Third Edition

# SCIENCE AND PRACTICE OF STRENGTH TRAINING

Vladimir M. Zatsiorsky
William J. Kraemer
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# Science and Practice of Strength Training


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To my grandchildren—Anastasiya, James, Yana,
Ellen, Irene, and Jaclyn—with love.

V.M.Z.

To my wife, Joan; my son, Daniel, and his wife, Amie; my daughters,
Anna and Maria; and my granddaughters, Olivia and Catherine:
Thank you for your love and support.

W.J.K.

I dedicate this text to the loves of my life—my wife, Mary,
and my children, Jared and Lindsey. Their undying and unconditional
love, and their appreciation of my passions and my career,
are a precious part of my life. Thank you!

A.C.F.

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# Contents

# Foreword

The third edition of *Science and Practice of Strength Training* was written by three authors who are internationally recognized as scientists and experts in the field of strength training. All are high-level scientific investigators and have a long history of practice in the field of strength training. Dr. Zatsiorsky has enormous experience in strength training from the former Soviet Union and Eastern Bloc countries. Professors Kraemer and Fry have vast experience and offer the American perspective on strength training. The text in this book is written in a unique and understandable manner, presenting the current knowledge of strength training and conditioning. Each of the authors has vast experience in teaching at universities, giving presentations at several international congresses, and leading seminars on the theory and practice of strength training. Such backgrounds have also enabled them to exchange information and new ideas in the field of strength training. The authors have an extensive collection of publications in the field as researchers in strength training. In addition, they also have vast experience as coaches and practitioners. Therefore, the text in the book represents a unique way to use science in designing successful strength training programs for various purposes. Consequently, it provides the reader with beneficial tools for developing strength training programs.

This book is for serious strength coaches, athletes, and fitness enthusiasts who desire to create individualized strength training programs to lead to successful gains in strength, power, fitness, and selective performance characteristics. This book is not for those individuals who look for a shortcut approach to strength training (such as one with an exact number of reps per set or one that says this exercise is better than that exercise). This book *does* cover all the aspects needed in the field of strength training: basic concepts of training theory; task- and athlete-specific strength; velocity and exercises in strength training; monitoring strength training; goal-specific strength training; program design; periodization; overtraining and recovery; specificity of exercises; and strength training for men and women, youth, and older athletes. You may have limited experience or more experience in the field of strength training. Either way, you will find provocative concepts that will affect your ideas on how to create and plan more challenging and specific strength training programs. I can highly recommend this book to all people who are seriously interested in strength conditioning, to get new ideas and to improve their knowledge as well as to work successfully in practice.

Professor Keijo Häkkinen, PhD
University of Jyväskylä, Finland

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# Preface

The field of strength training has continued to advance, yet the fundamental principles that govern the development of strength remain constant. With the past, present, and future considered, we are excited to present this third edition of *Science and Practice of Strength Training.* Dr. Zatsiorsky and Dr. Kraemer were colleagues for almost 10 years at The Pennsylvania State University. Our collaboration as authors continues into this third edition due to an ongoing mutual interest in and passion for the topic of strength training. To address the continued dimensionality of strength training, we are honored to bring on Dr. Andrew Fry as a coauthor for this edition. Dr. Fry was a doctoral student of Dr. Kraemer's at Penn State and has continued his impressive scientific career in the study of strength training research over the past 27 years.

Just as the second edition built on the first edition, we have continued this approach by expanding on the concepts and complexities of how to develop strength and power to optimize the development of athletes and fitness enthusiasts of all ages. In addition to updated information, this revised text includes new chapters on training velocity in the weight room, overreaching and overtraining, and monitoring athletes in the weight room to better assess progress and effectiveness of the programs used.

