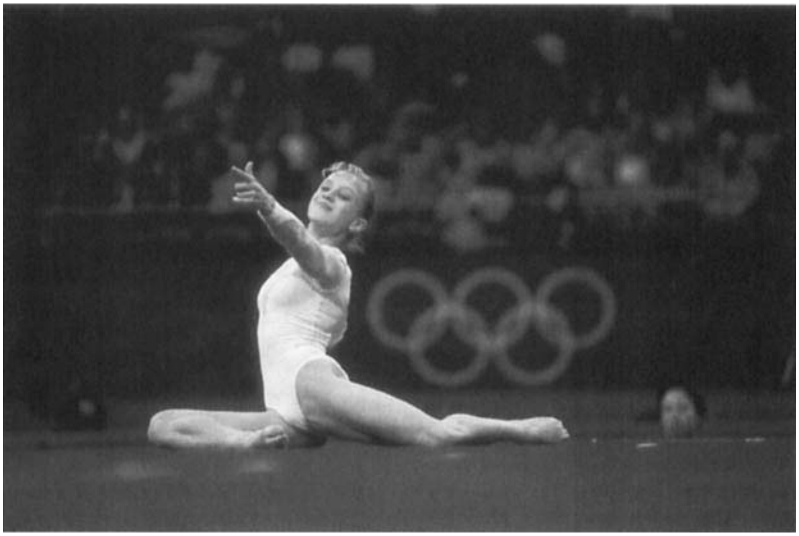


Fig. 5.17 Gymnastics performance relies on a combination of skill, grace and power. Photo © Allsport/S. Botterill.

enabling the muscle to create a large amount of force per cross sectional area in a very short time period. The characteristics of Type II fibres demand energy from the anaerobic energy systems, which includes the ATP-PC and glycolysis energy sources.

Injury profile

High risk factors and the extreme physical demands of gymnastics make for a large incidence of injury within the sport. As an athlete becomes more skilled and competitive, the possibility of both acute and chronic injury increases. More hours spent in training will increase exposure time to possible injury, resulting in more acute injuries. Over time, as the athlete becomes more skilled, the load during training sessions will increase, providing a greater opportunity for chronic injuries.

For example, prior research has delineated the incidence of injury in terms of location and in terms of severity. Snook (1979) investigated where injuries occurred in competitive women gymnasts. Of the 70 athletes studied, 47 sustained injuries in the lower extremities where the highest incidence of injury was reported; the upper extremity received the fewest injuries. Another study investigating the severity of gymnastics injuries was conducted on 26 collegiate women gymnasts. The women gymnasts detailed here sustained 106 total injuries over a 4-year span. Sixty of these injuries (57%) were of acute onset and related to a gymnastics event. The remaining 46 (43%) were of gradual and chronic overuse (Wadley & Albright 1993).

The battle to keep gymnasts free from injury is never ending. Gymnastics coaches, strength and conditioning specialists and medical support personnel must be aware that the nature of the sport calls for athletes to train and compete while injured. Sands *et al.* (1993) reported that women gymnasts train with an injury approximately 71% of their training time and a new injury can be expected in 9 out of every 100 training sessions. Because of this extremely high rate of injury, the strength and conditioning professional must develop consistent and reliable training regimens both to prevent and rehabilitate injuries incurred by athletes.

Programme design

The following is a breakdown of a gymnast's year separated into four parts: post-season; off-season; pre-season; and in-season phases.

Post-season

This period is considered a relaxing, active recovery phase of approximately 1 month in duration. It is vital for the gymnast to participate in activities they truly enjoy psychologically outside of gymnastics, which may include cycling, swimming, aerobics or tennis. Emphasis should be placed upon injury rehabilitation and general maintenance of physical fitness at this time. A post-season is vital for preventing burn-out, as training for gymnastics comprises a very intensive year even though it is broken down into segments.

Off-season

The off-season begins approximately 1 month after the last competition has taken place and lasts throughout the summer months. In this phase, the emphasis should not be based on gymnastics but on general conditioning and building strength. The first week of the programme should familiarize the gymnast with the loads, repetitions and form that will be used for each exercise during the training sessions. A progression from general conditioning towards increased force development is achieved during this time period with three phases of training during the off-season with each phase lasting 4 weeks. Endurance training is allowed but long slow runs should be kept to a minimum while speed is accentuated. Cross training is encouraged for variety in training the different energy systems. Emphasis is placed upon strengthening the shoulders and wrists in order to prevent overuse symptoms from repeated force extension during the competition season (Aronen 1985).

The following represents a progressive summer programme suitable for collegiate women gymnasts.

Phase 1

Monday	Wednesday	Friday
Back squat	Leg press	Lunge
Close grip bench press	Incline bench press	Bench press
Leg curl	Stiff leg deadlift	Leg curl
Bent over row	Front pull down	Seated row
Calf raise	Leg extension	Calf raise
Shoulder lateral raise	Back extension	Shoulder press
Internal rotation	Wrist curl	Incline sit ups
External rotation	Crunch	Internal rotation
Sit ups		External rotation

All exercises of phase 1 are performed for 1–2 sets of 10–12 repetitions per set.
Rest periods range from 1 to 2 min between sets and exercises.

Phase 2

Monday	Wednesday	Friday
Back squat*	Leg press*	Lunge or split squat*
Bench press*	Incline bench press*	Bench press*
Leg curl *	Leg curl*	Leg curl*
Lateral pull down *	Front shoulder raise	Seated row*
Calf raise	Leg extension	Calf raise
Shoulder press	Back extension	Shoulder press
Incline sit ups	Wrist curl	Internal rotation
Internal rotation	Sit ups	External rotation
External rotation		Crunch

*Denotes exercises performed for 3 sets of 8–10 repetitions per set. All other exercises are performed for 1–2 sets of 10–12 repetitions per set.
Rest periods range from 1 to 2 min between sets and exercises.

Phase 3

Monday	Wednesday	Friday
Back squat*	Leg press*	Lunge or split squat*
Bench press*	Incline bench press*	Close grip bench press*
Leg curl*	Leg curl*	Leg curl*
Lateral pull down*	Front shoulder raise	Seated row*
Calf raise	Leg extension	Calf raise
Shoulder press*	Back extension	Shoulder press*
Incline sit ups	Wrist curl	Internal rotation
Internal rotation	Sit ups	External rotation
External rotation		Crunch

*Denotes exercises performed for 3 sets of 6 RM per set.
All other exercises are performed for 2 sets of 8–10 repetitions.
Rest periods range from 2 to 3 min between sets and exercises.

Pre-season

The pre-season starts in September and goes through to December. In this phase, training the rate of force development starts in combination with lifting for strength. Rate of force development is a determining factor of programme design for competitive sports if the time available for rate of force development is less than 0.3 s (Zatsiorsky 1995); gymnastics is such a sport. For example, performance of the front aerial somersault requires maximal force development within 0.27–0.59 s (Kinolik *et al.* 1980). The application of ballistic movements, such as jump squats and medicine ball throws, will accommodate this component of gymnastics training. Rotational power is also emphasized during this period because of the need for rotational skills in gymnastics.

Interval systemic training should be included in the programme at this time to help facilitate the increasing volume of routine work during the gymnastics sessions. An interval training session consisting of 20 min should be broken down into 30-s and 1-min intervals. For example, when cycling, alternate between a 30 s to 1 min sprint followed by a 2–3 min rest period or complete recovery. The rest period is of lower intensity but is not a complete cessation of movement.

A progression from low intensity preparation exercises to high intensity ballistic exercises is incorporated into the pre-season. This period of the training year will prepare the athlete for competitions beginning in January and is broken down into three phases lasting approximately 5 weeks each.

Phase 1

Monday, Wednesday, Friday

Squat (3 × 10)
Stiff leg deadlift (3 × 10)
Bench press (3 × 10)
Seated row (3 × 10)
Upright row (2 × 10)
Reverse curl (2 × 10)
Sit ups (2 × 15)
Wrist curl (3 × 10)
Wrist extension (3 × 10)
Internal rotation (2 × 10)
External rotation (2 × 10)
Pronate/supinate rotation (2 × 10)

1–2-min rest periods between sets and exercises.

Phase 2

Monday (force development)

Squat (3 × 10)
Bench press (3 × 10)
Stiff leg deadlift (3 × 10)
Upright row (2 × 10)
Reverse curl (3 × 10)
Wrist curl (3 × 10)
Wrist extension (3 × 10)
Internal rotation (2 × 10)
External rotation (2 × 10)
Pronate/supinate rotation (2 × 10)
Sit ups (2 × 15)

Wednesday (power development)

Medicine balls
Squat, jump and toss (2 × 8)
Underhand throw (1 × 8)
Lateral throw (1 × 8)
Chest pass (1 × 8)
Giant circle (1 × 8)
Hip rotation (1 × 8)
Lateral bend (1 × 8)
Good morning (1 × 8)
Resistance
Side lunge (2 × 10)
Wrist flexion (2 × 10)
Wrist extension (2 × 10)
Hip adduction/abduction (3 × 10)
Isometric gripping (2 × 10)

Friday (rate of force development)

Squat jump (3 × 8)
Military press (2 × 10)
Lateral pull down (2 × 10)
Bench press (2 × 10)
Seated row (2 × 10)
Leg curl (2 × 10)
Heel raise (2 × 10)

2-min rest periods between sets and exercises.

Phase 3

Monday

Hang clean (3 × 5)
Squat (4 × 5)
Stiff leg deadlift (3 × 8)
Incline bench press (4 × 5)
Front pull down (3 × 8)
Shoulder press (3 × 8)
Towel chin up (2 × 8)
Toe raise (2 × 8)

Wednesday

Medicine balls
Giant circle (1 × 10)
Hip rotation (1 × 10)
Good morning (1 × 10)
Squat, jump and toss (3 × 6)
Underhand throw (2 × 6)
Overhead throw (3 × 6)
Lateral throw (3 × 6)
Chest pass (2 × 6)
Partner twist pass (2 × 20)
Sit ups (2 × 15)

Friday

Squat jump (4 × 5)
Squat jump (no counter movement) (2 × 5)
Bench press (4 × 5)
Vertical row (3 × 8)
Leg extension (2 × 8)
Leg curl (2 × 8)
Military press (3 × 8)
Pull up (2 × 8)
Toe raise (2 × 8)

Rest period ranges from 2 to 3 min between sets and exercises.

In-season

This final phase of the year lasts the entire competition season and follows approximately 2 weeks of active recovery over the holiday break. Training during this period peaks the gymnast for rate of force development and overall power heading into the major competitions of the competitive season, primarily the conference championships and national championships. Interval training for endurance is eliminated and all energies are focused upon recuperation for competition. Particular attention must be paid to the athlete's psychological status and adaptation to training; avoid overtraining at all costs. Injuries must be accounted for and the programme needs to be adjusted with creativity to progress those athletes unable to perform the core exercises because of injury. The in-season period lasts approximately 12 weeks.

Tuesdays (heavy)	**Thursdays (light)**
Jump squat (3 × 6)	*Landing squat* (3 × 6)
Incline press (2 × 6)	Shoulder press (3 × 6)
Towel chin up (3 × 8)	Leg extension (2 × 8)
Back squat (3 × 6)	Leg curl (2 × 8)
Stiff leg deadlift (3 × 6)	Bench press (3 × 6)
Medicine balls	Long row (2 × 8)
Block off throw (2 × 6)	Internal rotation (2 × 8)
Overhead toss (2 × 6)	External rotation (2 × 8)
Partner twist pass (2 × 6)	Pronate/supinate twist (2 × 8)

Rest periods range from 3 to 5 min between sets and exercises.

Athletes are coached to perform light days with loads that are approximately 75% of the prescribed RM. For example, a landing squat calling for 6 RM would utilize a load that could be handled for 8 RM.

Conclusions

Taking into consideration all the training aspects of gymnastics—strength, rate of force development, isometric strength, local muscular endurance and systemic endurance—a coach and athlete must take apart each routine and look at every skill specifically and how it relates to each aspect of training. Then apply it to the three training phases throughout the year: off-season, pre-season and in-season phases. Making the strength and conditioning training of gymnastics skill-specific will help to optimize performance.

Tennis

Tennis is a very interesting sport to study as it is played all year around (Fig. 5.18). In such a situation, non-linear training programmes have been used to deal with week-to-week changes in the match demands. However, supplementary strength training has been classically periodized so the training programme must be developed around a player's schedule. For example, during weeks where no match play takes place, frequency of training can be increased. Effective periodization schedules are very demanding which is why it has been recommended that a non-linear programme may be easier to implement. Despite the development of a larger tennis ball for some competitions—to slow the game down—inclusion of resistance training is vital for the players to deal with the 'power game' now in full swing.

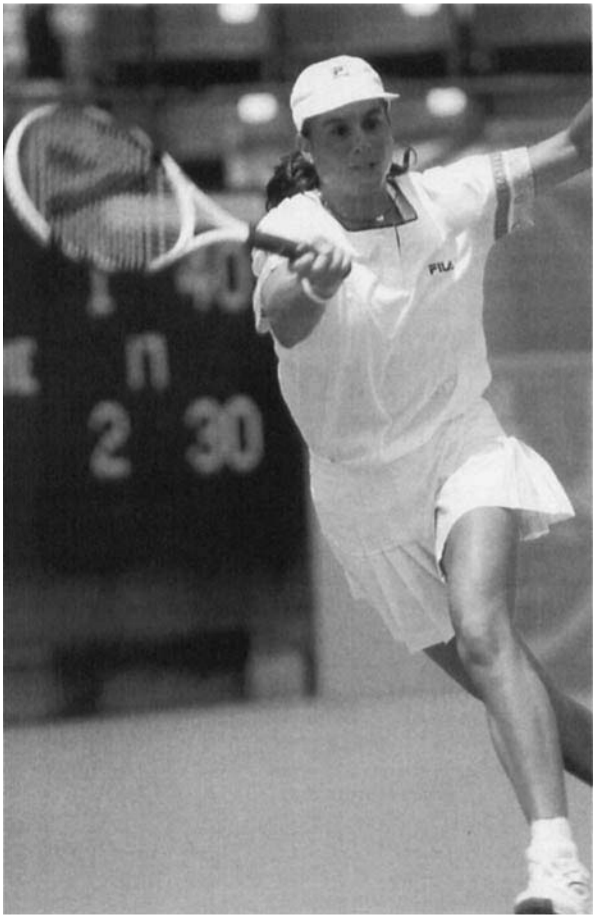


Fig. 5.18 Tennis players must adapt to demanding competition and practice schedules. Carefully designed periodized strength training programmes must be performed throughout the year in order to be effective. Photo © Allsport/D. Leah.

Tennis players can benefit from a properly prescribed and supervised resistance training programme. It helps the player:

1 improve performance;
2 prevent injury; and
3 prolong a competitive career.

It is important for the tennis player to realize that the strength and conditioning programme he or she participates in has been specifically designed for tennis. Resistance training contributes to improved performance by increasing the overall strength and power of the body. Furthermore, in a competitive world where the physical demands of the sport are increasing each year, physical training is a vital investment toward successful long-term health and performance. As players get younger, exercise training to meet the physical demands of the sport needs to be started at a younger age in order to prevent injury and possibly extend a competitive career. Resistance training provides an exercise stimulus which contributes to the development of muscles, bones, ligaments and tendons. This combats possible overuse in the arms, shoulders, back, knees and ankles from tens of thousands of tennis shots and hours on the court. Thus, a little consistent time and effort in this area of sport conditioning can result in long-lasting benefits.

Tennis is a very demanding sport because of the long hours spent on the court. Over the years, the sport has changed because of advances in equipment and skill of the competitors. Today, tennis is a fast paced game with the need for strength, speed and power to perform at top competitive levels. The physical demands on the body are great. Today, more than ever, a real need exists to balance the physical stresses of the game with a 'training stimulus' which enhances the ability of the body to meet and overcome the physical demands. This is especially true for younger tennis players who, only too often, attempt to simply 'play themselves into shape'. A resistance exercise programme can be a major part of this training stimulus but how does one go about developing one?

Needs analysis

First examine the sport of tennis and really understand what the demands are. What does a tennis player 'need' in his or her resistance training programme? What 'needs' can be addressed by a resistance training programme? The needs analysis consists of several topic areas which need to be examined prior to starting a resistance training programme. They include:

1 basic bioenergetics;
2 basic biomechanical aspects;
3 common sites of injuries; and
4 possible individual considerations.

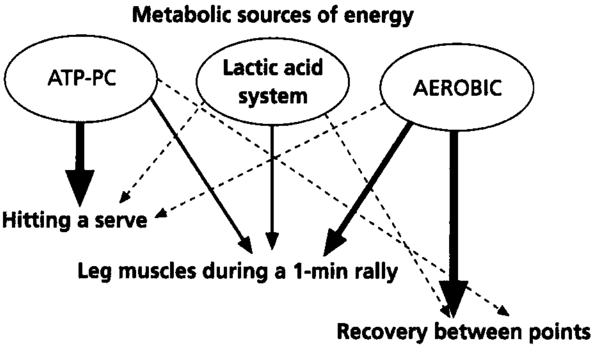


Fig. 5.19 Example of how the different energy systems contribute to different aspects of tennis. Each metabolic source of energy contributes to the demands of the activity. It is the magnitude of that contribution that will differ depending upon the time and power output demands placed upon the muscle. The magnitude of the contribution is estimated by the size of the arrow.

Once an examination of these areas is complete, the answers to questions concerning the 'acute programme variables' (choice of exercise, order of exercise, load, number of sets and length of rest periods), which actually make up the basis of the programme design can be addressed.

The optimal programme is then written. It may still need to be modified because of administrative considerations and limitations (e.g. space, time and number of athletes to train) but, within administrative constraints, the best resistance training programme possible for the tennis player needs to be implemented. Such a programme is characterized by sport- and individual-specific components to improve performance and prevent injuries.

Bioenergetics of tennis (Fig. 5.19)

Tennis performance involves various skills (e.g. hitting the ball, sprinting to make a shot) which are highly anaerobic and of a high power nature. The ATP required by muscles comes from a combination of anaerobic and aerobic sources. Anaerobic metabolism has two basic components. The ATP-PC (high energy phosphates) system provides the immediate fuel from local stores in the muscles, and the lactic acid system refers to the production of ATP from carbohydrate breakdown at such a high rate that the aerobic pathways get backlogged and lactate accumulates as a byproduct.

In recent investigations of tennis match play, blood lactate levels did not increase much above rest. This indicates that the energy coming from the lactic acid system is not as great as some people believe or that the lactate is being cleared from the body before it can accumulate in the muscle and blood. The fact that large accumulations of lactate do not occur in a tennis match means that the energy demand is not maintained at a high rate for long enough periods of time to surpass the ability of the other energy systems. Therefore, the energy is gained from aerobic metabolism, especially during the recovery intervals, and predominantly from the anaerobic sources of stored phosphates (ATP-PC system) during the performance of the actual tennis skills. However, it is quite possible that, during an unusually intense point rally lasting a minute or so, significant acute demands would be placed upon the lactic acid system. Because such a pace is not maintained through an entire match and recovery is allowed, lactic acid is removed from the body quite effectively. The overall moderately paced continuously contributing aerobic processes, which use oxygen to produce ATP, are adequate in replenishing some of the ATP-PC in certain muscles between shots and to a high degree in the whole body between rallies. Resistance training can improve the metabolic function of the muscle to store and use more ATP and PC and, thus, enhance the performance ability to produce repeated high intensity spurts of exercise involved in each rally.

COMPARISON OF RESISTANCE TRAINING AND METABOLIC TRAINING

Resistance exercise programmes which utilize longer rest periods of 2–3 min also depend more on stored ATP-PC during a workout. Thus, resistance training programmes with longer rest intervals may closely 'mimic' the metabolism used in much tennis match play. The young athlete must train to meet the extremes of the game and shorter rest period workouts used over the course of the training cycle would help address such needs.

For variation and workout time economy, shorter rest periods (1 min or less) are popular. This helps 'bracket' the metabolic profile of a tennis match. When rest periods are 1 min, the lactic acid system makes a greater contribution of energy for the resistance training workout. This is demonstrated by the accumulation of lactic acid in the muscles and blood. Recent studies have shown that blood lactic acid levels increase 8–10 times above rest when 1-min rest periods are used, compared to only 2–4 times above rest when 3-min rest periods are used. The lactic acid values of a tennis match are similar to the 3-min rest period workout (2–4 times above rest).