The textbook has been developed from our vast experience in the field and contains documented experiences of more than 1,000 elite athletes, including Olympic, world, continental, and national champions and record holders. Dr. Kraemer also brings coaching experience from junior high school through college levels. His work on training studies with collegiate and professional athletes brings an additional dimension to the textbook that expands its conceptual relevance. Dr. Fry has studied strength training for decades with a particular interest in overtraining; his work with high school, college, and national and international athletes in the weight room parallels his molecular and cellular work on muscle, allowing him to make valuable connections between the lab and weight room programming.

*Science and Practice of Strength Training* is for readers who are interested in muscular strength and ways to enhance their development. Thus, it is for coaches, students who plan to become coaches, and athletes who want to be self-coaches. It is designed for serious readers who are willing not only to remember and repeat the information but also to understand it and put it to use. Over the years, coaches and athletes have asked each of us for the best exercise, method, or training program to develop strength. Answers to such questions are complicated, because no single program works for all athletes at all times or under all conditions. The individual needs of each athlete vary, and what works at one point in time may not work at another time. The best programs are those that are based on solid principles and concepts with the understanding that change is inevitable.

This textbook is written for the practitioner, and thus we provide a straightforward examination of the concepts and principles needed to make decisions on appropriate program design for athletes. While many try to oversimplify the topic of strength training, it is, by nature, complex yet understandable. Many aspects of the book address this complexity while providing straightforward approaches for specific circumstances. We offer program examples to demonstrate some of the principles and concepts discussed in the book; however, it is not meant to be a recipe book, because such an approach is fraught with pitfalls.

Strength training research has been growing dramatically each year and gives further credibility to concepts that were for many years only anecdotal. Despite that, the design and practice of strength training programs will never solely be the result of following the step-by-step processes found in scientific studies. Instead, it is the combination of solid principles, practical insights, coaching experiences, and directions based on scientific findings that results in the optimal knowledge for creating a program for a specific athlete.

This book is no doubt filled with biases, as it is heavily influenced by our experiences. Dr. Zatsiorsky's experience is predominantly in the former

Soviet Union, former East Germany (German Democratic Republic), and Bulgaria. Dr. Kraemer and Dr. Fry bring an American perspective. The integration of our separate perspectives has yielded much success and has allowed many hybrids of training theory to be put forth.

This book is intended to be comprehensive. Concepts that are outdated or have been shown to be ineffective through research have been modified or eliminated to provide an up-to-date overview of training concepts and theories that are on the cutting edge of both practice and science.

The book consists of three parts. Part I describes the basis of strength training and includes three chapters. Chapter 1, Basic Concepts of Training Theory, emphasizes the concepts that are, for the most part, the bedrock of strength development. In Chapter 2, Task-Specific Strength, the principles related to task specificity are developed. Chapter 3, Athlete-Specific Strength, is designed to enhance one's knowledge on how programs can vary by sport and individual athlete needs. Part II examines some of the important concepts in strength training. Chapter 4, Training Intensity, shows how important and varied the concept of intensity is in a strength training program. Chapter 5, Timing in Strength Training, examines different phases and progressions in program concepts. Chapter 6, Exercises Used for Strength Training, provides an overview of the choices of program exercises and their differences and applications. Chapter 7, Velocity in the Weight Room, presents new concepts in how strength is expressed at different velocities of movement and how it impacts performance. Chapter 8, Injury Prevention, addresses how one can prevent common injuries and how strength training is vital in injury prevention in sports. In Chapter 9, Overreaching, Overtraining, and Recovery, vital research from the past 30 years shows the importance of proper progression and recovery to eliminate injury and loss of progress in a strength training program. Chapter 10, Monitoring Athletes in the Weight Room, presents concepts and ideas for athlete monitoring to determine the effectiveness of strength training programs being used and athlete progress toward training goals. This leads into Chapter 11, Goal-Specific Strength Training, which is vital for progress in each training cycle. Finally, in Part III, we take a closer look at different populations with Chapter 12, Strength Training for Women; Chapter 13, Strength Training for Young Athletes; and Chapter 14, Strength Training for Senior Athletes.