Shorter rest periods (1 min or less between sets and exercises) in a resistance training workout will lead not only to increased muscle and blood lactic acid levels, but also to greater fatigue and, potentially, lower resistances (loads) being used for each set. Symptoms such as nausea, dizziness and greater fatigue can also be observed. This means that gradual progression to shorter rest periods is vital for the young tennis player to gain physical and psychological toleration of this type of resistance exercise stress. Short rest workouts should not be used when the tennis player is trying to learn a new exercise or in the early phases of a resistance training programme, as the metabolic stress is counterproductive both to learning and toleration of the workout. After a base programme has been utilized for starting a young player on a resistance training programme (see Chapter 3), over the course of several workouts the rest time between sets can be cut down by 10 s each workout. Ultimately, the rest between exercises is also reduced in a short rest workout protocol (e.g. circuit weight training).

Here is where the 'good judgement' of the athlete and coach is needed. The coach needs to watch and see how each athlete responds. If excessive symptoms are presented, increase the rest allowed and maintain that level until the athlete does not present any symptoms during or after the workout.

The advantages of a short rest resistance training workout protocol are as follows.

1 The body develops the physiological and psychological ability to tolerate intense exercise.
2 The high intensity endurance of the muscles trained is increased.
3 It provides variation in training and at different phases of the season it allows for optimal 'time economy' to address the resistance training needs of the tennis player.

However, it should be understood that the metabolic profile of such short rest programmes does not pattern itself after the typical metabolic demands in a tennis match. The major reasons for considering such workout protocols are the economy of time and the metabolic preparation for the extreme demands in a tennis match.

Not all exercises should be performed under low rest conditions. Performing a large number of total body multijoint exercises, special exercises for certain muscle groups (e.g. rotator cuff exercises) and when training for optimal strength and power, all necessitate longer rest periods of at least 90 s. As a resistance training method in tennis, short rest programmes really only add a 'metabolic dimension' to the tennis player's physical and psychological ability to meet the extreme metabolic demands of tennis match play. Such programmes need to be used for the proper reasons and at proper times in the training cycle.

Biomechanical aspects

The study of human movement is called biomechanics. The coach and athlete are not expected to perform sophisticated biomechanical analyses, but a basic understanding of the biomechanics of tennis in terms of the muscles used and a profile of the activity is important when attempting to implement a tennis-specific resistance training programme. In order to understand the choice of exercises in a resistance training programme, the muscles used in tennis have to be understood. In this section, a very basic overview of the muscles used in the sport of tennis is discussed. This leads to an understanding of the 'exercise specificity' involved with choosing resistance exercises that use the same muscles as in tennis and thus constitute a sports-specific programme.

MOVEMENTS AND MUSCLES MOST IMPORTANT FOR TENNIS PERFORMANCE

Except for the serve, all tennis strokes are partially under the control of the tennis player's opponent. The velocity, stroke type and amount of spin of the oncoming ball, as well as its direction in relation to the tennis player's position on the court, will affect his or her stroke. Although the tennis player's goal is to get his or her body in such a position in relation to the ball that an 'optimal' swing can be utilized, such a position cannot always be attained. A great variety of stroke actions therefore result from the interactions of the ball's three-dimensional position, spin, velocity and direction, anticipated at impact with the racquet, and the desired outcome in terms of velocity, direction and spin.

Imparting force on the ball is dependent on muscular strength and power (speed–strength). A good tennis stroke is difficult to execute if it does not begin with a good base. As only a few shots are hit from the ideal body position, resistance training is needed to tolerate the forces on the muscles and joints that arise from such game conditions. Even when the tennis player is reaching, a strong lower body will go a long way in providing stability and sufficient body alignment for an effective stroke. The support provided by the legs, especially in single leg support (reaching for a wide ball, bending for a low ball), demands more basic strength of a slower nature.

In most sports, upper body actions—as in tennis strokes—begin with applying force against the ground using the muscles of the lower body. This is not always readily apparent in tennis as a result of the eye-catching arm swings involved in the various types of strokes. The force is initiated by a push off action and is sequentially increased by a series of contributing muscles (see forehand drive example) as it moves up the body, through a system of links to reach the racquet. The different muscles serve to accelerate the involved body segments culminating in a high racquet velocity. Additionally, because the body segments in this path generally decrease in size, their velocity consequently increases further. This means that muscles such as the shoulder, which are situated at a later point in the chain, need to produce strength under higher velocity conditions.

Isometric muscle actions (no movement of the muscle while force is being exerted) are also used in tennis. Examples of such isometric actions include the gripping of a tennis racket with the muscles of the hand, using postural muscles of the upper body, hips in holding the upper body in a crouched position with knees bent in a ready position, and holding a racket with the shoulder and arm muscles in three-dimensional space in place for a net volley. Dynamic resistance training will improve isometric strength if the exercises used contain the same angle as those used isometrically in tennis.

If weakness or lack of endurance exist at a certain angle of a joint range of motion, or in a specific configuration of the body where an isometric position is vital to the skill, isometric resistance training of that specific joint angle can be performed. Various isometric muscle actions in tennis are part of the overall biomechanical profile of the sport.

In the context of this chapter to determine what basic muscles are involved in general tennis strokes, only aspects necessitating dynamic high muscular forces and movements are considered.

Forehand drive

Push-off—calves, quadriceps (front thighs), gluteals (buttocks).

Trunk rotation—obliques (part of abdominals) and spinal erectors (low back).

Forehand swing—anterior deltoid (front shoulder), pectorals (chest), shoulder internal rotators and elbow flexors (e.g. biceps—front of upper arm).

One-handed backhand drive

Push-off—calves, quadriceps (front thighs) and gluteals (buttocks).

Trunk rotation—obliques (part of abdominals) and spinal erectors (low back).

Backhand swing—upper latissimus (side of back), rhomboids and middle trapezius (upper back), posterior deltoid (rear shoulder), middle deltoid (outer shoulder), shoulder external rotators and triceps.

Two-handed backhand drive

Push-off—calves, quadriceps (front thighs) and gluteals (buttocks).

Trunk rotation—obliques (part of abdominals) and spinal erectors (low back).

Backhand swing—non-dominant side: pectorals (chest), anterior deltoid (front shoulder), shoulder internal rotators; dominant side: upper latissimus (side of back), rhomboids and middle trapezius (upper back), posterior deltoid (rear shoulder), middle deltoid (outer shoulder), shoulder external rotators and triceps.

Serve, overhead volley

The serve and the 'smash' are at the top of the list in terms of being able to benefit from strength increases. They are both highly ballistic, especially the serve with its totally preprogrammed nature, with little or no tracking component. This allows the greatest amount of force to be applied.

Trunk rotation—obliques (part of abdominals) and spinal erectors (low back).

Knee and hip extension prior to impact (when a knee flexion position is used in the toss/backscratch phase)—quadriceps, gluteals.

Arm swing—pectorals, shoulder internal rotators, latissimus (sides of back) and triceps (rear of upper arm).

Arm extension—triceps.

Wrist flexion—wrist flexors (inside of forearm).

Recovery

Upon completion of a stroke, the tennis player needs to recover to the ready position in anticipation of the next shot. This involves either shuffling or sprinting. For a tennis player to accelerate his or her body across the court, muscles (primarily lower body) are required to produce force but with a high velocity. Players also depend on slower strength when changing directions and when initially pushing off. The sooner the tennis player can get to the ball, the more time is available to prepare a solid and balanced base from which to deliver the next stroke.

Ready position

The ready position places a demand primarily on the calves, quadriceps (front thighs), gluteals (buttocks), spinal erectors (low back) and anterior deltoids (front shoulders). Improved strength in these muscles decreases the effort required of the tennis player to achieve and maintain a good ready position, or to do it repetitively during a rally or match.

Grip

A firm grip is required in tennis. It enhances racquet velocity during the swing, improves control by reducing free twisting of the racquet in the hand during ball–racquet impact, and optimizes the amount of force that is transferred from the tennis player's body to the ball. A good position and stroke action can be negated by a grip that succumbs to the torque of the racquet on impact. The primary muscles involved are grouped under:

- wrist flexors (inside of forearm); and
- wrist extensors (outside of forearm).

Common sites of injuries

In addition to the biomechanical analysis of tennis, understanding the common sites of injury can help in the choice of exercise used in a resistance training programme. This is especially important as the individual consideration of an injury is unique to each athlete. With the help of sports medicine profiles, tennis-specific injuries can be reviewed as certain areas have a higher probability of sports-related injury. Understanding the injury profile in tennis allows an exercise programme to be developed which attempts to strengthen the muscles, joints and bones so that injuries can be prevented or reduced in severity.

In tennis, as with any sport, the demands of playing the sport sometimes exceed the ability of the player's body to overcome the opposing forces. Some injuries are acute and traumatic, others are developed over a chronic period of time from continual use, yet others are 'waiting to happen' because of deficiencies in strength and muscular balance. It is especially the younger tennis player who can benefit from proper training in an attempt to eliminate or reduce the injuries observed in older tennis players resulting from chronic overuse and inappropriate strength and muscle balances.

AGONIST–ANTAGONIST IMBALANCES AND SITES OF TENNIS INJURIES

Strength is important for injury prevention, especially to the tennis player's shoulder, elbow and lower back. Contralateral imbalance of large muscle groups that are directly or indirectly anchored by the spine can have a negative effect on the vertebral column and the spinal erector muscles that stabilize this structure. More commonly, joint integrity may be affected by unfavourable antagonist–agonist (unilateral) muscle strength imbalances which are often sport-induced. It is sometimes suggested that the athlete will have a greater risk of injury about a particular joint if the respective antagonist : agonist strength ratio does not meet a certain value.

When looking at the research that has been performed with tennis players, certain key areas emerge as possible risk sites. We can hypothesize about how tennis may be contributing to or creating such imbalances.

HANDGRIP

The average person who has not performed resistance training has a stronger handgrip on the dominant side. When this difference is emphasized in the tennis player, it provides obvious evidence of tennis's highly unilateral facet of gripping the tennis racquet. Additionally, the wrist flexor muscle group used in the handgrip may be adapting to its role in attempting wrist stability upon impact with the ball on forehand strokes, as well as its role in wrist flexion during the serve contact phase. However, there is no readily apparent reason for this contralateral imbalance to have any functional implications.

ELBOW

Affecting the elbow, actions such as the forehand drive can lead to a stronger biceps muscle (agonist) on the tennis player's dominant side (right biceps for a right-handed player) that is stronger than the triceps muscle (antagonist) of the same side. If a two-handed backhand drive is utilized, it may lead to the same imbalance (antagonist–agonist) in the non-dominant arm. Clinicians sometimes cite a triceps : biceps ratio of 1 : 1 meaning that when these two muscles are approximately equal in strength, problems are found less often than when one of these is stronger than the other. The forehand drive may also contribute to a stronger dominant side biceps compared to the non-dominant side. The same type of imbalance (contralateral) can exist in the triceps. Even though the dominant side triceps may be weaker than the biceps on the same side, backhand volleys and the serve may lead to a triceps muscle that is stronger than that of the non-dominant side.

SHOULDER

At the shoulder there has been some indication that the internal rotator muscles may undergo tennis-stimulated strength increases. This may lead to an external : internal rotator ratio that is somewhat lower than the suggested ratio of 2 : 3. Furthermore, stronger internal rotator muscles on the tennis player's dominant side, compared to the same muscle group on the non-dominant side, may be a reflection of overload created by the forehand drive and the serving action. The stimulation received by the dominant side pectorals from the serve and the various forehand strokes may result in a contralateral imbalance although recent research has not shown this to be the case in university women tennis players. Their non-dominant pectorals are probably exposed to a significant amount of stimulation by the use of the two-handed backhand.

LOWER BODY AND TRUNK

There should not be any abnormal strength ratios in the tennis player's lower body. For example, there is no reason why a tennis player should not be able to reach a right hamstrings : right quadriceps (antagonist : agonist) strength ratio of approximately 2 : 3 as is often suggested by clinicians. This means that the hamstrings group (rear of the thigh) is expected to have two-thirds the strength of the same side quadriceps group for safe performance by the knee. The tennis player can expect the sport to place an approximately equal demand on leg muscles compared to their opposite side (contralateral) counterpart (e.g. left : right quadriceps). Only a very few aspects of tennis may emphasize a certain lower body muscle or muscle group over its same side antagonist or its contralateral partner. On the other hand, if the mostly unilateral nature of the involvement of the upper body in tennis causes abnormally shifted demands on the muscles of the trunk, including the spinal erectors and the abdominal internal and external obliques, the tennis player may be compromising the long-term health of the vertebral column.

Resistance training can improve strength ratios by strengthening a relatively weak antagonist to more appropriately counter a sport-induced strong agonist. The antagonist provides deceleration forces (eccentric muscle action) to the limb or body segment by being activated as it is elongated. Therefore, the stronger it is, the better it can act as a shock absorber to the accelerative forces developed by the agonist. With contralateral imbalances, training weights selected should enable the trainee to contribute equally with both sides. This means that until the two partners are approximately equal in strength, the stronger muscle group is not receiving a training stimulus; otherwise, the imbalance would be maintained. As discussed in Chapter 1, resistance training can also play a part in augmenting joint stability via increased strength and thickness of connective tissue, such as tendons, ligaments and cartilage.

Individual considerations

Programmes can be designed for the sport but that does not mean that every tennis player who performs the programme will have all of his or her needs met. Individual considerations and needs have to be addressed. We have already seen that the 'progression' of a resistance training programme is highly individualistic and requires attention during each workout. Other aspects of what an individual brings to a programme need to be considered in the overall design and implementation of a resistance training programme.

One can visualize it as overlaying the sport resistance training programme on top of the individual's needs and seeing what still is not covered. This is especially important with children where a lot of individual needs exist, ranging from basic strength to specialized injury prevention. Thus, each programme should provide a time when the tennis player can address his or her own specific needs beyond the basic programme progression of the tennis-specific workout.

AESTHETICS/HYPERTROPHY

From an aesthetic perspective, a tennis player may, over time, develop unwanted size imbalances as a result of tennis-induced muscle hypertrophy (increase in muscle size). Such growth would occur in the muscle groups that have been previously discussed as being highly utilized in tennis. As an example, following a few years of tennis playing, the dominant side forearm (wrist flexors and extensors) may become larger than those of the non-dominant side as, to a certain extent, muscle size and strength go hand-in-hand. With resistance training, the weaker (and smaller) side would be the one to respond with increasing strength and hypertrophy until the two sides were equal. This requires that the larger side is not exposed to greater weight than the smaller side. Here is where the weaker side may need to be individually programmed with more sets to speed up the progression to muscular balances for size and strength. With the younger tennis player, starting a proper resistance training in the early phases of a career can help prevent such sport-induced differences in size and strength of muscles.

INJURY OR SICKNESS

The injury profile of an athlete provides vital information when designing a resistance training programme to address individual needs. Injury or prior injury may necessitate that a completely different programme approach be taken with a particular body part, joint or muscle. For example, if a prior injury leaves a particular muscle group weaker or smaller in size, the number of sets may have to be dramatically increased to stimulate size and strength increases. Therefore, rather than just doing 3 sets of 10–12 RM for the right quadricep, 5–7 sets of 10–12 RM may have to be performed for a period of time in the training programme to help gain a size balance. This is because the volume of exercise performed in resistance training is related to the increases in the size of the muscle. While the lower volume programme will make gains over time, the rate of the improvement will be much slower. Thus, changing the programme to stimulate more equitable size and strength profiles of limbs often requires changing the programme to meet the specific individual need.

Tennis-specific resistance training programme

Through research with tennis players, the following programme was shown to be effective in increasing strength and power, and improving tennis-specific components of the sport. Its use after a base programme is straightforward, as many of the exercises are already understood. Rotation of the loads also provides variation within the programme over the training cycle.

Exercises and order

Squat*
Bench press*
Single leg curl
Bent over lateral raise
Lunge/one leg split squat
Shoulder (military) press*
Single leg extension
Front lateral pull down*
Back hyperextension
Internal/external shoulder rotator cuff exercises
Hip tucks
Wrist extension/wrist curl
Bent-leg sit ups
Arm curl

Load

When modified for the young tennis player, **only for the exercises marked with an asterisk above**, the load is rotated for each workout between moderate (8–10 RM), heavy (3–5 RM) and light (15–20 RM). One can also add a power training session into the rotation. This is called ‘rotational variation’ in the load. It is best to put the heavy training session in the middle of the week, with moderate and light loads being used at beginning and ends of the week. The rest of the exercises can use loads of 10–12 RM.

Rest period length

When heavy loads are being used, rest periods should be about 2–3 min. For light and moderate loads rest periods of about 1 min can be used. It is important that the younger tennis player feels rested and ready for the next set of repetitions. Guidelines can only be given to assist in workout economy and development of the toleration for exercise stress; the player’s physical response is the determining guideline if the workout stress is too great or not.

Number of sets

When heavy load or power exercises are being used, 3–4 sets can be used for the exercises as repetitions are very low, with 3 sets for light and moderate loads. One can rotate between 1, 2 and 3 sets for each of the other exercises. This will provide for time, economy and variation in the volume of the workout.

Pre-season programme

A circuit format can be used for pre-season training with 10-RM loads and 30–60-s rest periods between exercises. This will allow for a change up in the metabolic profile of the workout. It may be desirable to only have the larger muscle group exercises included in a circuit and save certain isolation exercises related to injury prevention (e.g. internal/external shoulder rotator cuff exercises, wrist exercises) to be performed at another time.

In-season programme

This programme can be used in-season as only the frequency will change from 3 to 1–2 times per week, depending on the competition schedule. The rotational nature of the workout allows for variation to be maintained throughout the training cycle. Heel raise exercises may be added to the in-season workout routine. Other exercises can be added or exercises replaced as long as the muscle or muscle groups trained by the programme are not neglected when changes are made.

Tennis-specific intermediate–advanced programme

Much of the athlete's progression depends upon age, maturation, toleration and training responses to the exercise programme. It is impossible to give examples of all of the different progressive changes that may occur over the course of a training programme, but different programmes can be demonstrated with increasing levels of sophistication in the acute programme variables. Remember, it is the acute programme variables which alter the configuration of the workout and allow progression of the programme to take place. Different programme progressions are a matter of reorganizing the acute programme variables over time (chronic programming).

The following is another programme manipulation which provides the coach with an example of how a change may be made to reflect more advanced training abilities of the tennis player. Again, progression is an individual process. In some cases, if programmes are not changed, the athlete becomes stale and loses interest in the resistance training programme and thus any benefits are reduced over time. Changing programmes to meet new needs or to maintain the gains that have been made is an important part of programme progression. Equipment availability would dictate and require certain exercises to be replaced and performed with available equipment.

Off-season programme

Off-season is understood to mean a time when no competitive matches are being played.

Frequency: 3 sessions per week. In this protocol the tennis player should alternate workouts A and B.
Resistance and repetitions:
Core exercises. Use rotational variation (10–12 RM; 7–9 RM; 4–6 RM) power exercises, 4–5 sets of 1–3 repetitions with 30% of 1 RM, for example with pulls and medicine ball exercises. A plyometric programme should also be added. Younger tennis players (< 16 years) usually do not go below 6 RM so their rotation would be ramped up but power exercises with the above loadings could be performed (e.g. 10–12 and 8–10 RM). (Noted in workouts by being underlined.)
Other exercises. 10–12 RM.
Sets:
Core exercises. 2–3 per exercise.
Other exercises. 2 per exercise.
Rest period lengths: use 2 min for loads < 10 RM and 1–1.5 min for all other resistances.

WORKOUT A
1. Bench press
2. Bent over row
3. Squat
4. Military press
5. Rear pull down
6. Leg curl
7. Shoulder internal rotation
8. Lying triceps extension
9. Standing heel raise
10. Wrist curl
11. Lumbar extension
12. Machine abdominal curl or bent-leg sit ups

WORKOUT B
1. Bench press
2. Bent over row
3. Squat
4. Military press
5. Rear pull down
6. Leg curl
7. Shoulder external rotation
8. Standing biceps curl
9. Seated heel raise
10. Reverse wrist curl
11. Lumbar extension (if not squatting)
12. Machine abdominal curl or bent-leg sit ups

Pre-season/off-season variation

Used for 4–6 weeks pre-season or as a change up in the off-season.
Frequency: 2–3 sessions per week. Alternate workouts A and B.
Resistance and repetitions:
Core exercises: Use rotational variation (10–12 RM; 4–6 RM: for a younger tennis player 10–12 RM; 7–9 RM). (Noted in workouts by being underlined.)
Other exercises: 7–9 RM (for a younger tennis player: 8–10 RM).
Sets: 2 per exercise.
Rest intervals: use 2 min for loads < 10 RM and 1–1.5 min for all other resistances.

WORKOUT A
1 Lying across body raise
2 Alternate: one-arm fly and low incline one-arm fly
3 Alternate: side lunge and hydraulic machine hip abduction/adduction (highest velocity setting)
4 Lying side lateral raise
5 Two-arm unilateral machine pull over
6 Alternating leg curl
7 Decline shoulder internal rotation
8 Low incline dumb-bell cheating French press
9 Standing heel raise
10 Incline shoulder external rotation
11 Two-arm dumb-bell wrist curl
12 Machine trunk rotation

WORKOUT B
1 Bench press
2 Bent over row
3 Squat and lunge
4 Military press
5 Rear pull down
6 Hydraulic machine one-leg leg curl (highest velocity setting)
7 Lying shoulder internal rotation
8 Low incline dumb-bell cheating French press
9 Seated heel raise
10 Lying shoulder external rotation
11 Two-arm dumb-bell reverse wrist curl
12 Alternate: machine abdominal curl and hydraulic machine abdominal crunch (highest velocity setting)
Alternate: do only one exercise in one workout and do the next exercise in the next workout.

In-season (time-saving version of pre-season programme)

Frequency: 2 sessions per week. Alternate workouts A and B. Minimum 24 h off before matches.
Resistance and repetitions:
Core exercises: Use rotational variation (10–12 RM; 3–5 RM: for a younger tennis player 10–12 RM; 6–8 RM) or periodize.
Other exercises: 6–8 RM (younger tennis player: 7–9 RM).
Sets: 2 per exercise.
Rest intervals: use 2 min for loads < 10 RM and 1–1.5 min for all other resistances.

WORKOUT A
1 Slightly bent over pulley side lateral raise
2 Alternate: fly and low incline fly
3 Alternate: side lunge and hydraulic machine hip abduction/adduction (highest velocity setting)
4 Lying shoulder internal rotation
5 Low incline dumb-bell cheating French press
6 Leg curl
7 Alternate: incline shoulder external rotation and decline shoulder internal rotation
8 Two-arm dumb-bell wrist curl
9 Standing heel raise
10 Machine trunk rotation

WORKOUT B
1 Bench press
2 Alternate: rear pull down and bent over row
3 Alternate: squat and split squat
4 Military press
5 Lying shoulder external rotation
6 Hydraulic machine two-leg leg curl (highest velocity setting)
7 Low incline dumb-bell cheating French press
8 Two-arm dumb-bell reverse wrist curl
9 Seated heel raise
10 Alternate: machine abdominal curl and hydraulic machine abdominal crunch (highest velocity setting)
Alternate: do only one exercise in one workout and do the next exercise in the next workout.

Alternative in-season tennis protocol

Two programmes are utilized in this programme and alternate each training session. Half of the team starts with workout A and the other half of the team performs workout B. Example: group 1, A; group 2, B; next session group 1, B; group 2, A.

WORKOUT A
Squat*
Internal/external rotators†
Bench press*
Bent-leg sit ups (crunch)†
Wrist flexor†
Shoulder press*
Row (elbows out)*
D leg curl†

WORKOUT B
Alternate between: split squat and dumb-bell side lunge†
Internal/external rotators†
Low incline fly†
Bent-leg sit ups (twist)†
Wrist extensor†
Bent over side lateral raise†
Calf raise†
S leg curl†

*Alternate between 5–7-RM and 10–12-RM loads.
†Alternate between 7–9-RM and 12–15-RM loads.
Frequency: twice per week.
Load: first 2 weeks 10–12 RM.
Rest: training groups of 2 or 3; try to *keep the approximate order listed.* Rest while partner(s) is performing the exercise. Training partners should help with spotting, encouragement and exercise performance.
Sets: start with 2 sets and over the season get up to 3 sets, especially when 5–7-RM load used.

Power training component

It is certainly becoming appreciated in tennis that physical capabilities and size are important factors. Over the years, a lack of understanding about the outcomes of resistance training in tennis players has been fuelled by the misconception that resistance training always produces the large muscles seen in body builders and weight lifters, which is certainly not the type of body that tennis players want. However, tennis-specific training programmes have now been developed and utilized by many top players and they are becoming accepted as part of a total conditioning programme. Yet there is still a great deal of potential to utilize tennis-specific resistance training programmes to improve the physical development of players and allow for higher levels of performance while preventing overuse injuries and sport-induced differences in physical development. The key to power exercises is high quality repetitions. Adequate rest is needed and small number of repetitions are used even with relatively light loads.

CHOICE OF EXERCISE

Exercises that can use any intensity and be lifted as fast as possible with that load are:
1 various Olympic-style lifts and their variations (e.g. hang cleans);
2 isokinetic exercises;
3 pneumatic or hydraulic exercises; and
4 medicine ball drills and plyometrics.

Basic programme (2–3 times per week)

Primary exercises
Hang clean (from knees)
Squat
Split squat
Bench press
Clean pull (from thighs)
Medicine ball throw
Push press
Seated row

Assistance exercises. Perform each exercise at least twice per week.
Rotator cuff exercises (also push ups on medicine ball at different arm levels)
Lateral pull down
Leg curl
Calf raise
Sit ups
Biceps curl

ORDER OF EXERCISE

The primary exercises are performed first in the workout. These are followed by the assistance exercises. Perform the more complex exercises, which require more skill and technique, before the less complex exercises, or the larger muscle group exercises before the smaller muscle group exercises.

NUMBER OF SETS

Start with 1 set and progress to 3–5 sets per exercise depending upon where the athlete is in a training cycle for the week, month and/or year.

INTENSITY

The power exercises are performed for 5 repetitions in the case of the Olympic-style lifts (cleans and pulls) with rotating intensities of: very light 30–40%; light 50–60%; moderate to heavy 70–80%; and very heavy 90–100% of 1 RM. Exercises which are not Olympic-style lifts (e.g. bench press, seated row) should rotate between: light 12–15 RM; moderate 8–10 RM; heavy 4–6 RM; and very heavy 1–3 RM. When using loads 6 RM or lower the athlete must make the attempt to move the weight as quickly as possible. The athlete should not try to do 'speed' repetitions with light loads using free weights, barbells or stack weight machines where you hang on to the bar and movement ends (e.g. bench press, shoulder press, curl, knee extension, leg curl). Isokinetic, pneumatic and hydraulic modalities do not have this problem of a weight bumping into a joint or causing deceleration of the limb as the athlete is trying to accelerate the limb through the range of motion as the resistance is accommodating.

REST BETWEEN SETS AND EXERCISES

Rest 2–3 min between sets and exercises in the power component of the workout. This longer rest is especially important when learning a new technique or trying increase to a heavier load in the workout. Assistance exercises can use 1.5–1 min rest between sets and exercises. Lighter loads > 8 RM or < 60% of 1 RM can use 1–2 min rest periods. When power training (e.g. moving a light weight as quickly as possible using hang cleans with 30% of 1 RM) a longer rest period of 2 min or greater should be used.

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Chapter 6

Special considerations in strength training

This chapter looks at some of the special considerations that sports medicine professionals need to be familiar with when designing resistance training programmes for athletes. Sex influences, detraining, overtraining and age considerations all impact the design of the programme.

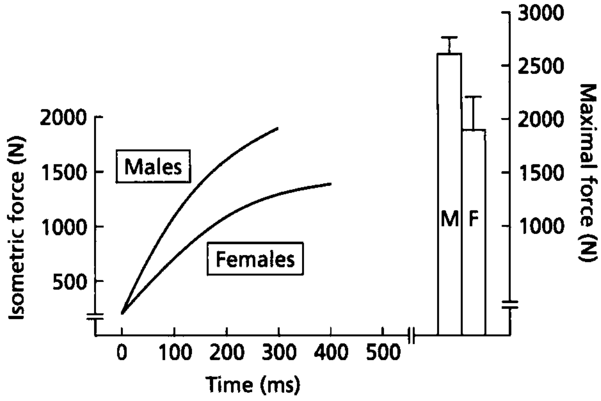


Fig. 6.1 Average force–time curves and maximal peak forces of the isometric bilateral leg extension action in males and females. (Modified from Ryushi *et al.* 1988.)

Sex differences

Absolute strength

Training women for sports performance follows the identical process as for men. Specific sex differences do exist (e.g. weaker upper body) but, by understanding such differences, additional programme elements can be added (e.g. more upper body exercises and total work) to limit the impact of such differences. The average woman's maximal mean total body strength is 63.5% of the average man's; isometric upper body strength averages 55.8% of that of a man; isometric lower body strength averages 71.9% that of a man (see data in Fig. 6.1, right-hand side). The large variation is caused by the large number of different single joint (elbow extension, shoulder flexion, hip extension) and multiple joint (squat, bench press, shoulder press) movements possible with both the upper and lower body. The data indicate that, in general, absolute (body weight not considered) lower body strength of women is closer to that of men than is absolute upper body strength.

This sex difference in 1-RM strength exists even when competitive power lifter's world records are compared for the same approximate weight class. In the Drug-free Power Lifting Association (1991), world records in the Collegiate Class in the 53-kg body weight class for women were 142.8-kg squat, 72.6-kg bench press and 156.8-kg deadlift and for men in the 52-kg body weight class were 183-kg squat, 115.9-kg bench press and 192.8-kg deadlift. Thus, the primary sex difference appears to be in strength and power and this difference is magnified in the upper body, chest and shoulder musculature of women. While the percentage of male strength increases, especially for women's lower body, various deficits remain when compared to men. If leg press strength is expressed relative to body weight and lean body mass, women are 92% and 106% as strong as men. The upper body appears to be at the greatest disadvantage when compared to men. Other data support the concept that lower body, but not upper body, strength is equal in men and women when expressed relative to body weight or lean body mass. Absolute isokinetic bench press and leg press strength of women is 50% and 74% that of men, respectively. When adjusted for height and lean body mass bench press strength of women is 74% that of men, but women's leg press strength is 104% that of men.

Eccentric isokinetic peak torque relative to lean body mass may be equated to a greater extent between the sexes than concentric isokinetic peak torque. Women's quadriceps and hamstrings concentric isokinetic peak torque relative to lean body mass at 60, 90 and $150°\cdot s^{-1}$ averages 81% of men's. But eccentric isokinetic peak torque relative to lean body mass at these same velocities of movement averages 93% of men's. This indicates that relative to lean body mass the lower body eccentric strength of women is almost equated to men's whereas concentric strength is not. This may be because women are able to use stored elastic energy to a greater extent than men, and women not being able to recruit as many of their motor units during concentric as compared to eccentric muscle actions. Whatever the reason, it is indicated that women may be better at performing eccentric than concentric muscle actions.

Thus, the majority of evidence indicates that the average woman's absolute upper and lower body strength is not as great as the average man's. Upper body strength and muscle mass are the most dramatic difference between the sexes. However, a large range of values exist when comparing absolute strength values. This large range is in part because of the large number of movements possible with both the upper and lower body musculature and to different strength/power testing methods (e.g. isokinetic, dynamic external resistance, isometric). If expressed relative to lean body mass or muscle cross-sectional area, the difference in strength between the sexes in many instances, but not in all, disappears. Eccentric strength relative to lean body mass may be equated between the sexes to a greater extent than concentric strength. Lower body strength, more often than upper body strength, is equated between the sexes when expressed relative to lean body mass or muscle cross-sectional area.

Power output

Power output in many sports or activities is a major determinant of success. One event where power output is a prime determinant of success is the snatch lift. Comparisons of international calibre Olympic weightlifters indicates that for the complete pull phase of the lift women's power output relative to total body weight is 65% of men's. Maximal vertical jump and standing long jump ability are also largely determined by power output. The average woman has been reported to have 54–73% of the maximal vertical jump (see Fig. 6.2 for the entire load–vertical jumping height curve) and 75% of the maximal standing long jump of the average man. For the standing long jump this translates to the average woman generating approximately 63% of the power generated by the average man.

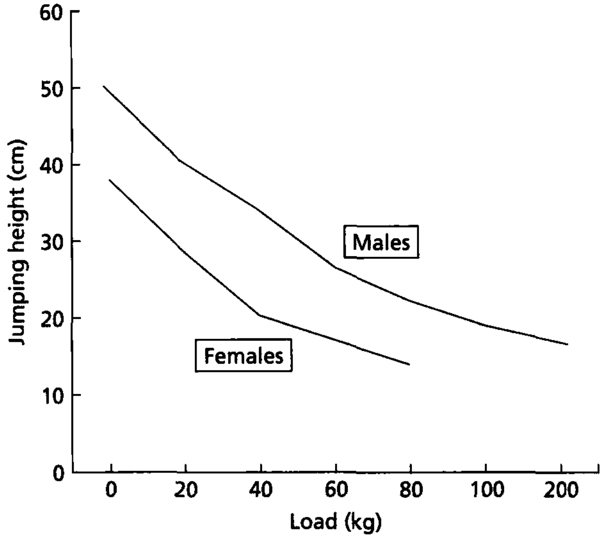


Fig. 6.2 The load–vertical jumping height curves in males and females. (Modified from Mero *et al.* 1987.)

This sex difference in power exists even when competitive weightlifter's world records are compared for the same approximate weight class (Fig. 6.3). For example, in the open age group category in weightlifting for the 52-kg body weight class, the 1992 world records for women in the clean and jerk was 108 kg and the snatch 72.5 kg, while for men the clean and jerk was 155.5 kg and 120.5 kg for the snatch.

Interestingly, when vertical jump ability is expressed relative to lean body mass, only small (0–5.5%) differences between the sexes are apparent. This indicates that differences in lean body mass may account for the differences in vertical jump ability between the sexes. However, power generated during the standing long jump per unit of lean leg volume by women is significantly less than that of men. Cycling short sprint ability (30 s Wingate test) is not significantly different (2.56% difference) between the sexes again if expressed relative to lean body mass. Accounting for differences in lean body mass between the sexes does not appear to explain lower power outputs and differences in performance in all other power type tests. If lean body mass is accounted for, women's running, short sprints and maximal stair climbing ability (Margaria–Kalamen test) is 77% and 84% of men's.

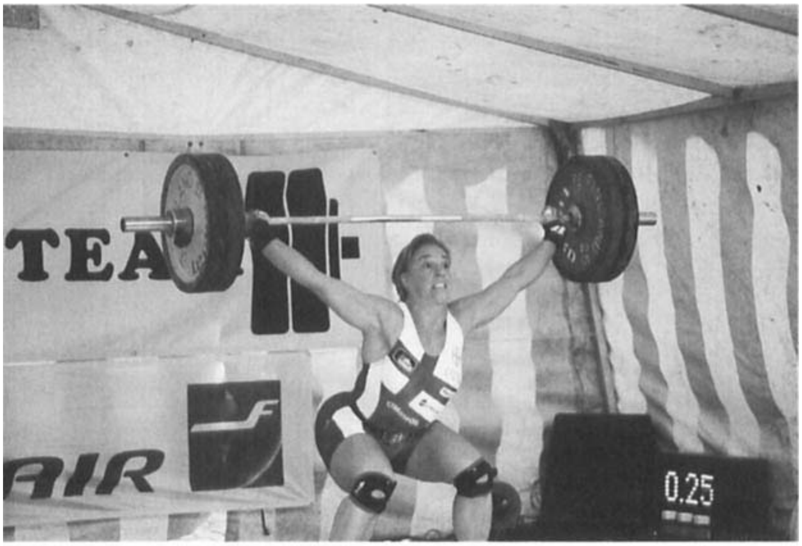


Fig. 6.3 Sex differences in strength and power exist even when comparing elite weightlifters.

Fig. 6.4 Drop-off in force–velocity curves in men and women are similar. Photo © Allsport/J. Gichigi.

Although the data are not consistent they do raise the question of why women may generate less power per unit volume of muscle. One possibility is a difference in muscle fibre size. Both muscle fibre types (Types I and II) are smaller in women than in men. While the percentage of fibres is similar in men and women, the size of the fibres is smaller even in trained women when compared to untrained men. It is not certain how variations in muscle fibre type may affect many sport performances. Power at faster velocities of movement may be affected if the force–velocity curve of women was different from men. However, it appears that the drop-off in force as the velocity of movement increases is similar in both sexes (Fig. 6.4). Furthermore, peak velocity during knee extension movement shows no difference between the sexes.

The rate of force development could affect power output. It does appear that the skeletal muscle's rate of force development is slower for the average woman than the average man, as shown in Fig. 6.1 (left-hand side) for the entire isometric force–time curve. Thus, the smaller power output of women's as compared to men's skeletal muscle may be partly caused by a slower rate of force development. The slower rate of stretch-shortening cycle force development in women would be partly caused by possible sex differences in muscle fibre distribution, and muscle fibre Types I and II area ratio. In addition, lower testosterone concentrations have been attributed to lower mental aggressiveness of many women for maximal activation of muscles.

Training effects

When performing the identical resistance training programme, previously untrained women gain strength at the same or a greater rate than previously untrained men (Wilmore 1974; Wilmore *et al.* 1978; Cureton *et al.* 1988). Over the course of a 10- and a 16-week resistance training programme, women gained strength at a rate equal to or greater than men. Greater absolute increases may be demonstrated by men but relative increases (percentage increases) can be equal to or greater in women than men.

Some initial evidence indicates that women's strength gains may plateau after 3–5 months of training and may not progress as well as men. This observation exists in leg muscle but might be more pronounced in the upper body where absolute muscle mass is less than in men and hormonal output brought about by training is different in women when compared to men. This type of plateau may represent a shift in physiological adaptation strategies that the body uses to adapt (neural or hypertrophy) to result in strength gains. Alternatively, it could represent a type of staleness brought about by a lack of periodized training. Nevertheless, it appears that the upper body chest and shoulder musculature is the most difficult to see continued gains in strength and size, most likely because of a reduction in the size and number of muscle fibres available for training.

Another misconception is that women's resistance training programmes need to be different to men's. Comparison of men and women who used identical resistance training programmes demonstrate that previously untrained women make the same if not greater gains in strength than previously untrained men. This indicates that programmes for women do not have to be different to those of men. The muscle groups that need to be strong or powerful to be successful in a particular sport are the same for both sexes. Thus, the goal of a resistance training programme would be to increase strength/power with the muscles needed for success in an activity, irrelevant of the athlete's sex.

In general, the upper body shows the greatest difference in strength between the sexes. It has been proposed that this is because women tend to have a lower proportion of their lean body mass in their upper body. Thus, it may be warranted to emphasize development of upper body lean body mass of women in sports where upper body strength is a limiting factor of performance. This does not mean that a programme to develop lean body mass in the upper body will be different between the sexes, but that women may benefit from having such a programme comprise a greater proportion of their total training volume in a year.

Muscle of both sexes responds to training in the same manner. Muscle force output is directly related to the muscle's cross-sectional area. A significant amount of individual variation does exist between cross-sectional area and force output. This appears to be true at all velocities of movement. However, there is some indication that maximal isometric force per cross-sectional area, maximal isometric force per unit volume of muscle, and 1-RM weight per cross-sectional area are lower in women's muscles than men's. Possible reasons for this potential difference in force output per cross-sectional area are the same as those previously discussed for possible differences in strength relative to lean body mass. Even if force output per cross-sectional area of muscle is different between the sexes it would have no impact on programme design.

In general, both sexes have the same percentage of Type I and II fibres in a particular muscle; however, fibre composition may vary from muscle to muscle. In general, differences are apparent in fibre size between the sexes. Untrained women have smaller Type I and II fibres than untrained males: cross-sectional area of an untrained woman's Type I and II fibres are 68% and 71%, respectively, of an untrained man's. These differences in fibre size appear to be apparent in strength athletes; women have 66% and 71% of the Type I and II fibre areas of their male counterparts.

Differences in fibre size are also apparent in the Type II subtypes with Type IIa and IIb fibres of women being significantly smaller than men's. This is true even when women have had the advantage of using anabolic drugs. It has been suggested that this difference in fibre size is not brought about by a difference in physical activity but is one of the innate differences between the sexes.

Men at rest normally have about 10–20 times the testosterone concentrations of women during prolonged strength training over several months or years. This may account for the larger increases in muscle hypertrophy in men than in women. However, there are other hormones, such as growth hormone and cortisol, that could also have an effect on muscle growth and hypertrophy. It has been pointed out that low concentrations of a hormone do not necessarily mean that the hormone does not have an active role in controlling a body function or process such as growth.

Investigations now show small but significant increases in testosterone, and free testosterone especially, with acute resistance exercise and on some occasions with resistance training. It has been shown that although resting blood testosterone concentrations in women may not change significantly during a 16-week resistance training programme, individual mean serum levels of both total and free testosterone correlate significantly with changes of muscle force production during the training programme. This indicates that small individual changes of testosterone concentrations brought about by training may affect the force capabilities of muscle in women. This may have increased importance during prolonged strength training to create more individualized training programmes to optimize the training stimuli.