We do not address drug use in sports, which continues to receive worldwide attention. We maintain that the practice is harmful to health, unethical in sport, and illegal. We believe that the much wider array of anabolic drugs now being used by athletes has diminished the desire to optimize training methods using the body's own natural anabolic mechanisms (e.g., the endocrine system). This book is written to allow the reader to train without drugs and to maximize the body's ability to make natural gains by optimizing the strength training programs used.

This book uses limited references to underscore the practical approach we took in writing it. With the knowledge base of the field of strength training expanding each year, we provide select references to books, reviews, and position stands to allow you to access more background reading material to enhance your understanding of various concepts and principles. If we were to provide all such references, the sheer magnitude of the book would overwhelm its practical nature. The integration of coaching theory and scientific underpinnings in this text continues to promote a more sophisticated practice of strength training.

# Acknowledgments

The third edition of this book represents a historical evolutionary timeline for both the authors and the content presented. Strength training has seen the development of myriad approaches that enhance the fundamental ability of the body to produce more force. However, many of the principles remain intact and are the bedrock of program design.

For the first edition, Dr. Zatsiorsky was aided by numerous people, including Dr. Richard C. Nelson, who founded the biomechanics laboratory at Penn State in 1967, and Dr. Robert J. Gregor (now professor emeritus at Georgia Tech University) and Dr. Benno M. Nigg (now professor emeritus at the University of Calgary), who invited him to be a visiting researcher at their laboratories. The first edition of the book was partly written during this time.

For the genesis of the second edition, Dr. Zatsiorsky and Dr. Kraemer both thank the many professionals at Human Kinetics, most notably Dr. Mike Bahrke, for bringing two former colleagues together again in a new collaboration on this topic of mutual interest and synergistic perspectives.

The third edition was stimulated by the support and persistence of Mr. Roger Earle, senior acquisitions editor in the Trade and Professional Division at Human Kinetics, a former weightlifter himself. He pushed to continue this iconic book by Dr. Zatsiorsky, whose fundamental principles and approaches to strength training have stood the test of time. While the second edition showed the expanse and evolution of concepts and theories with the addition of Dr. Kraemer's authorship, this third edition will benefit the readership of this book by cutting through the myriad misinformation now pervasive on this topic with the addition of Dr. Fry's expertise.

We would also like to acknowledge Ms. Hannah Werner, our managing editor at Human Kinetics, for her patience and help in the process of producing this work. We would also like to say a special thank you to the many team members at Human Kinetics who worked so hard to make this book the best it could be from all of the different perspectives needed in book publishing, including Anne Hall, developmental editor, Denise Lowry, graphic designer, Kelly Hendren, senior art manager, Joe Buck, senior graphic designer, Heidi Richter, illustrator, and Joanne Brummett, production director.

Dr. Kraemer is indebted to many people, and it would be impossible to do justice to their many contributions. I must thank Dr. Steve Fleck, with whom I have worked for decades in this area, and my late friend Coach Jerry Martin, who worked with me day by day at the University of Connecticut for over a decade to develop a model for bridging the gap between the laboratory and the weight room.

Dr. Fry would like to thank William J. Kraemer and Robert S. Staron; these mentors showed great patience, helped me develop an appreciation of the topics covered in this text, and allowed me to pursue related lines of research while a student and postdoctoral fellow. Also, a thank you to all my colleagues, both coaches and academics, who have helped me better understand the principles and concepts applied in these chapters. To my numerous and valued students, who have been part of innumerable discussions, planning sessions, and data collections over the years: These interactions have kept me inspired and up to date on developing training concepts. Don't ever underestimate the value of these opportunities to learn. Finally, a thank you to the athletes and fellow coaches who have willingly permitted me to apply many of these training principles to their programs.