It has recently been demonstrated that up to 30% gain in upper arm size can be seen in women after 6 months of periodized resistance training. Some women do develop a large amount of hypertrophy from resistance training. A group of women athletes, after a 6-month resistance training programme, exhibited an increase of 37% in upper body strength and 3.5, 1.1 and 0.9 cm (5, 4 and 2%) increases in shoulder girth, upper arm circumference and thigh circumference, respectively. Larger increases in lean body mass and limb circumferences than normal in some women probably result from several factors including:

- higher than normal resting testosterone, growth hormone or other hormone(s);
- greater acute hormonal response than normal to the performance of resistance training;
- lower than normal oestrogen : testosterone ratio;
- genetic disposition to develop a large muscle mass;
- ability to perform more intense resistance training programme;
- smaller muscle fibre sizes and numbers; and
- muscle fibre distribution (high percentage of Type II fibres).

However, the specificity of heavy resistance vs. explosive (power) resistance training with regard to changes in the slopes of the force–time and force–velocity curves are similar in women and men. Maximal force and power training modes should be modified with the requirements of the sports event as well as the individual athlete at a given time. However, in some cases women may need more maximal force and power to optimize their performances in power and speed types of activities.

Performance and menstrual problems

Many myths exist as to the role of the menstrual cycle in training and performance. Premenstrual symptoms or dysmenorrhoea could have a detrimental effect upon sporting performance and some medical professionals recommend use of oral contraceptives or progesterone injections to control the occurrence of menses and to avoid competing while menstruating. Olympic medal performances have been won during all portions of the menstrual cycle; thus the effect of the menstrual cycle on performance is unclear and is probably very individualistic.

Sex impact conclusions

For sports or activities requiring upper body strength and power the needs analysis for a women must take into account their weaker upper body musculature, in absolute and relative terms, as compared to men's. The smaller upper body muscle mass of women, in general as compared to men, may limit women's performance in sports requiring upper body strength or power. Thus, the training programme for such sports or activities should stress upper body exercises in an attempt to increase total upper body strength and power. This can be accomplished by adding two or three more upper body exercises and/or one or two extra sets, as volume of exercise may be very important for the upper body training effects on muscle mass.

The weak upper body musculature of most women also causes problems in the performance of structural exercises, such as power cleans and squats. In these types of exercises women may find it very difficult or impossible for their upper bodies to support the resistances their lower bodies can tolerate. Incorrect form for these exercises should not be tolerated to allow the individual to lift greater resistances. Foot stance may have to be widened to take into consideration hip width. The sacrificing of form can cause injury to the athlete. Instead, the programme should stress exercises to help strengthen the upper body musculature.

Detraining

Effects on the neuromuscular system

A cessation of heavy resistance training or a reduction in volume, intensity or frequency of strength training for a certain period of time is called detraining. Strength training may be stopped or reduced because of injury or as a planned part of the yearly training cycle. It is important to know the basic adaptations taking place in the neuromuscular system during detraining in order to design optimal training programmes for improving performance and maintaining strength or power during the periods when resistance training is stopped or reduced.

Detraining following strength training leads to specific functional and structural adaptations in the neuromuscular system. These changes take place in a direction opposite to those resulting from strength training. The magnitude and time course of neuromuscular adaptations during detraining are influenced by the amount and intensity of the preceding strength training, the overall training history of an individual subject or athlete, amount and type of physical activities utilized during detraining, and the length of the detraining period.

Detraining subsequent to heavy resistance training (in previously untrained subjects) leads to a decrease in the maximal voluntary neural activation of detrained muscles (Fig. 6.5). However, the decrease in the maximum electromyography (EMG) of muscles does not necessarily take place during the very first week of detraining but most likely during the first 2–4 weeks of detraining. The decreases found in muscle fibre areas of both fibre types during detraining (Fig. 6.5) are clear indicators of muscle atrophy because of termination of systematic strength training. Because the size of individual muscle fibres decreases, detraining also leads to a decrease in a detrained cross-sectional area of the whole muscle in question. This is true for both men and women. It can be concluded that detraining subsequent to heavy resistance training may result initially in a reduction in maximal voluntary neural activation of detrained muscles, whereas thereafter muscular atrophy tends to increase gradually during prolonged inactivity.

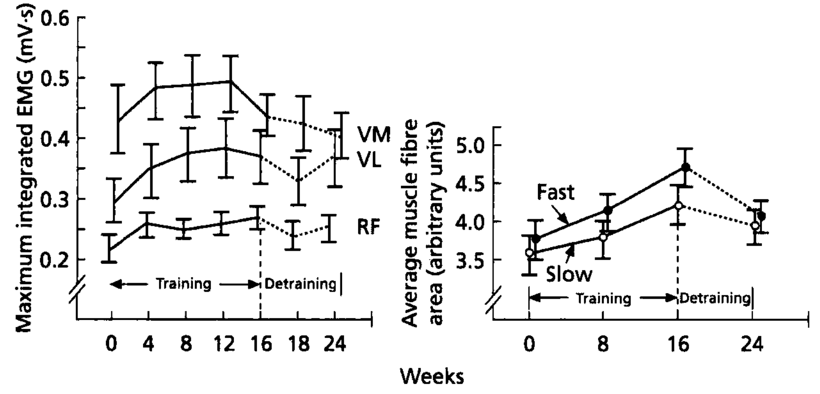


Fig. 6.5 Maximal voluntary activation (integrated EMG) of the leg extensors (VL, vastus lateralis; VM, vastus medialis; RF, rectus femoris) and muscle fibre areas (for the VL) during strength training and detraining in men. (From Häkkinen 1993.)

Effects on maximal force

The functional and structural adaptations taking place in the neuromuscular system during detraining lead to considerable decreases in muscle strength. However, the time course of strength decrease is unique so that the decrease in maximal force does not take place necessarily during the very first week of detraining. It is possible that there would be even a slight occasional increase in strength during the very first week of detraining in both previously untrained subjects and strength athletes (Figs 6.6 and 6.7). This is most likely to happen in those strength athletes who have used very high volumes of resistance training preceding the detraining as discussed earlier with regard to optimal peaking under the conditions when the volume of training is periodically decreased (see Fig. 6.7).

However, it is inevitable that detraining will lead to a large decrease in maximal force during the first 2–4 weeks of detraining (Figs 6.6 and 6.8). It is also likely that this critical period of time is then followed by a strength decrease at a diminished rate (Fig. 6.8). It is reasonable to suggest that the initial decrease in maximal force during the first 2–4 weeks of detraining may be a major consequence of the initial decrease in the maximal neural activation of detrained muscle, thereafter the reduced strength may be primarily related to the degree of muscle atrophy. Detraining leads to a great decrease in strength but the strength decrease during detraining for a few weeks or a couple of months will result in a strength level after detraining that is still greater than pretrained levels.

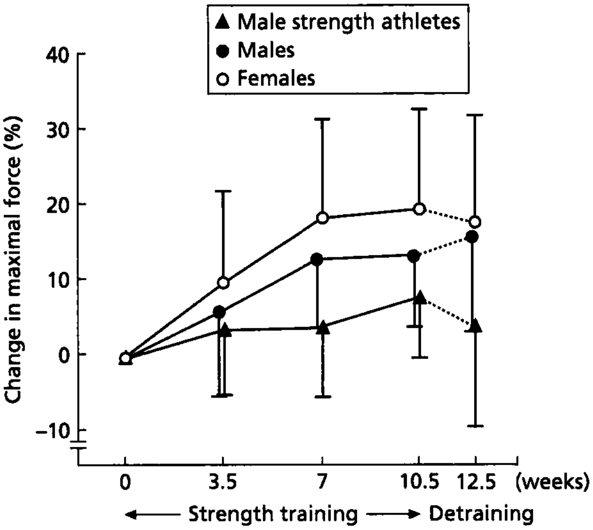


Fig. 6.6 Maximal force during heavy resistance strength training and detraining in men, women and male strength athletes. (From Häkkinen 1993.)

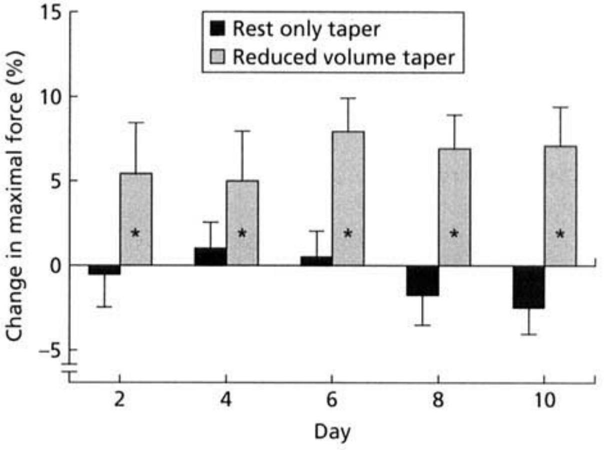


Fig. 6.7 Changes in maximal force after strength training followed by rest or reduced volume training. (Modified from Gibala *et al.* 1994.)

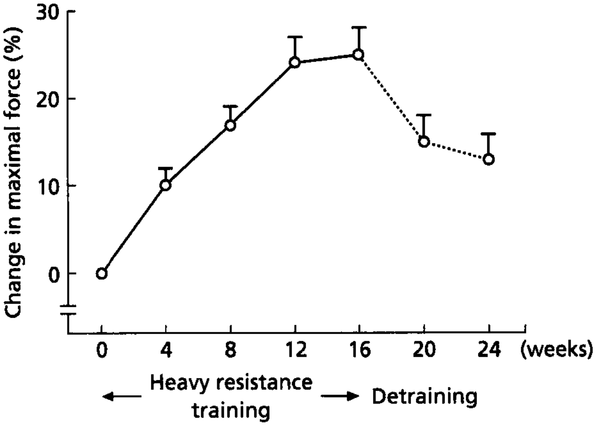


Fig. 6.8 Maximal force during heavy resistance strength training and detraining in men. (From Häkkinen *et al.* 1985).

Effects on explosive strength or power

Detraining subsequent to heavy resistance training will lead to much more minor changes in explosive strength or power in comparison to that taking place in maximal force. This may be attributed to the specificity of the preceding heavy resistance training accompanied usually only with modest increases in explosive strength characteristics, such as vertical jumping power and explosive isometric force production. It is even possible that a short period of detraining (such as a week or two) after heavy resistance training will lead to some periodical increase (peaking) in explosive force production. This information could be utilized in designing resistance and power training programmes, especially for power and sprint athletes.

Because of the specificity of training, detraining subsequent to explosive resistance training (low loads and high movement velocities) will lead to significant decreases in explosive strength and power characteristics of the muscles, accompanied with only modest changes in maximal force or muscle mass. The magnitude and time course of power decrease during detraining subsequent to explosive resistance training is related to the amount, type and intensity of the preceding training period, the overall training history of an individual athlete, the amount and type of physical activities utilized during detraining, and the length of the detraining period. A short period of detraining or a reduction in the volume of explosive training may lead to periodical peaking in explosive strength and power, especially in those athletes who have used high or over high volumes of training during the preceding explosive resistance training.

Detraining conclusions

In conclusion, the role of continuous strength training is vital not only for strength development but also for the maintenance of strength and muscle mass. There is a need for proper strength training planning and recovery periods to minimize effects caused by detraining and/or inactivity among athletes. The duration of recovery periods after the competitive season or a reduced volume of resistance training during the competition season (in-season resistance training) should be matched with the specific requirements of the sport event. The recovery period should be long enough to allow time for the recovery processes of the body before the next preparatory season but not too long to lead to unnecessarily large decreases in muscle mass and strength. Part of detraining or of the recovery period may be useful, especially in strength athletes, for maintaining strength training. This refers to lower volumes of resistance training while maintaining the intensity of the loading at relatively high levels.

Overtraining

The obvious goal of any sports training programme is to optimize sport performance. When the training programme is carefully designed and takes into account the numerous contributory factors to performance, it is likely that maximal or near-maximal performances will result. However, this ideal situation does not often occur, resulting in less than desirable results. On one hand, it is possible that undertraining occurred and that an insufficient stimulus was used to attain the intended goals; on the other hand, it is likely that too great a training stimulus was prescribed. When this occurs, the risk of the long-term problem of overtraining is greatly increased. What is not always understood by the coach and athlete is that this is an avoidable problem. The careful use of proper training principles can provide protection from overtraining.

When studying the role of overtraining in resistance-trained individuals, it becomes readily apparent that much of the scientific data available on overtraining addresses this problem for endurance activities. As is the case with much of the exercise science literature, only recently has resistance exercise become a major focus of the sport science research community. As such, there is much to be learned about the problem of overtraining for those using resistance exercise. This is particularly important because strength training is the fastest growing fitness and recreational activity over the past several decades. When reading the existing overtraining literature based on endurance exercise, one must be aware that the performance responses and physiological mechanisms reported may not apply to the markedly different demands of resistance exercise. As such, there is a great need for scientific inquiry into the overtraining phenomenon as it relates to heavy resistance exercise.

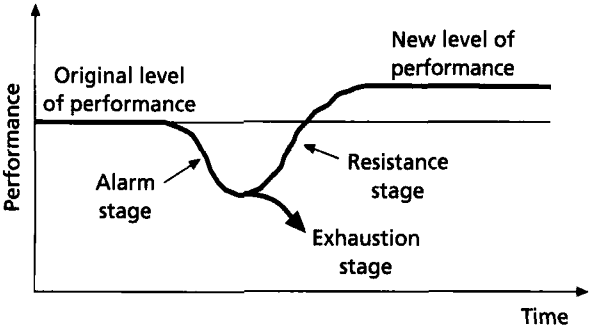


Fig. 6.9 Changes in maximal performance before, during and after a single training session.

Definition of overtraining

Before proceeding it is critical to define overtraining. For our purposes, overtraining is defined as any and/or maintenance of high-intensity training volumes or increase in volume and/or intensity of exercise training resulting in long-term performance decrements lasting several weeks or months or longer. The crucial factors here are that performance is adversely affected, and that this performance decrement lasts a considerable period of time. It is not possible to recover from overtraining by simply taking a few days or even a week off from training. One way to look at the stress of overtraining is to compare it to the General Adaptation Syndrome (GAS) proposed by Hans Selye (1956) (see Fig. 6.9). The GAS provides a simple model for describing how a biological system deals with stressors of all types. When the biological system is initially presented with a stressor, the first response is the alarm stage. Performance is impaired as normal functioning of the system is interfered with. Eventually, the system can counter the stressor via the resistance stage. It is during this phase that the ability to adapt to the stressor is developed. Eventually, the system reaches a new level of performance which permits greater resilience to future stressors. If the system is unable to resist the stressor, exhaustion occurs. According to Selye, when advanced stages of exhaustion occur, death of the system results. Although it is unlikely that reaching the exhaustion stage in sport training will result in death of the athlete, a more likely scenario is that hopes of successful sporting performance in the near future are pretty much dead.

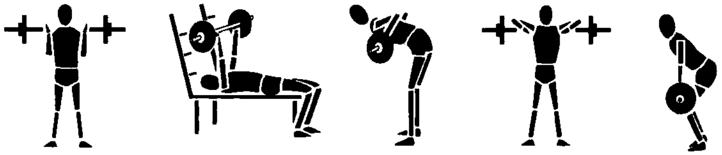
Although not originally developed for exercise or sporting purposes, the GAS lends itself well to describing both the short- and long-term stresses of exercise training. For our purposes, the stressors are associated with either a single training session or the chronic effects of a long-term training programme. As shown in Fig. 6.9, when the stress of a single training session is encountered the athlete will become fatigued and performance will decrease. When the training session ends, the stress is removed and recovery can occur. If recovery is optimal, a new level of performance is possible as the body supercompensates for the stress of the workout, and the following training session is timed to coincide with this new level of performance capacity. If the training session is too stressful (e.g. too great a volume and/or intensity), the individual is unable to respond adequately and exhaustion occurs. Recovery from even a single bout that is excessively exhausting can require a long recovery that interferes with the training progress of the individual. If the long-term effects of training are being considered, the alarm stage may simply be the response to a stressful phase of training. Such stressful training must be coordinated with phases of adequate recovery to allow long-term progress. When overtraining occurs, too much time has been spent in the alarm phase with inadequate time in the recovery phase. The net result is the long-term condition of overtraining and the ensuing impairments in performance.

It is important to realize that not all phases of stressful training will result in overtraining. For example, many successful coaches and athletes will prudently include training phases of very high volume and/or intensity. Often, these phases will produce short-term decreases in performance. However, such a situation is not overtraining, but instead is often termed overreaching. Overreaching can be a very beneficial phase of training, provided that the coach or athlete knows when to back off the training. If performance is adversely affected, it is readily regained with only a short recovery period of just a few days or 1–2 weeks. It is commonly believed that such training phases will result in a rebound in performance within a few weeks, with the athlete attaining new and higher levels of performance, much like the supercompensation following the resistance phase of the GAS. Such training techniques are used by coaches throughout the world. Good examples of overreaching are often seen in the pre-season training for North American sports. In many cases, the athlete reports to the training camp approximately 1 month prior to the start of the competitive season. During this time, very stressful training occurs. However, the wise coach knows when to decrease this training stress so that the athlete can recover and rebound to new performance levels in anticipation of the forthcoming competitive season. Thus, when carefully administered, overreaching can be a very beneficial part of many training programmes.

The term overtraining syndrome is sometimes used to indicate the impaired performances associated with overtraining as well as the accompanying symptoms. Overtraining itself refers to the actual training that leads to performance decrements. Numerous symptoms have been associated with overtraining, although most are a result of studies of endurance activities (Table 6.1).

One additional point regarding overtraining is that this condition may not occur as often as some would believe. It is important to differentiate between the athlete who mistimes his or her training for a competition and ends up with less than expected results, and the athlete who is truly overtrained and will not be able to return to previous performance levels without an extensive lay-off from training.

Table 6.1 Summary of suggested symptoms associated with overtraining. (Modified with permission from Fry *et al.* 1991.)



Performance	⇓ Performance (muscular strength and power, muscular endurance, cardiorespiratory endurance), ⇓ training tolerance, ⇓ motor coordination, ⇑ recovery requirements, ⇑ technical faults, altered range of motion
Physiology	Altered HR, ECG, blood pressure and respiration patterns, ⇓ body fat and postexercise body weight, ⇑ $\dot{V}\text{O}_2$, $\dot{V}_\text{E}$, HR and lactate accumulation at submaximal workloads, ⇑ basal metabolic rate, chronic fatigue, sleep and eating disorders, menstrual disruptions, headaches, nausea and gastrointestinal disturbances, muscle soreness and damage, joint and muscle aches and pains
Psychological	⇑ Feelings of depression and apathy, ⇓ self-esteem, ⇓ ability to concentrate, easily distracted, sensitive to stress, ⇓ self-efficacy
Immunological	⇑ Occurrences of illness, ⇓ rates of healing, impaired immune function (neutrophils, lymphocytes, mitogen responses, eosinophils)
Biochemical	Hypothalamic dysfunction, ⇑ serum cortisol and SHBG, ⇓ serum total and free testosterone, ⇓ testosterone : cortisol ratio, ⇓ serum Hb, iron and ferritin, negative N_2 balance, ⇓ muscle glycogen, ⇓ bone mineral content, altered glucose tolerance, ⇓ mineral concentration, ⇑ urea concentration

⇑ Increased; ⇓ decreased.
ECG, Electrocardiogram; Hb, haemoglobin; HR, heart rate; SHBG, sex hormone-binding globulin; $\dot{V}_\text{E}$, volume expired; $\dot{V}\text{O}_2$, oxygen consumption.

Elite athletes are typically under the direction of highly trained coaching staff who are sensitive to the problems of overtraining. As a result, appropriate training programmes are used and the athletes routinely undergo assessments to establish levels of sport fitness. Athletes who train themselves, or who follow ill-conceived training programmes, are certainly at greater risk of overtraining. Often, an athlete will have a below par performance which may be blamed on overtraining. In many cases, this is simply the mistiming of attaining their peak performance. Such a condition is readily recovered from in a relatively short period of time, and rectified with an improved training programme. Athletes who are experiencing an extremely stressful phase of training may also be classified as overtrained. As previously indicated, such a condition is most likely overreaching, because a short period of recovery can bring the athlete back to an acceptable performance level.

Overtraining cues from the acute resistance exercise variables

Thus far we have only concerned ourselves with characteristics of the long-term programme, but what about the design of a single training session? When considering how overtraining relates to resistance exercise, it helps to have an understanding of the five acute resistance exercise training variables. These five variables account for all possible designs of a single training session. Strength training can come in many forms and variations. All the possible variations in a single resistance exercise training session can be described by the following.

1. Choice of exercise.
2. Order of exercise.
3. Volume of exercise.
4. Intensity (load).
5. Rest between sets.

One of the fundamental problems with prescribing resistance exercise is the tremendous number of choices available and the complex interactions possible between these choices. Furthermore, each of these variables can impact the risk of overtraining if not properly prescribed. Let us take a closer look at each of these acute training variables and their overtraining implications.

Choice of exercise

Unlike many other forms of exercise, resistance exercise is complicated by the vast variety of exercises and exercise modalities available. When designing an optimal programme, it is desirable to utilize all the appropriate resources possible, which includes the best exercises for the objectives. In many situations, the coach or athlete may be limited in what exercises may be performed simply because of the equipment available; even so, a tremendous amount of variety is usually still possible. The following are several considerations concerning choice of exercise and the possible implications for overtraining.

MUSCLE INVOLVEMENT

The appropriate resistance training exercises must involve the relevant musculature for the sport or activity being trained for. This means determining the primary and secondary movers for the sport, as well as the assisting synergistic muscles critical for optimal performance. Such an analysis is often termed the functional anatomy of the sport, and determines what body parts will be emphasized during training. The analysis requires a thorough understanding of the muscle involvement of the exercises selected. Incorrect selection of exercises can result in an overemphasis of certain body parts. A possible example of this is overuse of the very popular bench press exercise. This exercise is often combined with numerous variations of the bench press (e.g. incline bench press, close grip bench press, decline bench press, dumb-bell variations of the bench press) as well as numerous shoulder exercises (e.g. shoulder press, lateral raises, behind the neck presses, front raises, bent over raises). The net result can be an overemphasis on the shoulder musculature. Overuse injuries of the shoulder are common in strength training when such an imbalance in exercise selection exists. While overuse injuries are not synonymous with overtraining, there is much potential overlap. The inability of a particular body part to tolerate the exercise load prescribed can contribute to maladaptation and impaired performances.

MUSCLE MASS

Selection of resistance exercises often depends in part on the amount of the musculature involved. One reason for this is that the desired training effect often includes the ability of various muscles and muscle groups to work together, hence the selection of exercises that depend on synergistic muscle activity. Through the coordinated neural activation of these muscles, the body may become more efficient in appropriately synchronizing their use on the sports field. Another reason is that exercises that activate large muscle masses are more time efficient than selecting numerous exercises that each involve only a small muscle mass. In addition, the simultaneous activation of large muscle masses provides a greater stimulus for several physiological systems. Among the most important may be the endocrine and the autonomic nervous systems which directly or indirectly regulate many of the acute and chronic responses and adaptations to resistance exercise. Because of the larger muscle mass involvement and greater stress, it is likely that the total training capacity may be less for large muscle mass exercises compared to small muscle mass exercises. An example of a large muscle mass exercise might be the barbell squat, while examples of small muscle mass exercises might be leg extensions and leg curls. Thus, the overall stress of performing barbell squats is greater than for leg extensions and leg curls. As a result, total training volume for large muscle mass exercises must be carefully prescribed so as to minimize the risk of overtraining. This does not mean avoid these exercises as, on the contrary, large muscle mass exercises are often the most important to include, but they are very stressful.

VELOCITY OF MOVEMENT

An elementary principle of exercise is the specificity principle, often expressed as the Specific Adaptation to Imposed Demands (SAID) principle. This states that in order to adapt in a desired manner, you must train in a similar manner. If high velocity of movement or high-power production is important, as it is to most athletes, then some components of training must be performed at high velocities or at high power. In the weight room this is best accomplished with certain exercises designed specifically for high velocities and high power production, specifically the Olympic-style weightlifting movements (snatch, clean and jerk, and related exercises). Although any resistance exercise can be performed at high velocity, proper technique may be sacrificed if performed too fast. However, the weightlifting movements are designed specifically to be performed at fast velocities. Other exercises that are sometimes performed in an explosive manner (at high velocity) include the barbell squat and the bench press. Thus, by carefully selecting the exercises, it is possible to train almost anywhere along the force–velocity curve. The concern for overtraining is that high-velocity exercises are often quite stressful. Technique is extremely important, and any deviation from proper technique may lead to inappropriate adaptation. As will be discussed later in greater detail, the rate of work production is very high for these exercises, meaning the exercise intensity is very high. Such types of exercise are potentially more stressful than typical weight room exercises. Therefore, as with large muscle mass exercises, total training volume and intensity for high-velocity resistances, exercises must be carefully prescribed so as to minimize the risk of overtraining. Again, this does not mean avoid these exercises as they may be critical to the desired training effect.

RANGE OF MOVEMENT

Most resistance exercise programmes specify using a full range of movement (ROM) for most exercises. It is well established that the greatest resistance exercise training effect is found in the ROM actually used for training. Limited ROM exercises are sometimes used for injury rehabilitation or for strengthening the 'sticking point' of an exercise (the weakest ROM of the exercise). However, some individuals use partial ROM exercises in an attempt to handle heavier loads. When wisely used, this is an advanced training method that allows desirable neuromuscular adaptations. On the other hand, if a partial ROM is used simply to allow a heavier load to be lifted, the body may be exposed to a greater load than is recommended. An example of this is the athlete who only descends part way down during a squat motion. The smaller ROM permits extremely heavy resistances to be used. Chronic use of such excessive loading may be a precursor to overtraining.

TRAINING MODALITY

The type of device used to provide the resistance is a significant factor in the training stress provided. One of the fundamental concerns for some is the use of free weights or machine modalities. Some of the advantages of free weights include the greater involvement of synergistic muscles, movement through three dimensions, and greater proprioceptive development. Additionally, free weights are considerably less expensive than resistance exercise machines. It has been noted that the actual force required by the involved muscles will vary according to the biomechanical characteristics of the exercise. As such, the use of free weights has been classified as dynamic constant external resistance, as there is movement and the external load (weight on the barbell or dumb-bell) is the same throughout the ROM. Numerous machine modalities have been classified as variable resistance devices. This includes isokinetic machines (controlled velocity), pneumatic machines (compressed air resistance) and machines with various types of cams and lever systems. The force produced throughout the ROM will vary depending on the mechanical characteristics of the machine. In many cases, variable resistance machines do not permit a clear indication of the actual load being used. However, these machines can be useful when the volume of exercise is appropriate. Hydraulic devices also provide variable resistance and, along with many isokinetic devices, do not provide eccentric resistance, only concentric. Recently, electronically braked machines have allowed the individual to use different loads for both the concentric and the eccentric phases of the exercises. As discussed below, eccentric loading can be very stressful, and a concern with these devices is whether a proper ratio between concentric and eccentric loading is being used. In addition, devices with no eccentric phase of resistance provide a lesser stress to the system, and may be missing an important training component for an athlete. In general, machines will limit the user to movement in either one or two dimensions, and thus provide less development of synergistic activity, neuromuscular coordination and proprioceptive control. As far as overtraining is concerned, it appears that because of the greater physiological demands, the training tolerance and capacity with free weights may be less than with machines. Therefore, training programmes are not readily transferable between machines and free weights. A judicious coach must realize the difference between these resistance exercise modalities to avoid overtraining.

TYPE OF MUSCLE ACTION

Skeletal muscle can produce force through several types of muscle actions. It has been well established that eccentric muscle actions are extremely stressful and produce greater amounts of muscle tissue disruption. As such, excessive use of eccentric activity can provide too great a training stress and may increase the risk of overtraining.

TYPES OF RESISTANCE

Many training programmes include not only free weights or machine resistance, but also other types of resistance. Examples might include body weight exercises, elastic bands and medicine balls. When determining training volume and intensity, these types of exercises may not be included in the calculations; however, it should be noted that these exercises contribute to the total training stress. Therefore, all exercises used should be accounted for when monitoring a resistance training programme. Failure to do so may result in underestimating the actual training stress and increasing the risk of overtraining.

Order of exercise

The second acute training variable is the order in which the exercises are performed during a training session. This variable is often overlooked, but can have a considerable impact on the physiological effects of training. General guidelines for order of exercise include the following:

1 Large muscle mass exercises before small muscle mass exercises.
2 Multijoint exercises before single joint exercises.
3 High power exercises before lower power exercises.

The rationale for such guidelines is that the exercises that are the most fatiguing and require the most motor coordination should be performed when the athlete is fresh and capable of utilizing proper technique. For example, if high power exercises (e.g. cleans, snatches) are performed when the athlete is fatigued, it is likely that less than optimal technique is used. When this occurs, the training effect is decreased and the risk of acute or chronic injury is increased.

The items in the above list are only guidelines. There are numerous variations for ordering resistance exercises. Sometimes the order is established specifically to bring on fatigued conditions in an attempt to mimic competitive conditions. Regardless of how the training session is ordered, the coach and athlete must be aware that this variable can have a tremendous impact on the training. Improper and stagnant ordering of exercises may be contributing risk factors for overtraining.

Volume of exercise

The most precise method for quantifying resistance training volume is to calculate how much work was performed. Work is measured in joules, and is defined by the equation:

Work = force × distance

In the training hall, volume of exercise can be estimated by the number of repetitions performed, the distance the resistance is moved and the load used. Work is exclusive of time; in other words, it does not matter how long it takes to perform the exercise. For example, athletes A and B both move the barbell 60 cm when they perform a barbell squat. Athlete A performs 10 repetitions with 100 kg in 20 s, while athlete B performs 10 repetitions with 100 kg in 30 s. Both athletes have performed the same amount of work (equal number of repetitions, equal distance moved, equal loads). Increasing the number of repetitions, the distance moved, or the load used will all result in greater work production. Thus, a tall person will produce more work when performing a barbell squat than a shorter person would because of the distance moved. Needless to say, this calculation may be necessary for research purposes, but is cumbersome for the coach or athlete to use on a regular basis. The simplest method for calculating volume of resistance training is total repetitions performed during a training session. It does not matter what the exercise is or what resistance is used. As a result, this measure tells us nothing about the quality of the work performed, but it is a simple measure of the quantity of exercise. It has been argued that a more useful measure is volume load. This is where the repetitions are multiplied by the load used. For example, three sets of 10 repetitions with a 100-kg load results in a volume load of 3000 kg (3 × 10 × 100 = 3000). Using this method for determining training volume includes the important factor of mass moved. Regardless of how volume is determined, one of the most important variables contributing to overtraining is the amount of exercise performed. Excessive training volume can result in a long-term overtrained condition.

Intensity (load)

Intensity can refer to either the mass of the resistance, or the rate of work production. The rate of work production is known as power. The following equations illustrate the relationship between work, velocity, force and power:

Work = force × distance
Velocity = distance/time
Power = force × velocity
= force × distance/time
= work/time.

We can consider the rate of work production from two perspectives: the power of an individual exercise, known as exercise intensity; and the power of an entire training session, known as training intensity. Exercise intensity is defined as the power of the actual resistance exercise movement. Examples of high power resistance exercises include cleans, snatches, jerks and speed squats, because of their high velocities as well as their heavy loads. High power exercises can be very stressful, and must be rationed appropriately. In most cases, exercise technique is paramount to maximal power production. If technique is compromised because of either short- or long-term fatigue, the training effect is lessened. Furthermore, high power activities are often referred to as 'quality' work as opposed to 'quantity' work. The result is that a tremendous training effect is obtained with relatively low volumes of high power activities. Excessive use of high power exercises may contribute to an overtraining effect.

Training intensity is defined as the rate of work production for an entire training session. The amount of work performed in a session contributes to this value, but the amount of time required to complete the session is of equal or greater importance. The length of the rest intervals between sets determines the total time to complete the training session. If athletes A and B both perform identical training sessions (same exercises, equal sets, repetitions, loads) but athlete B takes twice as long to complete the workout, then athlete A has a greater training intensity. The desired training intensity will be dependent on the objectives of the programme. If high levels of muscular endurance and lactate tolerance are desired, then a high training intensity may be necessary. If maximizing muscular strength and power are a priority, then training intensity must be decreased to permit adequate recovery between sets. Improper manipulation of training intensity may expose the athlete to an increased risk of overtraining.

A more common use of resistance exercise intensity is the determination of the load to be lifted. In the most simple sense, intensity is defined as the mass on the barbell or machine. When an individual lifts 200 kg on a leg press, he or she is using a greater intensity than when he or she lifts 100 kg on the leg press. Another way to look at it is if two athletes perform maximal effort for 10 repetitions, the person who lifts more weight is training at a greater intensity even though both athletes are giving a maximal effort. While this definition of intensity may be correct, it is not often used by the coach or athlete. Most people are interested in relative intensities where the strength levels of the individuals, as measured by their 1 RM, are accounted for.

There are several different ways to express relative intensity. Percentage of 1 RM is sometimes used for relative intensity; for example, a training programme may prescribe a load of 80% of 1 RM. If the 1 RM for the exercise is 200 kg, the load to be used would be 160 kg. The advantage of using percentage of RM loads is that it can be applied to individuals with varying strength levels. A disadvantage is that different individuals may be able to perform different numbers of repetitions at any set percentage. Furthermore, different exercises may have different repetition capabilities at any set percentage. Nevertheless, this method of prescribing, when correctly used, can be very effective and precise.

RM load can also be used to define the relative intensity. For example, if the training prescription requires that 10 repetitions be performed with maximal effort, it can be given as a 10-RM load, that is, the most weight that can be lifted 10 times. An advantage of this method of prescribing relative intensity is that the exact number of repetitions can be prescribed. The disadvantage is that there is likely to be some trial and error to find the exact load needed. Prescribing submaximal training days may be problematic until the exact load needed for any RM load (3, 5, 10, 15 RM, etc.) is known. Furthermore, if submaximal training sessions are not included, using this method will mean that all sets are performed to absolute failure. This may work for a short training phase, but this intensity will be difficult to maintain over extended periods of time.

Mean intensity is used to describe the average relative intensity used for all sets of a training session. This measure is helpful for quantifying the intensity inclusive of all sets of all exercises. To simplify this measure, sometimes sets under a certain relative intensity (e.g. 70% of 1 RM) are not included. This method of quantifying the relative intensity of a training session or other training period does not always reflect small amounts of very high intensity exercise, but simply provides a general description of intensity.

Regardless of how intensity is defined, overtraining is extremely dependent on this variable. Excessive intensity of all types and a lack of varying intensity can readily contribute to overtraining.

Rest between sets

This acute training variable can be manipulated to provide tremendous variety in the metabolic characteristics of the training session. Training intensity is affected by the interset rest intervals, so both of these variables are related. When high power activities or high force exercises are desired, long rest intervals (e.g. 3–5 min) are used to allow adequate recovery before subsequent sets are performed. If the glycolytic energy system is to be emphasized, rest intervals can be extremely short (e.g. ≤ 30 s to 1 min). Rest intervals can be anywhere along this time continuum. It is easy to underestimate the impact of this single acute training variable. If an improper rest interval is used for the intensity selected, the stress of the training session can be greater than desired, and can contribute to overtraining.

Training periodization

Long-term training, whether it is resistance exercise or some other form of conditioning, must be planned in advanced to ensure greater potential for long-term success. The long-term planning is referred to as training periodization, as the training year is divided into several periods where different physiological and performance parameters are prioritized. Periodization can also be based on a multiyear programme as many athletes may function on an Olympic cycle (4 years), or a collegiate career (4–5 years). Regardless of the time period, the long-term objectives and goals are specifically addressed in this plan.

The goals will depend greatly on the sport or activity being trained for. For example, an Olympic-level athlete competing in an individual sport may wish to peak their performances only once every 4 years. This is often apparent in sporting performances during the year following the Olympic Games. Performances are often down at this time as athletes are performing high volumes of training in preparation for the next Olympic Games 3 years away. This scenario is not necessarily overtraining because this is part of the carefully designed long-term training plan for that individual. On the other hand, athletes participating in team sports may not have the luxury of devoting an entire training year or competitive season to long-term preparatory training. These athletes may have to reach peak or near-peak performances every year. As a result, the long-term training programme will differ greatly depending on the demands and characteristics of the sport or activity.

At a very basic level, training periodization can be described by Matveyev's Model of Periodization (Fig. 6.10). This model describes the relationship between training volume and intensity at different phases of the training cycle. Early preparatory work involves large volumes of exercise that must be performed at relatively low intensities because of the amount of training. This can be a very stressful phase of training because of the large amount of exercise. The following phase involves the transition to a lower volume and increasing intensity. The final phase prior to the actual target date is the competition phase where training volume is at its lowest and intensity at its greatest. This is where the final touches for peak performances are acquired. After the training peak, an active recovery period is used to allow restoration of training capacity.

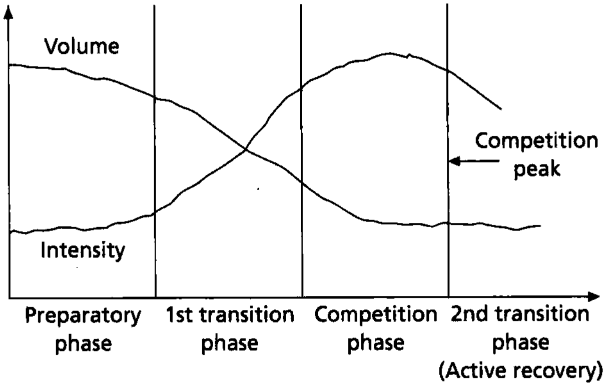


Fig. 6.10 Relationship between training volume and intensity at different phases of the training cycle.

Perhaps one of the most critical messages to be learned from this model is that of the inverse relationship between volume and intensity. When volume is high, intensity must be low, and vice versa. Although this relationship can be violated for short periods of time (e.g. overreaching), the long-term training plan must respect this relationship to optimize performance and to minimize the risk of overtraining. Without a doubt, the most important factor for avoiding overtraining is a properly designed training programme. No nutritional supplement, specially devised training device or other ergogenic aid can do more for the avoidance of overtraining than can the design of the training programme. The wise and prudent coach will be well versed in all the intimate details of training methodologies for their sport or activity. Furthermore, resistance exercise readily lends itself to precise quantification of training data, thus permitting accurate monitoring of the training stresses.

Physiology of resistance exercise overtraining

Although resistance exercise has become a critical part of most successful athletes' training regimen, most of the scientific overtraining literature deals with endurance sports and activities. As a result, many of the signs and symptoms of overtraining reported in Table 6.2 may not even apply to resistance exercise overtraining. Regardless of the type of

Table 6.2 Training factors potentially contributing to resistance exercise overtraining.

- Training volume and intensity not inversely related
- Relative intensity (% RM or RM load) too high for extended periods with little variation
- Training volume (number of sessions, exercises, sets and repetitions) too high for extended periods with little variation
- Improper training intensity (time to complete training session)
- Excessive volume of high-power exercises (exercise intensity)
- Excessive volume of most stressful exercises (e.g. large muscle mass exercises)
- Inadequate recovery
- Performing every set to absolute failure every training session
- Improper exercise selection:
  - Overuse of certain muscles, muscle groups or joints
  - Development of muscle imbalances
- Improper exercise technique and/or inappropriate range of motion
- Excessive use of eccentric muscle actions resulting in muscle disruption or damage
- Effect of training modality:
  - Different training capacity and tolerance for free weights vs. machines
  - Availabity of concentric, eccentric and isometric muscle actions varies
- Improper order of performing exercises or failure to vary order
- Failure to account for the cumulative stresses from other forms of training (e.g. sport-specific training, cardiorespiratory training)

RM, Repetition maximum.

training, the phenomenon of overtraining is difficult to study closely. Typical approaches include either examining athletes after overtraining has already occurred, or developing a training protocol designed to induce an overtrained state. Either approach presents many limitations, thus contributing to the inability to answer definitively the question 'what causes overtraining?'

Concerning resistance exercise, three different study approaches have been used:

1 the effect of excessive training volume;
2 the effect of excessive relative training intensity; and
3 the effect of combining resistance exercise with other forms of training (combination training, training compatibility).

The first two approaches are attempts to isolate the individual acute training variables of volume and intensity, while the latter approach provides a more real life setting where athletes routinely combine resistance exercise with other forms of training and conditioning. The following is a brief description of what is known about performance and physiological responses to resistance exercise overtraining.

Performance

Although numerous symptoms of overtraining may be present, the single most important variable for diagnosing overtraining is a decrease in performance. Overtraining is sometimes associated with plateaux in performance, but it is difficult to differentiate these plateaux from the performance plateaux that can occur during normal training. Furthermore, scientific investigations are typically required to analyse data using standard statistical methods. The slight changes in performance that may be critical to a coach or athlete are often far from being significant from a statistical perspective. The net result is that it is sometimes difficult to demonstrate performance decrements during scientifically controlled experiments. Decreased performance caused by overtraining should also be differentiated from a mistimed training peak. It is not unusual for an athlete to experience a below par performance as a result of poor timing to the programme plan, which is different from an actual overtraining scenario.