Each of us would like to acknowledge the multitude of athletes, students, graduate students, and faculty colleagues who have worked with us in the weight room, in classes, and in research projects, thereby providing us with the intellectual challenges and exciting discussions that have enriched our experiences, insights, and views on strength training. Finally, we thank the many strength and conditioning professionals and fitness enthusiasts in the field who have encouraged our work and motivated us to continue to develop our scientific theories and concepts in resistance training, many of which are found in the pages of this book.

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# Symbols and Abbreviations

| | |
|---|---|
| ACWR | Acute:chronic workload ratio |
| BW | Body weight |
| $CF_{mm}$ | Maximum competition weight |
| CK | Creatine kinase |
| CV | Coefficient of variation |
| $\Delta F_m$ | Gain in maximal force |
| EMG | Electromyography |
| EMS | Electrical stimulation of muscles |
| ESD | Explosive strength deficit |
| $F$ | Force |
| $F_m$ | Maximal force attained when the magnitude of a motor task parameter is fixed |
| $F_{mm}$ | Maximum maximorum force attained when the magnitude of a motor task parameter is altered |
| FT | Fast-twitch muscle fibers |
| $g$ | Acceleration due to gravity |
| GH | Growth hormone |
| HR | Heart rate |
| HRV | Heart rate variability |
| Hz | Hertz |
| IAP | Intra-abdominal pressure |
| IES | Index of explosive strength |
| IGF | Insulin-like growth factor |
| IMTP | Isometric midthigh pull |
| LBPS | Low back pain syndrome |
| MHC | Myosin heavy chain protein |
| MSD | Muscle strength deficit |
| MU | Motor unit |
| N | Newton; the unit of force |
| $P_m$ | Maximal muscular performance attained when the magnitude of a motor task parameter is fixed |
| $P_{mm}$ | Maximum maximorum power attained when the magnitude of a motor task parameter is altered |
| POMS | Profile of Mood States |
| RC | Reactivity coefficient |
| RESTQ | Recovery-stress questionnaire for athletes |
| RFD | Rate of force development |
| RM | Repetition maximum |
| SD | Standard deviation |
| ST | Slow-twitch muscle fibers |
| $T_m$ | Time to peak performance |
| $TF_{mm}$ | Maximum training weight |
| $V_m$ | Maximal velocity attained when the magnitude of a motor task parameter is fixed |
| $V_{mm}$ | Maximum maximorum velocity attained when the magnitude of a motor task parameter is altered |
| VJ | Vertical jump |

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# PART I

# BASIS OF STRENGTH TRAINING

The primary goal of this book is to provide readers with practical recommendations, or a prescription, for training athletes. Practical advice, however, cannot be given without first providing descriptions of what should be trained and why some methods are better than others. Part I of the book describes theory, while part II covers a host of different topics on the methods of strength training, injury prevention, and monitoring to ensure the success of the program. Part III deals with training for specific populations.

The first part, which is entirely descriptive, develops several concepts in a natural, sequential order. Chapter 1 is introductory and provides an overview of the principles of training theory: It describes the peculiarities of adaptation to a physical load; discusses two prevailing theories of training—the supercompensation theory and the fitness-fatigue theory—both of which are widely and enthusiastically embraced as effective methods; and spells out the nomenclature of training effects. Although the concepts and terminology introduced in this chapter are used throughout the book, the chapter is self-contained and presumes that the reader has no prior scientific knowledge.

Chapters 2 and 3 address the factors that determine muscular strength. It is assumed that readers have some knowledge of exercise physiology and sport biomechanics, or at least are acquainted with the basic physiology of the muscles. Readers who are not familiar with this material, however, should not be discouraged from reading the book; the main concepts are explained in a format intelligible for a reader with a minimal background in exercise and sport science. Readers who do have trouble understanding chapters 2 and 3 need not read them in one sitting but can return to them later while reading the balance of the book.