One of the most common measures of performance for resistance exercise is 1-RM strength. In general, the human body appears to protect 1-RM strength guardedly, thus making it difficult unequivocally to diagnose overtraining. Attempts at inducing overtraining using high training volumes have been unsuccessful in eliciting decreases in 1-RM strength. These results would suggest that the population studied (elite junior age weightlifters) possessed a greater training capacity than originally thought. When overtraining was induced using high relative intensity training, 1-RM strength was not compromised using

90–95% of 1-RM loads, but did decrease by approximately 11% when 100% of 1-RM loads were used daily over a 2-week period. This suggests that small changes in the relative intensity can be critical during heavy phases of training. In general, however, it is extremely difficult to elicit deceases in 1-RM strength unless extreme training programmes are used.

High-volume training has not been shown to affect lower body maximal power, but was shown to decrease the ability to maintain lower body power as measured by repeated vertical jumps. On the other hand, high-intensity overtraining was not shown to affect measures of lower body jump power, but has resulted in markedly decreased sprint performances. The slower sprint times appear to be primarily a result of slower times through the first 10 m, the most critical part of the sprint for many sports. When isokinetic strength was measured, the largest decreases in strength occurred at the speed closest to the training speed, which is in agreement with the training specificity principle. When combination training was used (resistance exercise and off-season conditioning drills for American football), 1-RM strength, maximal power, sprint speed and agility may all be compromised. Although these performance decrements were readily recovered from, these data indicate that this type of training, which is used for many sports, may not produce optimal results and could lead to the longer term condition of overtraining. In general, when training compatibility is an issue, maximal improvements in any performance variable are difficult to attain because of the compromising nature of this type of training.

Most of the performance measures studied during overtraining research are relatively gross in nature. It is likely that more sensitive performance measures may include rates of force development, efficiency of electrical activity (integrated EMG/force), and explosive strength deficits (rates of time-limited force development). Future research will need to focus on increasingly sensitive measures to attain a better understanding of the overtraining phenomenon.

Biomechanics

It has been suggested that altered movement mechanics may contribute to impaired performances during a state of overtraining. While this is likely to be true, it is difficult to identify definitively unless video and/or force plate analyses are performed. The limited data available indicate that high-volume phases of weightlifting training result in subtle but important changes in snatch lift technique. Even though 1-RM strength was being maintained or even increased, lifting technique was exhibiting evidence of technique breakdown. Barbell trajectories showed a greater horizontal displacement, evidence of greater swinging of the bar and a failure to keep the barbell close to the body during the second pull of the lift. Further study is required to understand fully the role of altered biomechanics in performance decrements caused by overtraining.

Muscle damage/disruption

Damage to the involved skeletal muscle can certainly contribute to short-term decreases in performance, but this is typically rectified by several days of decreased or suspended training. The phenomenon of overtraining is not caused simply by one or several sessions of overly stressful training leading to muscle damage. Although muscle damage is a possibility, the long-term effects of overtraining are not typically brought about by this single problem. On the other hand, if significant amounts of damage occur, and the athlete fails to alter training to accommodate the problem, recovery will be compromised. When this occurs, long-term ramifications could result. Conditions of rhabdomyolysis have been reported with severe training, most likely caused by inappropriate training prescription.

Injury

Improper exercise prescription can lead to overuse injuries, a potential contributor to an overtraining syndrome. Such injuries can be manifested in skeletal muscle as well as joint structures. Such injuries are typically difficult to recognize prior to their actual onset. Occasionally, strength ratios between antagonistic muscle groups may provide some indication of potential problems, but this is not a very exact method. One unique situation permitted the study of the onset of an overuse syndrome during a controlled laboratory setting using high relative intensities (100% of 1 RM). Overuse of the knees occurred for one subject during high intensity overtraining, and resulted in extremely large decreases in 1-RM strength (> 30%). It appeared that proprioceptive afferent inhibition from the knee joints may have been present during dynamic actions, but such inhibition was not present during isometric actions. Such data suggest that the method of assessing performance decrements is critical (dynamic vs. isometric) because isometric measures indicated no decreases in strength.

Autonomic nervous system

It appears that the autonomic nervous system is intimately involved in overtraining. As such, it has been theorized that two forms of overtraining exist: sympathetic and parasympathetic overtraining. Sympathetic overtraining occurs when the sympathetic nervous system is activated to compensate for developing performance decrements. Eventually, the sympathetic system becomes exhausted and parasympathetic activity predominates, resulting in parasympathetic overtraining. Theoretically, sympathetic overtraining precedes parasympathetic overtraining, which is an advanced state. Large volumes of endurance training (up to 30 km daily) have resulted in conditions similar to parasympathetic overtraining. As might be expected, performances were compromised for up to 1 year after such training. To date, no studies have recorded such a parasympathetic overtraining syndrome with high volumes of resistance exercise. However, excessive daily use of high relative training intensity (100% of 1 RM loads) over a 2-week period has resulted in what appears to be a sympathetic overtraining syndrome. Despite large increases in circulating catecholamines, performance was adversely affected with recovery of up to 8 weeks required for some individuals. It appears that the skeletal muscle had maladapted to the high relative intensity training, perhaps through alterations in the adrenergic receptor properties of the muscle. Further research is required to determine if such a mechanism is responsible for the performance decrements observed.

Endocrine responses

Perhaps the hormonal responses associated most with overtraining are those of testosterone and cortisol, and the ratio between these two. As has been reported for endurance overtraining, high volumes of resistance exercise have resulted in decreased serum testosterone and augmented cortisol, both at rest and postexercise. Such responses contribute to a typically decreased testosterone : cortisol ratio both at rest and postexercise. It has been postulated that this ratio is indicative of the anabolic–catabolic balance of the body, and is related to the training status of the individual. Although the testosterone : cortisol ratio has been strongly associated with the accompanying training stresses, it appears that such a relationship is not necessarily causal. A more likely regulating mechanism is the sympathetic nervous system which moderates both the hormonal and the skeletal muscle systems. Contrary to what is observed for high volumes of resistance exercise, resistance exercise overtraining caused by high relative training intensity has exhibited little effect in the resting or exercise-induced testosterone or cortisol concentrations. Of further interest is the fact that luteinizing hormone (LH), which helps regulate testosterone, and adrenocorticotrophic hormone (ACTH), which helps regulate cortisol, were not affected by the high relative intensity overtraining. As a result, it is not possible to diagnose resistance exercise overtraining solely by the steroid hormone responses. Combination training protocols have sometimes reported decreased testosterone : cortisol ratios, perhaps an indication of impending overtraining with these high-volume training regimens.

Growth hormone is an important hormone both for its anabolic and metabolic properties. When high-volume resistance exercise overtraining occurs, decreased growth hormone concentrations are evident at rest and postexercise. This is a typical adaptation to a well-designed training protocol that stresses glycolytic and oxidative metabolism. As such, it does not appear to provide a sensitive marker for overtraining. Furthermore, no changes of growth hormone responses are evident with high relative intensity overtraining. Taken altogether, it appears thus far that the pituitary gland, which is the source of growth hormone, LH and ACTH, is not a site of maladaptation with high intensity resistance exercise overtraining.

Skeletal muscle adaptations

It is well established that skeletal muscle can adapt to resistance exercise via hypertrophy and fibre type transitions. The hypertrophy response is fibre type dependent, varying with the relative intensity used. The fibre type transitions are primarily from IIB to IIA. To date, no data exist to determine the effect of resistance exercise overtraining on the hypertrophy or fibre type transition responses. Although muscle protein expression can be influenced by training, thus influencing muscle performance, no data exist regarding such phenotypic expression brought about by resistance exercise overtraining. Perhaps the sites of most interest regarding skeletal muscle responses to overtraining are the adrenergic receptors. It is known that receptors for the catecholamines associated with the sympathetic nervous system are extremely adaptable. Future study must begin to investigate the role of such receptors.

Metabolic responses

High volumes of resistance exercise have resulted in decreased lactate and ammonia responses to exercise, which are both typical responses to training. Postexercise blood glucose levels were decreased, and were speculated to be caused by a diminished sympathetic response, although this was not measured. Circulating free fatty acids were elevated, which may have been an attempt to replenish muscle glycogen stores. To date, no studies have examined the muscle glycogen response to chronic high-volume resistance exercise. High relative intensity overtraining has also reported decreases in lactate responses to exercise. Whether this is a symptom of overtraining or simply a normal adaptation to training is not known. If a sympathetic overtraining syndrome existed, as previously suggested, it is possible that anaerobic glycolysis may have been impaired, thus resulting in a lower work capacity prior to fatigue. High relative intensity overtraining does not appear to deplete muscle glycogen stores as indicated by muscle biopsies. Needless to say, because of the differing metabolic requirements of high volume vs. high relative intensity resistance exercise overtraining, different sites of maladaptation are likely. Further research is necessary to clarify more fully the metabolic responses to such stressful training. Such an understanding may provide guidance for nutritional or supplementational interventions for resistance exercise overtraining.

Immune responses

To date, no studies have closely investigated immune responses to an actual resistance exercise overtraining syndrome. Unlike endurance overtraining, where considerable study of the immunological responses to stressful training exists, this is uncharted territory for resistance exercise. The few data existing on immune responses to high volumes of resistance exercise indicate only slight alterations in this physiological system. As with numerous other systems, immune responses to resistance exercise overtraining is a topic for further study.

Psychological responses

Psychological parameters may provide the most fruitful potential for the coach or athlete dealing with overtraining. It has been well established with endurance types of overtraining that mood disturbances occur, as reflected by the Profile of Mood States. High volumes of resistance exercise for a 1-week period (tripling of training volume) have also resulted in mood disturbances. In addition, there is some evidence to suggest athletes become more ego involved during this type of training (they become more focused on outcome rather than on effort and improvement). Whether this effect was because of the actual high-volume training regimen, or the living, coaching and training environment is not known. It has been well established both in the classroom and the sports setting that long-term enjoyment and progress is enhanced with a strong task orientation. Interestingly, anxiety levels were unaffected by the high volumes of resistance exercise. When high relative intensity overtraining was monitored, no changes in mood states were observed, although the instrument used may not have been sensitive enough to detect subtle, but important, changes. However, what was observed was a decrease in self-efficacy. The lifters became less and less confident in their lifting abilities even though the lifting task was constantly adjusted for their current strength levels. Such psychological alterations could have a profound effect on sporting performance, especially when combined with physiological maladaptations.

Overtraining conclusions

As can be readily seen, resistance exercise provides a very complex training scenario. Such complexity can easily translate into an inappropriate training regimen that can lead to overtraining in numerous ways. Essential to avoiding resistance exercise overtraining is a thorough understanding of the training stimulus and long-term resistance exercise prescription. Only through proper periodization can training be optimized and the risk of overtraining minimized. Although much further research on resistance exercise overtraining remains to be carried out, several important facts emerge. Resistance exercise overtraining is not identical to overtraining resulting from endurance activities. As the various physiological systems are stressed differently with resistance exercise, overtraining of this type is characterized by different physiological symptoms. Common to all overtraining scenarios, however, is the fact that performance is adversely affected, and recovery is a long-term process.

Age considerations

With athletes competing at both ends of the age continuum (e.g. Junior and Masters competitions) one must take the perspective that if an individual is capable of participating in sports competition, they are also capable of the supplementary training required to prepare safely for such competition (Fig. 6.11). The concept of 'playing yourself into shape' only leads to injury and less than optimal performance. Strength programmes can differ with respect to volume of exercise and intensity of exercise but should reflect the same process of exercise prescription for a well rounded but sport-specific programme to be used by the athlete.

Junior athletes

The early controversy about strength training surrounded the obvious question, 'Can young children really improve their muscular strength?' Initial studies in this area in the 1970s were unable to demonstrate strength gains in children after a resistance training programme, thus prompting many people to say that strength training is of little value to younger children. It is now known that the lack of strength improvements in various studies over the years may have been because of poorly designed resistance training programmes and/or poor experimental designs. Building upon previous scientific studies, all of the more recent investigations in the 1990s provide solid evidence showing muscular strength and power improvements are indeed possible in children, including prepubescents.

In some cases even muscle size has been shown to be improved in prepubescent boys, but typically the gains are mediated via neurological mechanisms in young children who are rapidly growing. The major difference between boys and girls is the maturation rate. Girls mature sooner than boys and, in fact, may be able physically to handle workouts better than boys at an earlier age. However, this has not been demonstrated. While the absolute gains in strength may be greater in boys during certain stages of growth and development, the relative gains in girls and women have been shown to be similar to boys and men. Girls and young women must carefully perform certain exercises, such as free weight bench press and incline press, so as not to injure breast tissue. Also, the possibility of difficulty of training during certain phases of the menstrual cycle exists but, as pointed out earlier, is highly individual. Nevertheless, few differences appear to exist in the training methods for boys and girls and men and women. Therefore, no special needs exist and any differences need to be accommodated within the individualization process for progression for a resistance training programme.

The difficulty of pinpointing certain age cut-off periods has been problematic because of maturation rates. Having the physical and psychological readiness to participate in a resistance training programme is a matter of individual maturity. Progression must be carefully graded and the toleration to exercise must be carefully monitored

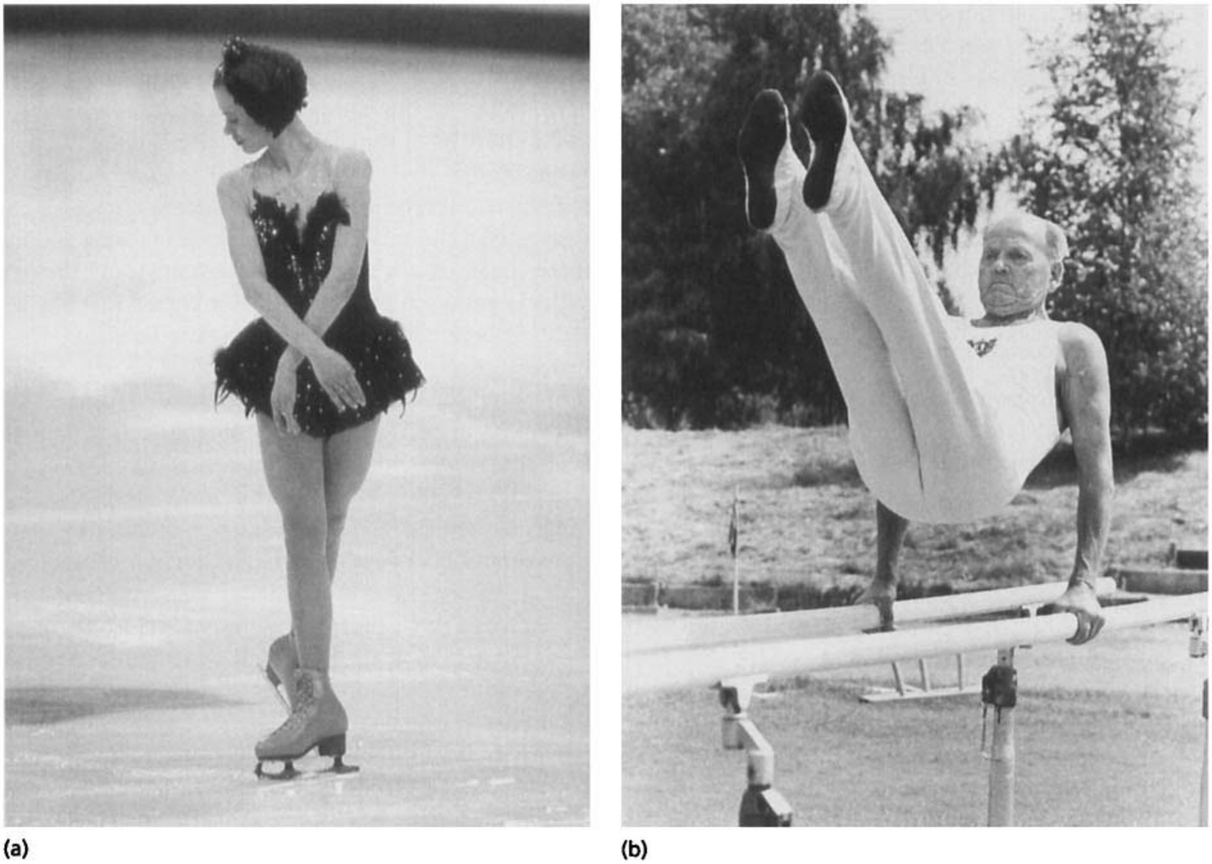


Fig. 6.11 (a) Age considerations in strength training are important for many young competitors in various sports such as figure skating. Photo © Allsport. (b) With masters athletes, care must be taken to provide for longer recovery periods from heavy lifting sessions.

over time. Table 6.3 gives a few basic guidelines for progression over the different ages of the child. The basic programmes target all the major muscle groups of the body (shoulders, chest, upper back, lower back, abdominals, front and back of upper arm, front and back of upper leg, calf, front and back of forearm, neck). The same body parts are trained each session and, initially, only one set is performed per exercise. In addition to multijoint exercises (e.g. squat, bench press), the programme also includes a number of single joint (isolation) exercises (e.g. arm curls, leg curls). Recent studies have shown that medicine ball power exercises are very effective in developing power in young athletes.

To date, many professionals are concerned when children use maximal or near maximal resistances (1–5-RM loads), yet no study beyond anecdotal evidence has shown why this is problematic. In fact, one may make the case that loads performed to failure at 6–10 RM may be more problematic as greater fatigue exists, and the potential for losing proper exercise technique or breaking form can result in injury. Ultimately, supervision and spotting are needed to limit or eliminate the injury potential in athletes of all ages. Years ago, the first response of many sports medicine professionals to the question as to whether children in sports should lift weights was to reply that it was unsafe to do so. Years later, after a

Table 6.3 Basic considerations for resistance exercise progression in children.

Age (years)	Considerations
7 or younger	Introduce the child to exercises with little or no weight, develop the concept of a training session, teach exercise techniques, keep total exercise volume low, include body weight, calisthenics and partner-resisted exercises, monitor exercise toleration of all workouts carefully, progress slowly
8–10	Gradually increase the number of weight training exercise choices, continue to stress exercise technique in all resistance exercises, introduce a few complex exercises, start gradual progressive loading of exercises, continue to monitor exercise toleration
11–13	Continue progressive loading of exercises, continue to teach more advanced exercise techniques, start using more complex manipulation of programme design, involvement in more of the goal setting, and development of the resistance training programme
14–15	Progress to more advanced youth programmes in sport-specific resistance exercise programmes, continue to emphasize exercise techniques, evaluate total stress of the competitive sport, and supporting strength and conditioning programmes
16 or older	Entry level into more adult-like resistance training programmes using heavier resistances, advanced workout designs only after enough background training experience has been gained

Note: If one enters an age level with no previous experience, progression must start at previous levels and move to the higher levels as exercise toleration, skill in exercise technique, and understanding of resistance training permits.

closer look at the situation and especially the young athlete, it is now apparent that this type of response was an overreaction based upon a certain degree of ignorance about what resistance training is all about. Furthermore, it was not consistent with the needs of young athletes for safe participation in sport and it did not reflect the actual risks involved in resistance training, which have been shown to be very low when supervised.

Masters athletes

A recent review concluded that masters athletes can train as hard as younger athletes using similar programmes but care is needed to compensate for differences in the recovery phenomenon. In addition, any inherent medical conditions (e.g. typically orthopaedic for older masters athletes) must be worked around with exercises to be used in a strength training programme. However, as resistance training is the most therapeutic of exercise modalities, one can view certain aspects of a programme as being rehabilitative in nature. The stress of the primary training modalities and sports competition need to be carefully monitored, especially in older age.

Compatibility of simultaneous strength and endurance training

The simultaneous training for both maximal force and aerobic endurance might compromise the development of strength and power. In 1980, it was demonstrated in a study by the late Robert Hickson and his colleagues at the University of Illinois–Chicago Circle that when an endurance programme was added to a strength training programme, 1-RM strength improvement was suppressed after about 2 months of training. This study demonstrated that the addition of an aerobic endurance training programme to a strength training programme contributed to at least a plateauing effect for strength. The physiological compatibility of simultaneous strength and endurance training has been a subject of great interest over the past 10 years. A variety of studies have demonstrated that strength can be either compromised or increased while no decreases in aerobic endurance capabilities have been observed.

The physiological mechanisms which may mediate such adaptational responses to simultaneous training remain unclear but the stimulus to the muscle fibre is one which is related to alterations in neural recruitment patterns and/or attenuation of muscle hypertrophy. Such physiological attenuation may, in fact, result in overtraining (decrease in performance). It is also possible that if simultaneous exercise training programmes are properly designed, it may just require a longer period of time for the strength and power to express itself because of the simultaneous development of several ultrastructure and enzymatic adaptations for multiple performance demands. Furthermore, the magnitude of the adaptation (e.g. amount of protein accretion in certain muscle fibres) may not be the same in a system (e.g. muscle) that is being trained by two high-intensity training programmes for both strength and endurance performed together. The key factor appears to be to prioritize training and not attempt to address both sports fitness parameters in the same training cycle. In addition, it had been previously demonstrated that simultaneous sprint and endurance training produced higher stress hormone responses of cortisol when compared to sprint or endurance training only. Here again, the need for training prioritization is suggested as a way to reduce stress. In one study (Callister *et al.* 1988) at Ohio University, it was shown that simultaneous sprint and endurance training impairs sprint speed and jump height power development. Thus, the interference of anaerobic training when high levels of aerobic training are undertaken appears consistent.

Unfortunately, most studies have utilized relatively untrained subjects to examine the physiological effects of simultaneous strength and endurance training. Few data are available regarding the effects of simultaneous strength and endurance training utilizing fit athletes who are able to tolerate much higher intensity exercise training programmes. Kraemer (1995) found that high-intensity interval and endurance training affected power performance and the rate of strength gain over 3 months. It had been previously observed for high-speed isokinetic torque production that power capabilities may be more susceptible to overtraining because of the addition of an intense supplementary endurance training programme. This may be caused by a wide variety of factors differentially related to neuromuscular function. Thus, it may be that power development is much more susceptible to the negative effects of combined strength and high-intensity endurance training programmes than slow velocity strength. It appears that it may be the extreme oxidative stress on the tissue even more than the modality that creates the alterations in the neuromuscular system counterproductive to power and high-speed development. In addition, this affects the adaptation of the muscle fibres.

Interestingly, in most studies maximal oxygen consumption improvements have not been shown to be affected by the simultaneous training. This was substantiated by almost identical improvements seen in maximum oxygen consumption tests and time trials for a 2-mile run. This suggests that even the inclusion of a strength training programme well beyond the type that might be used by almost all runners does not adversely affect the oxidative or running capabilities. Thus, no incompatibility has been apparent for the endurance runners adding a strength and power programme to their training. The use of a resistance training programme (more sport specific) by runners can help to offset the tremendous pounding on the lower body musculature, but also add in performance by improving the rate of force development (see Chapter 5).

Simultaneous training has been shown to either result in no changes or increases in Type I and II muscle fibre areas. Data support the concept that muscle fibre type area adaptations to simultaneous training differs from the single training mode adaptations. The fact that all muscle fibres hypertrophied when strength/power training is performed alone demonstrates that recruitment patterns followed typical size principle order with Type I fibres being recruited with this type of programme that included both hypertrophy and strength/power components. The lack of power development in the groups that simultaneously train appears to be a function of neural mechanisms or unknown changes in the Type IIA fibres, as power is typically related to motor units with the fast twitch fibre populations. Thus, changes in fibre populations are different with simultaneous training of both strength and endurance. Furthermore, because of overuse injury some resistance training might be warranted for runners as the reduction in Type I and IIC fibre sizes were not indicative of any advantage in maximal oxygen consumption or 2-mile performance times. The findings of size antagonism (no change in Type I fibre hypertrophy when both modes are performed) on the cellular level are unique, as Type I fibres are affected by both oxidative stress and high force recruitment stimuli. It appears the Type I and II muscle fibres are differentially responsible for the endurance and strength/power training adaptations in the simultaneous training programmes.

Incompatibility of training may be attributed to a large extent to the extreme stress of adrenal activation caused by the total amount of high intensity exercise. Whether or not successful adaptations can occur remains dependent upon the ability of various anabolic compensatory mechanisms (e.g. testosterone, insulin-like growth factors, growth hormone) eventually to override a catabolic environment.

Is incompatibility an overtraining phenomenon? It appears that the inappropriate use of supplementary training modes, such as endurance exercise, may have the potential to interfere with the most optimal adaptational response of a given system (e.g. neuromuscular system) for a specific performance variable. If performance becomes depressed or plateaus off well below expectations, it is possible that it is a result of a training error in the volume of supplementary exercise performed. At present, only endurance and strength training compatibility modes of exercise have been combined to examine simultaneous training.

Sports competition

Other factors, such as extreme volumes of physical competition, may contribute to an overtraining state in a matter of days. It has been observed that elite wrestlers tolerate a loss of 6% body mass and maintain performance. However, with 2 days of tournament wrestling they dramatically lose isometric force capabilities of the grip strength and upper body strength over those 2 days (unpublished data). Concomitantly, whole body power as measured via power production on a force plate makes no significant changes. Such observations indicate that athletes may make special adaptations to the rigours of their sport and then only certain performance characteristics may be susceptible to further physical and emotional stress of competition.

By being aware of the highly interactive environment of training and competition, remedies as simple as a few days of rest may prevent an overtraining problem. The importance of periodization of training and sport competition start to take on dramatic importance when one considers that intensity and volume of exercise and competition are two of the primary contributors to overtraining. Any programme variable has the potential to contribute to an overtraining state but can be periodized if there is awareness that it may pose a problem (e.g. rest period lengths between sets and exercises and acid–base toleration). We are far from understanding all of the biological bases of overtraining but clues as to what the factors and variables are in the configuration of a workout should help in the very careful detective work necessary to manipulate (overreaching) or prevent it. Incompatibility of multiple training modes may play one particular part in the overtraining phenomenon.

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Chapter 7

Medical aspects and administrative concerns in strength training

Introduction

This chapter comprises a basic overview of the administrative and medical aspects related to strength training. It has been shown that strength training is one of the safest physical activities that can be carried out. Paramount to this is the use of proper exercise technique, safe equipment, proper spotting and appropriate supervision. The optimal exercise stimulus must be created for the athlete in the training session. If administrative problems exist (e.g. not enough equipment, inappropriate equipment, too many athletes) the optimal programme cannot be performed as planned and a less than optimal exercise stimulus is created. The coach must also be aware of some of the fundamental aspects of the medical issues related to strength training. Only too often athletes train under less than optimal conditions and this affects the development of their full sporting potential. Limiting any negative impacts from administrative variables (e.g. space, equipment, time) will allow the programme to be implemented as designed.

Medical aspects of strength training

A preparticipation physical with a thorough musculoskeletal examination is warranted and prudent for any athlete prior to participation in a sport. A sports medicine team (medical support personnel, therapists and physicians) needs to monitor the health and injury status of the athlete.

Know if the athlete is injured

It is extremely important that the athlete's injury status is tracked carefully. The programme can only be modified to address a known injury. Athletes often injure themselves on the field, gym, court or in other recreational activities, and do not tell anyone because of fear of prejudice or losing a competitive advantage. They then go into the weight room and perform an exercise which demands an adequate function of the joint or muscle that is injured and it is only then that they complain about the injury. The response that the resistance exercise caused the injury is thus untrue, as the injury was caused outside the weight room and the athlete only gained first hand knowledge of its severity by challenging it with a resistance training exercise. Therefore, injury checks that are not threatening to the athlete and provide for individual feedback regarding the exercise programme need to be made frequently. Ideally, the injury status of each athlete is known before engaging in any aspect of a strength and conditioning programme. More detailed tracking of the source of injuries observed during or after a resistance training workout needs to be made by the sports medicine staff and coaches. The athletes need to feel free from any external pressures when discussing possible injuries and how the exercise programme can be modified to meet their needs.

Keep updated medical records

The medical records of the individual athlete need to be taken into consideration and medical guidance given, especially when an athlete is coping with a chronic disease such as diabetes, asthma or heart irregularity. Underlying disease states will, at times, dictate certain aspects of the exercise training programme. At the very least it is important to understand the physical and medical profile of the athletes involved in a resistance training programme so that preparation can be made for any rare medical emergencies that may occur. Sports medicine professionals need to respond rather than just react to the situation. Prior knowledge helps with this aspect of sports care. This concept also underscores the need for an emergency plan of action for the 'weight room' and at the sporting competition and training venues.

Common injuries and their treatment

Most injuries sustained in the weight room fall under the categories of dermatological (skin) and musculoskeletal (muscles, tendons, ligaments and possibly cartilage and/or bone).

Skin disorders

Skin disorders of the palms of the hands most commonly include calluses and friction blisters. A blister is a fluid-filled lesion, usually found on the hands, filled with clear or sometimes bloody fluid that results from the repetitive friction associated with grasping a bar, handle or dumb-bell while performing weight training repetitions. This is an acute injury that, although benign in nature, can interfere with the comfort and safety of training.

The best way to treat a small blister (< 5 mm diameter) is to pad or cushion it from further damage, with a sterile pad while the body resorbs the fluid naturally and heals the lesion. A larger blister (> 5 mm) may heal quicker and allow continued training comfort if one takes a small sewing needle, which has been sterilized by holding a match to the tip for a few seconds, and piercing the blister at its periphery so as to allow drainage of the fluid through the resulting small opening. The skin on the blister should not be removed as it serves as a 'natural bandage'. Padding in the form of a sterile pad, or gauze held in place with athletic tape, or the use of padded weightlifting gloves may help heal and prevent future blisters.

A callus is a circumscribed hyperkeratotic (heaped up skin cells) lesion usually found over the bony prominences of the palm (metacarpal heads). The natural history of an area on the hand which would otherwise form an acute blister is to become a callus if the friction and pressure is applied in short exposures with enough recovery in between workouts to allow the body to slowly build multiple layers of keratin (surface tissue cells of the skin). Calluses are the means the body has of hardening an area which requires additional protection from repeated friction. If calluses become too large they may cause pain because of the pressure they place on tissue (bones, tendons or nerves) beneath. If this happens, then gently rubbing with a pumice stone or shaving the calluses with a sharp blade will alleviate the problem. If the callus is soaked for a few minutes in warm water, the excess keratin will become visible by turning white. This also serves to soften the callus, so that rubbing or shaving is facilitated.

Occasionally, a blister may form underneath or even over a callus if the frictional forces are sufficiently acute. The treatment for this is the same as for a blister. A blister may sometimes become infected, especially if the skin over it is torn away. If this happens, the blister base will turn very red and sore, and ooze pustular (yellow) fluid which tends to crust. This condition needs medical attention.

Abrasions are also known as 'turf burn', 'rug burn' or 'strawberries.' These are a partial erosion of the epidermis caused by acute friction. A common abrasion occurs on the chin when the athlete performs overhead or military press if the knurled part of the bar contacts the chin during the lift. Another common situation is when the thigh is abraded during a pulling movement in the power clean or other pulling exercises, as proper technique requires movement of the bar as close to the body as possible.

Prevention of abrasions is easily accomplished by some preventive planning and protection of the area of skin in jeopardy with some form of cover. In some cases chalk is used to provide lubrication and reduce friction of the bar on the skin, but is not a deterrent as physical protection is minimal. Once the abrasion has formed, treatment is accomplished by washing the area gently with soap and water, applying a topical antibiotic ointment (e.g. bacitracin or mupirocin) and covering the abrasion with a non-adherent dressing to protect the wound.

Another common condition for athletes is dry skin or xerosis. Frequent showering and washing with soap eliminates the skin's vital oils (sebum) resulting in cracked skin with dry scales. The treatment is to decrease temporarily the number of repeated wetting and drying exposures and the use of soap. After bathing, while the skin is still moist, use emollients such as baby oil (greasy), Eucerin or Moisturel to help keep the skin from excessive dryness.

Acne is a common skin disorder found in athletes and is identified by comedones (blackheads) and red papules and pustules. It occurs most commonly on the face, neck, shoulders and chest. Acne is not caused by certain foods and lack of personal hygiene, but is a complex disorder caused by genetics and bacteria. Nor is it technically communicable to other individuals. While occurring most commonly during the teenage years, it can persist well into adulthood. Home treatment consists of washing the face gently with a mild soap, such as Dove, twice a day, followed by gentle drying of the face, and application of an over-the-counter keratolytic (keratin-removing) agent such as 5 or 10% benzoyl peroxide cream (e.g. PersaGel, Oxy5 or 10, Clearasil). If this does not control mild acne, then medical consultation should be sought, as the ultimate goal is to prevent the scarring of the skin that can occur with moderate to severe acne.

Folliculitis is a localized infection of the hair follicle which appears as a small pustule centred around the hair shaft. Although usually occurring on the arms and legs, it can occur almost anywhere there is hair on the body. *Staphylococcus aureus* is the causative organism and mild cases may be treated with gentle washing with soap and water followed by the application of a topical antibiotic ointment, such as bacitracin or mupiracin. It is technically a communicable condition, but is not likely to be transmitted unless prolonged skin contact between individuals (not likely in the weight room) such as wrestling occurs. If the condition is not controlled by simple measures or becomes more widespread, then medical attention should be sought.

Musculoskeletal injuries

Although contusions (bruises) are possible if weights are dropped on muscle, tendon or bone, the most common acute weight room injuries are sprains and strains. By definition, sprains affect ligaments, while tendons and muscles sustain strains. If the strain is significant enough and/or repetitive then tendonitis or myositis (inflammation of tendon or muscle, respectively) may develop.

Ligamentous sprains are distinctly uncommon in the weight room because body positions and resistances are generally manipulated in controlled intentional fashion. In fact, strains are much more commonly sustained during unintentional falls or during competitive sports activity.

Strains of tendons and muscles, on the other hand may be common if the athlete is extending his or her limit in the weight room. Commonly strained muscles or tendons include bicipital (biceps), triceps, flexor muscles of the wrist, rotator cuff (four muscles and associated tendons of the shoulder), neck, rhomboid major and minor (upper back muscles which stabilize the scapula), low back, hamstrings, patella (quadriceps) and calf.

Strains are acute injuries which are noticed at the time of injury; soreness, swelling and stiffness resulting from inflammation are generally present. Depending on the severity of the strain, a day of rest may suffice or, in the case of severe strains, several weeks of recovery may be required prior to resumption of maximum effort lifts. Immediate use of ice to the strain, preferably as a slurry of ice and water—ice alone has poor contact area with injured tissue—in a zip-lock plastic food bag applied for 10–15 min may be effective in limiting the extent of the injury. Ice may be applied for pain and inflammation management several times a day if required. Using ice for longer periods of time is no more effective and may, in rare cases, cause frostbite. The use of ice for several days after an injury is recommended. Once the injury is clearly healing appropriately, heat may actually be a preferred modality because heat increases blood flow to the injured tissue and thereby improves delivery of healing resources to the tissue and carries detritus away. During the acute early phase of an injury, increasing blood flow by the use of heat may be counterproductive because inflammation and swelling will increase.

The early use of an anti-inflammatory medication (e.g. aspirin, ibuprofen or naproxen), may help with mild discomfort and decrease a 6 out of 10 pain to 4.5 by blunting the sharpness. However, there is no evidence that anti-inflammatory agents hasten the speed of recovery. In fact, it may be argued that by slightly blunting the pain, an athlete may use the injured tissue more than is advisable and forestall expedient tissue healing. Beyond this, gentle range of motion involving the affected tissues—by contracting, relaxing and stretching—may help the tissue to recover function more expeditiously. Gentle massage may also be of benefit because, in the same way as heat, increased blood flow may hasten healing.

If first aid measures of apparent mild strains to muscles and/or tendons do not seem to be effective in the first few days following injury, then it is advisable to seek medical attention for a more complete evaluation.

Recommendations for the over-40 (masters) athlete

It is generally accepted that ageing has a negative effect on the ability of an athlete to tolerate and recover from difficult training. Intuitively, this makes sense, and anecdotal as well as empirical evidence seems to support this assumption.

There are situations where a masters athlete may be performing at the level of an athlete 10–20 years younger, and may even be engaging in training of similar intensity and volume, with commensurate recovery. However, this is likely to be the exception rather than the rule. The issue may well be one of performance capacity rather than age *per se*, i.e. as performance capacity degrades by virtue of diminished training or increasing age, the ability of tissue to recover sufficiently prior to a repeat training exposure is reduced.

Whatever the aetiology, it is well established that strength and power diminish as a function of age. It therefore seems prudent to allow more recovery time between exercise exposures. The precise amount of additional recovery cannot be specified because every athlete is different. It may benefit the masters athlete to experiment with differing recovery periods in his or her workout routine to discover the optimal amount.

The corollary to diminished recovery capacity may be that masters athletes are also more likely to be injured. Again, this is a generalization which may apply to the majority but not necessarily to all masters. Therefore, it may be of benefit to consider a reduction in total volume of work, although the intensity of the workload need not necessarily be reduced. This will decrease the probability of injury, while also enhancing recovery capacity. It has been established with modern training technology that it is the 'quality' of the training sessions that is more important than 'quantity' of total work for performance related gains.

Beyond total volume reduction and increased recovery periods, there is probably little that the masters athlete needs adjust with respect to his or her training routine as a pure function of age. Individual responses to training must always take precedence over a blanket recommendation or cookbook formula for training. With keen attentiveness to training and recovery response, and resultant flexibility in the implementation of the training programme, masters athletes need not compromise the quality of their programmes or the achievement of superb results.

Medical clearance

The American College of Sports Medicine (ACSM) recommends that anyone over the age of 35, who is starting a rigorous exercise programme, should receive a medical examination and clearance first. This recommendation is a very conservative one. In general, for a typical individual of any age or sex who has no identified heart disease, severe blood pressure uncontrolled by therapy (> 180/105 mmHg), Type 1 diabetes (insulin-dependent), or musculoskeletal disabilities which preclude normal range of motion for anticipated strength exercises, a specific physician-performed preparticipation examination is not essential. If pre-existing heart disease, uncontrolled blood pressure, insulin-dependent diabetes or significant musculoskeletal limitations are present, then a physical examination by a physician with recommendations and treatment initiated for the health issues of concern prior to the institution of a strength training programme is advised. It should be ensured that the athlete has a good musculoskeletal examination as a component of any preparticipation physical examination.

Some myths of strength training related to medical issues

There are many myths associated with strength training. A few of the most significant ones still impact the effectiveness of a strength training programme for athletes. Fears of medical problems are related to the development of these myths.

Squat exercises

One of the most enduring myths of strength training is the danger of squats or deep knee bends on the integrity of the knee. There is no convincing evidence that squats are injurious to the knee. One suspects that this impression derives from power athletes who, by the nature of competition, are performing at the physical limits of their tissue, and injure themselves performing 1-RM squats. The available studies show no relationship between squats and ligamentous laxity of the knee or increases in knee susceptibility to injury. To the contrary, strength training which includes the knee tissue (cartilage, ligaments) should reduce the likelihood of injury and, if anything, reduce laxity in the knee joint because of preservation of tissue elasticity and strength. The key is proper exercise technique.

As athletes grow older, performing a squat exercise movement with one's body weight can help in the development of functional abilities that are keys to physical fitness. The use of squats with one's body weight as the resistance mimics many activities which are performed throughout life during the course of everyday activities.

Low back pain: the curse of insufficient strength

An issue of considerable importance for the masters athletes—or for anyone—which requires debunking is that of back strength training for the prevention or treatment of low back pain (LBP). LBP is pervasive and accounts for many lost days training. The irony is that much of LBP is preventable and can represent detraining or lack of sufficient tissue-specific strength for the demand placed upon the back.

There is much misunderstanding about back strengthening. Even in the US military forces, a group that a priori would be expected to have a greater degree of fitness and thus fewer fitness-associated problems, LBP is as prevalent as in the non-military population. In fact, the rest or reduction in activity and demand usually prescribed for LBP causes the back tissues to detrain. Furthermore, once an athlete injures his or her back there is a tendency to avoid activities which involve the back entirely. This avoidance, in the long run makes LBP development and maintenance an even greater likelihood. As the principal issue surrounding LBP is lack of strength for the activity required of the back tissues, the only intervention that will strengthen the tissues of the back and make them more injury resistant or to facilitate healing of injured low back tissue is strength training.

Abdominal training can augment back health. This is best performed in a manner that at least minimizes the compressive forces on the intervertebral cartilaginous discs. Abdominal crunches with the knee and hip joints at approximately 90° angles can be recommended. This position is attained by lying on the back and placing the soles of the feet on the wall in front and then adjusting knees and hips to the proper angles. The second recommended abdominal exercise is the L-seat of gymnastics. This is an advanced exercise requiring hamstring flexibility as well as considerable pre-existing abdominal strength to perform properly. Most athletes will require elevated and, preferably, padded parallel bars to perform this exercise, and will benefit from a training partner who can, if necessary, assist the individual in raising their legs (locked at the knee) to the L position and then lowering them back down. The eccentric or negative aspect of this particular exercise is extremely effective if performed with good form and under control. Finally, obliques may be worked in many different fashions: lying sideways on a roman chair device; a rotary torso machine; or lying sideways on an inclined sit-up board (or even a flat mat, but the range of motion will be reduced).

For athletes with pre-existing LBP from injury or disuse, medical concerns about aggravating pre-existing pain often preclude any activity employing the back. For athletes in rehabilitation it is a good idea to consult with a physician knowledgeable in the use of strength training for the rehabilitation of LBP. Many physiatrists (physical medicine physicians) and physical therapists are especially effective in this area of rehabilitation. It is important to confirm that the therapist understands and endorses the use of strength training as an effective tool for back training. If the therapist does not believe in strength training, he or she certainly will not prescribe a programme that includes it.

Administrative considerations

While a full overview of weight room management and care is beyond the scope of this handbook, it is important that the sports medicine professional and coach understand that without a proper weight training facility the effectiveness of the training programme is limited. Weight room design, equipment and capabilities continue to improve and are as important in their preparation as any other piece of equipment in the sporting environment.

The administrative responsibility for running a weight room has become more dramatic over the past 10 years with the greater number of equipment options, higher number of athletes to train and safety issues, which in many countries have legal implications for practice. The primary responsibility of the professional responsible for this aspect of the programme is the care of the facility and the implementation of the resistance training programme for athletes. Each athlete needs individualized attention in today's advanced training using modern technology but coaches need to have a fundamental background in basic exercises, such as power clean, in order to use what lifts are needed for any given situation based on the needs analysis (Fig. 7.1).

After the coach has designed the optimal individualized sport-specific programme for an athlete, he or she must be able to administer it effectively and efficiently to an entire team or teams. This becomes more challenging when larger teams of athletes need to be trained in the same conditioning facility. Time management without limiting the effectiveness of the training programme becomes a primary concern. Administrative considerations that limit the implementation of the programme design should be carefully addressed in future planning. Equipment and space are the most pressing problems in most training facilities examining elite athletes. The major administrative concerns are:

- availability of equipment;
- availability of competent coaches/trainers;
- number of athletes;
- availability of space; and
- availability of time.

Availability of equipment

With the type of equipment available to create a specific type of external resistance, ranging from a standard barbell to new computerized resistance machines, we are entering a new age of equipment design, equipment diversity and equipment options. With over 140 equipment companies selling various types of weight training equipment the diversity of training tools for the strength and conditioning coach is greater than ever. The sports medicine professional needs to be able to evaluate the equipment capabilities independently of the marketing claims made by the company. More equipment diversity allows a greater number of options for individualizing the exercise stimuli in the attempt to optimize the training effects for the athlete. The addition of more and more equipment can also result in space problems. More options in the choice of exercise may enhance the potential of the training technology used for a given athlete or sport (e.g. eccentric loading machine for training downhill skiers).

Fig. 7.1 Calluses are the body's way of hardening an area, such as the hands, that is continually used in a lifting movement. Photo © IOC/Olympic Museum Collections.

As computers start to be integrated into the process of the loading of muscle, more specialized exercise protocols will be realized but whether such technology will replace the barbell remains to be seen. Although sophisticated equipment is not necessary to develop a resistance training programme, the proper development of weight room equipment allows more diversity and programme options when designing a resistance training programme. Weight training equipment represents the 'tools' available in the conditioning of different aspects of human performance. Nevertheless, equipment availability and quality of the weight room is often a problem for coaches and trainers who must train large and/or diverse groups of athletes. The development of the type of resistance training facility is related to the variety of exercise programmes which need to be implemented.

In general, exercises are performed using free weights, machines or other equipment configurations (e.g. rubber bands, slides, medicine balls). It is important to understand that many machines are built to fit the average man so younger athletes (e.g. divers, gymnasts, figure skaters), some women, and athletes of either small or very large stature may find it difficult to position themselves properly on many machines and other pieces of equipment which fix a person into a specific position. Improper positioning may not allow proper exercise technique, full range of exercise motion, proper resistance applications and could result in various types of overuse injury (e.g. microstops causing microtrauma). If alterations, such as the use of a seat pad or back pad, are made to a machine to allow proper fit or positioning, make sure the adjustment is solid (e.g. pad or support does not slide or move) and capable of withstanding the stress of lifting activity associated with the loads used. Any makeshift changes made to equipment must be performed carefully and must not compromise the safety of the athlete. Many free weight exercises require more time to learn proper exercise technique than many exercises performed on machines. However, if an individual can grasp and hold a dumb-bell or barbell, it fits them, and so proper fit when using free weights is not a major administrative concern.

Knowledge of the characteristics of each piece of equipment must be carefully studied and understood in order to optimize the strengths and minimize the weakness of each piece of equipment used. Understanding the type of strength curve that characterizes each movement in an exercise programme is important in order to match it with various types of equipment. For example, rubber cords, which fit all body sizes, can only produce an ascending strength curve as rubber-type materials provide more resistance as they are stretched. Movements with other than an ascending strength curve (e.g. bicep curls, as elbow flexion represents a bell-shaped curve) will not be optimally trained when using rubber cords. The specific exercise movements to be trained must be matched with the characteristics of the equipment available.

If the equipment available is minimal, viable substitutes must be found; it is possible to make some equipment. However, safety must never be compromised when developing makeshift equipment (e.g. barbells made of rods and cement-filled cans). It is possible to substitute other forms of exercise, such as plyometrics, paired partner exercises, dynamic drills (e.g. stair running), in situations where no resistance training equipment is available to address certain aspects of training. Nevertheless, these are only temporary solutions until the optimal training equipment can be obtained. This becomes more important as the level of specialized physical development for the athlete becomes paramount for success on the elite level of competition.

Availability of competent coaches and trainers

The availability of a highly motivated, scientifically based and professional group of strength and conditioning coaches is vital to the success of any programme. More than ever, the development of strength and conditioning coaches who use the body of scientific literature for the basis of practising the profession is becoming more important to develop professionals. With the many 'philosophies and mythologies' associated with strength training, the profession requires those who can use sound scientific principles and rationales for the decision making process in programme development, design and implementation. Often, not enough strength and conditioning coaches are available to work with large numbers of athletes and this limits the individualization necessary for programmes related to sport performance. Coaches need to be versed in all of the fundamental knowledge bases in exercise and sports science and have a fundamental knowledge of sports medicine as it applies to strength training. In addition, an open mind and the ability to practise the profession using a 'scientific approach' will be paramount as technology and research progresses.

Organizing the number of athletes training (Fig. 7.2)

Too many athletes in a training facility can reduce the capacity for optimal training. Better organization and flow patterns need to be employed if such space limitations exist. Knowing the time preferences, daily schedules and practice demands for all of the athletes who use the facility will help develop more effective schedules for the facility. When trying to train different athletes or teams with different programmes care must be taken to crossmatch the equipment and time demands of the workout. Examination of the different programmes to be conducted in the facility helps in this organizational effort. This information is used to adjust the exercise order of the various training programmes in order to eliminate lines of people waiting to use the equipment. This is especially important when timed exercise workouts (e.g. 1-min rest periods) are critical to the effectiveness of the exercise stimulus (e.g. training acid–base toleration with short rest programmes for wrestlers or 400-m sprinters). Efficient patterns of movement are accomplished by workout cards which dictate the exercises and sequence of movements to be used. Free times in the weight room can be used but this should be used for workouts that are not dependent upon timed exercise workouts. Proper sequence of exercise and adherence to rest periods in designed workouts are vital to implementation of an effective training stimulus.

The amount of training time available can cause problems if the designed training programmes do not match the projected training time that is available. The length of a training session, including rest periods, should be calculated immediately after the session is planned. Too often 'quick fixes', such as the sole use of low-volume programmes or limiting the number of training days per week to the level of 'maintenance' training, are an ineffective response to optimizing time management of athletes. Large muscle group exercises and short rest periods are acute variable choices which can provide time economy, but should only be prescribed in appropriate situations. If necessary, only the fewest number of small muscle group exercises should be eliminated to allow the training session to fit into the available time. In addition, the exercises eliminated should be the least important exercises needed to achieve the goals of the programme. Short rest periods (< 1 min)

Fig. 7.2 Suitable space in the weight room must be provided for structural lifts on a platform. Photo © IOC/Olympic Museum Collections.

should only be used when higher blood lactate levels are desired and the trainee has the fitness level to tolerate these. It is important not to compromise training programme symmetry which addresses each side of a joint, upper and lower body musculature, and structural whole body exercise movements.

Proper spotting technique (Fig. 7.3)

It has been shown that a training partner is vital to the training success of the athlete. A training partner who is knowledgeable about exercise technique and spotting for each exercise is vital for a safe weight room environment. Even machine exercises can benefit from proper spotting on exercise technique. Injuries are low with resistance training but are a result of accidents (e.g. dropping a plate on your foot) and exercise technique breakdown resulting in muscle strains or pulls. Of paramount importance is the use of proper spotting technique for each exercise so that a safe resistance training programme can be implemented. A basic checklist for spotters is as follows:

Fig. 7.3 Proper spotting is needed for optimal safety in the weight room. Photo © IOC/Olympic Museum Collections.

- Ask how many repetitions the athlete will attempt.
- Know the proper exercise technique being performed by the athlete.
- Understand the performance characteristics of the equipment used.
- Know the proper spotting technique for the exercise.
- Be sure the spotter(s) is strong enough to assist the lifter with the resistance being used.
- Be attentive to the lifter at all times.
- Stop the lifter if exercise technique is incorrect.
- Do you know what to do if a serious injury occurs? Is there a standard weight room plan?
- No fooling around or joking, as this is important business.

The goal of correct spotting is to prevent injury. In addition, an effective training partner can help motivate the athlete during demanding workouts. An athlete should always have access to a spotter in the weight training facility.

Spotting and exercise technique practice

When teaching a new exercise, demonstrate proper exercise and spotting techniques and discuss the major points of the techniques. Then allow each trainee to try the exercise with a light resistance, such as a barbell or dumb-bell with no weight plates on it, or even a broomstick. For an exercise performed with a machine, using a light resistance may mean removing all weight from the machine or taking the pin out of the weight stack. After the athlete attempts to perform the exercise, point out any flaws in technique. Then continue further technique practice with light resistances; this will minimize the effects of fatigue during the learning stage. The athletes should also demonstrate and practise proper spotting techniques for each of the exercises used in a programme.

More time will usually be needed to teach proper exercise and spotting techniques for free weight exercises than for most machine exercises. This is because free weights require the lifter to balance the resistance in all directions (left, right, forward, backward, up, down). Most machines 'groove' the exercises into one plane of movement and require little if any balancing. This fixed movement pattern is one of the strengths of a machine and can also be one of its weaknesses. Additional time may also be needed to teach proper exercise techniques for multijoint exercises, such as squats, because coordination of movement at several joints is needed.

Attempting to teach techniques for too many exercises at once, especially multijoint exercises (e.g. power clean), will slow down the learning process. How many exercise techniques a person can learn at one time will vary. A general guideline is seven or eight exercises, of which one to three can be multijoint exercises.

Mistakes in the weight room that can increase the probability of injury are related to the following:

- The lifter attempts to lift too much weight.
- The lifter uses improper lifting technique.
- The lifter improperly places feet or hands on a resistance training machine so they slide off the pedals or handles.
- Placing hands on the pulley system of a resistance training machine.
- Placing hands between the weight stack of a resistance training machine.
- Spotters are inattentive.
- There is improper behaviour in the facility.
- A bench or piece of equipment slides during the exercise.
- Worn out equipment breaks during lifting (e.g. machine cables or pulleys).
- Not using collars on free weights.
- Accidentally dropping free weight plates while loading or unloading a bar.

Even though injuries are rare, a resistance training facility should have an emergency plan to deal with a serious injury requiring medical attention. The plan should be posted in the weight room, and all supervisors should be familiar with it. An emergency plan might include the following information:

- Phone number of the nearest ambulance service and/or hospital.
- Location of the nearest hospital or emergency room.
- Training facility address and any pertinent information emergency personnel need to locate the weight room.
- Alphabetical card catalogue of athletes' home and business phone numbers and addresses.

A phone should be located in the weight room. Supervisors should know the location of the nearest phone. In addition, all supervisors should have basic first aid and cardiopulmonary resuscitation skills.

The prescription of resistance training is both a science and an art. Ultimately, individualized programmes provide for the most optimal changes in the exercise prescription process. This results in the best overall training response for the individual. A paradigm for exercise prescription has been developed and presented in this textbook and provides the framework for optimal design of resistance training programmes. While guidelines can be given, the art of designing effective resistance training programmes comes from logical exercise prescription followed by evaluation and testing, and interaction with the trainee. Prescription of resistance training is a dynamic process which requires the strength and conditioning coach to respond to the changing levels of adaptations and functional capacities of the trainee with altered programme designs to meet the changing training goals.

Equipment maintenance

Resistance training equipment is very durable; however, some preventative maintenance of equipment will increase its life and is necessary for its safe operation. This is true whether the equipment is in a health club, school weight room or in a home setting. Welds on equipment should be inspected for cracks and bolts checked for tightness at least weekly. A cracked weld or loose bolt can easily be the cause of an injury.

Resistance training equipment is made out of metal and excessive moisture causes metal to rust. One frequently overlooked aspect of preventative maintenance is to have adequate air circulation in the training facility so that excessive moisture is not a problem. The simplest and easiest ways to ensure adequate air ventilation is to keep doors and windows open and to use fans when and where possible. An air conditioner or dehumidifier should be installed in the facility if necessary to keep the moisture level down. If rust develops on a piece of equipment, naval jelly should be used to remove it immediately and the rust spot touched up with a rust-resistant paint. Keeping the moisture level low in the facility will help maintain the appearance of the equipment by preventing rust and add to its life expectancy.

Lubrication of equipment

Resistance training equipment has many moving parts which need to be lubricated to operate smoothly and to prevent wear. A spray-on silicone lubricant is best for most lubrication needs. Chains should be lubricated and cleaned regularly to ensure their smooth operation. Weight stack rods need to be cleaned and lubricated weekly when in heavy use so that the weight plates slide freely and smoothly. Fine steel wool is effective for removing dirt from weight stack rods. In addition, the bushings in weight stack plates need to be inspected for wear and smooth operation and replaced if necessary to prevent damage to the weight stack rods.

Cables and pulleys

Many pieces of equipment have a cable and pulley or a chain and pulley arrangement which can become worn. They should be inspected regularly to ensure they are aligned properly and that they are operating smoothly. The bearings of the pulley need to be lubricated regularly. The pulley should also be checked for side to side wobble and tightened if necessary. A pulley and cable or chain that is not operating smoothly will wear out very quickly. For safety reasons worn cables, chains and pulleys should be replaced.

Weight plates

Free weight plates and weight plates in a weight stack on a machine crack and break occasionally. The most common cause of this is dropping of the resistance after completion of a repetition. Dropping of free weights should not be allowed and neither should excessive 'banging' of plates of a weight stack during performance of exercises. Welding of weight plates after they are cracked or broken is possible, but is difficult because of the high graphite content of many weight plates. In most instances, welding of weight plates does not last and therefore it is normally best to retire the broken plate and replace it. For exercises (e.g. deadlift, high pulls) in which the plates commonly hit the ground, rubberized type 'bumper plates' can be bought but are more expensive.

Olympic bars

Olympic bars are barbells, 218 cm in length, used for Olympic and power lifting. They have revolving sleeves on each end that allows the weights to rotate during a lift. This allows the bar to revolve during the lift and prevents ripping skin off the hands of the lifter. Olympic bars are very durable, but a few problems can develop. The bar may become bent. This can be a result of having the supports holding the bar very close together and loading the bar heavily. This can happen especially if the bar is left loaded overnight or between training sessions. Therefore, the bar should be unloaded when it is not in use. The revolving sleeves on Olympic bars at times become loose and normally this can be remedied by tightening the Allen screw at the end of the sleeve. The sleeves should also be regularly lubricated with a light lubricant. After lubrication the sleeves should be wiped clean and care must be taken because, if lubricant is on the outside of the weight, plates will easily slide off of the bar. This is one reason that the use of collars on all free weight bars should be mandatory. Olympic bars come in a wide price range and it is typically the less expensive bars that develop problems. Therefore, when obtaining Olympic bars make sure they are of quality construction and have good tensile strength.

Upholstery

Keeping the surfaces of the weight training equipment clean is paramount for a clean environment. The benches and seats of resistance training equipment are covered with vinyl or Naugahyde. Disinfectants used to remove moisture, sweat and dirt from these coverings over time will cause it to crack. Therefore, regular cleaning with a strong disinfectant should be followed by a mild soapy rinse. A vinyl restorant product should also be applied to these surfaces regularly. To help prevent the build-up of dirt on these surfaces, clean clothing should be mandatory in the facility and a shirt should be worn when in the facility. In addition, towels should be used by the lifters to wipe off sweat after they have finished with a piece of equipment. If the vinyl or Naugahyde becomes excessively cracked or ripped, it can be replaced. Most equipment companies sell replacement pads for their equipment. However, it is often also possible to have a local upholsterer re-cover the pad.

Floor protection

If possible, a dark rubberized flooring should be installed throughout the facility. Rubber mats should be placed where weight plates will most likely be placed on the floor or dropped. This is especially true in the area where such lifts as power cleans will be performed. Typically, lifting platforms are placed in the areas where power cleans and variations of the Olympic lifts are performed. An official Olympic lifting platform is 4 m square. It is constructed of wood and is designed to protect the floor if the barbell is dropped.

Resistance facility tool kit

The most frequently needed tools to make simple repairs to equipment should be kept in the facility. A training facility tool kit should include the following:
- complete set of Allen wrenches;
- Phillips and regular head set of screwdrivers;
- files for smoothing rough spots on equipment;
- staple gun;
- complete socket set;
- paint touch up equipment;
- bolt cutters;
- measuring tape;
- light spray silicone lubricant;
- naval jelly;
- strong disinfectant, rubber gloves, mild soap, vinyl restorer, sponge and bucket to clean upholstery.

Resistance training accessories

The three most commonly used resistance training accessories are a weight training belt, gloves and shoes. Although all three do offer some positive aspects they are not absolutely necessary for a safe and effective resistance training programme.

WEIGHT TRAINING BELT

A weight training belt is designed to help support the lower back. Although weight training belts come in many sizes, a belt small enough to fit small children is not made. Use of a belt is not necessary when performing resistance training exercises; it is merely an aid to counteract a lack of strong abdominal and lower back musculature. Weight training belts do help support the lower spine but not from the back as is commonly thought. The belt gives the abdominal muscles an object to push against, allowing the build up of pressure in the abdomen which pushes against the lower spine from the front. In fact, the wide part of the belt would be best served by being in front of the abdominals. Many weightlifters do not use a belt as they want to develop the strength of the musculature alone. Belts should never be tightened except for heavy lifts during a training session (e.g. 3 RM and lower). Athletes often wear them for style and looks rather than functional needs.

Wearing a tightly cinched belt during activity causes a higher blood pressure than if the activity were performed without a belt. This makes the pumping of blood by the heart more difficult and may cause undue cardiovascular stress. Wearing a belt during resistance exercises where the lower back is not heavily involved is not recommended but can be permitted during lifts involving the lower back. However, it should not be used to alleviate technique problems in an exercise because of weak lower back and abdominal muscles. Assistance exercises to strengthen the abdominal and lower back muscles should be a part of all training programmes. This helps eliminate chronic weakness of these areas which can lead to poor exercise technique. In addition, strong abdominals and lower back musculature can help in injury prevention to the lower back during all physical activity.

WEIGHT TRAINING GLOVES

Gloves are available that are specially designed for resistance training. These gloves do not cover the fingers, but only the palms of the hands. They offer some protection for the palms from the knurling on many barbells, dumb-bells and handles of resistance training equipment. The protection that gloves offer may help prevent the formation of blisters or the ripping of callouses on the hands. However, they are not absolutely necessary for the safe performance of resistance training.

WEIGHT TRAINING SHOES

Weight training shoes are mainly designed to give good arch support, a tight fit so the foot does not slide around inside the shoe and a non-slip surface on the sole to prevent slipping while lifting. Weight training shoes offer little or no shock absorbance in the sole of the shoes, thus any force or power developed by extending the leg or hip is not used to compress the sole of the shoe and is available to lift the weight in such exercises as the squat or clean. A shoe with a non-slip surface on the sole and good arch support should be worn during resistance training but it does not have to be a shoe specifically designed for power or Olympic type weightlifting.

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