Chapter 2 lays the foundation for the notion of muscular strength, classifying and explaining the evidence collected by measuring muscular force. It introduces the concept of maximal muscular performance, as well as two primary relationships (parametric and nonparametric), and defines the notion of muscular strength. It then follows with a detailed discussion of various factors involved in motor tasks, such as resistance, time available for force development, movement velocity, movement direction, and body posture. The integrating idea for these diverse topics is rather simple and straightforward: exercise specificity. For training to be effective, exercises should be similar to the main sport activity, and the exercise similarity should be established according to the criteria discussed in this chapter.

Chapter 3 addresses muscular strength from another standpoint: that of the performer rather than the motor task. Some people have greater strength than others. Why? What properties do elite athletes have that allow them to be exceptional? The internal factors determining muscular strength are latent. Hence, they can be identified only by using a physiological approach. If we are able to identify them, we open the road to goal-directed training of these primary factors, so the exercises and methods addressed here will center on specific targets rather than on strength in general. This chapter is based on facts and theories originated by exercise physiologists. Two main groups of internal factors are discussed: muscular and neural.

Among the muscular factors, primary attention is given to the muscle dimension and its counterpart, body weight. Other factors, including nutrition and hormonal status, are briefly highlighted as well. The neural mechanisms, such as intra- and intermuscular coordination, are reviewed in the later sections. Chapter 3 is essential for understanding training methods.

CHAPTER 1

# BASIC CONCEPTS OF TRAINING THEORY


Strength conditioning theory is part of a broader field of knowledge, the science of training athletes, also termed *training science* or *theory of sport training*. Training science courses cover the components of athlete preparation, including conditioning (not only for strength but also for speed, endurance, flexibility, and other motor abilities); learning of sport technique; and periodization, that is, variation of training programs in a season. Throughout this book, the concepts and approaches developed within the framework of training science are used extensively. In today's world of strength and conditioning, it is crucial to have programs designed with careful consideration of basic scientific principles for each individual and sport. Optimizing program development and safety for each athlete must be a priority. This chapter introduces you to the issues of training in general. The ideas and terminology you encounter here will be used in the remainder of the book.

## Adaptation as a Main Law of Training

If a training routine is planned and executed correctly, the result of systematic exercise is improvement of the athlete's physical fitness, particularly strength, as the body adapts to physical **load**. In a broad sense, **adaptation** means the adjustment of an organism to its environment. If the environment changes, the organism changes to better survive in the new conditions. In biology, adaptation is considered one of the main features of living species.

## Immediate and Delayed Effects of Training

Immediately after a training session, performance usually degrades due to **fatigue**. Nobody expects to become stronger after 1 set of drills or a single training session. So, why do multiple training sessions over time end in performance improvement? Improvement occurs because the body adapts to the progression and repeated exposure to the training load.

However, one must also consider **maladaptation**, the inability of an individual to positively respond when programs are not progressively applied and when the loading and metabolic demands exceed the adaptive potential of the organism. In short, maladaptation implies too much, too soon.

Exercise or regular **physical activity** is a very powerful stimulus for adaptation. The major objective in training is to induce specific adaptations in order to improve sport performance. This requires adherence to a carefully planned and executed training program. From a practical point of view, the following four features of the adaptation process assume primary importance for sport training:

1. Stimulus magnitude (overload)
2. Accommodation
3. Specificity
4. Individualization

## Overload

To bring about positive changes in an athlete's state, an exercise **overload** must be applied. A training adaptation takes place only if the magnitude of the **training load** is above the habitual level. During the training process, there are two ways to induce an adaptation. One is to increase the training load (intensity, volume) while continuing to employ the same drill—for example, endurance running. The other is to change the drill, provided that the exercise is new and the athlete is not accustomed to it.

If an athlete uses a standard exercise with the same training load over a very long time, there will be no additional adaptations and the level of physical fitness will not substantially change (figure 1.1). If the training load is too low, detraining occurs. In elite athletes, many training improvements are lost within several weeks, even days, if an athlete stops exercising. During the competition period,

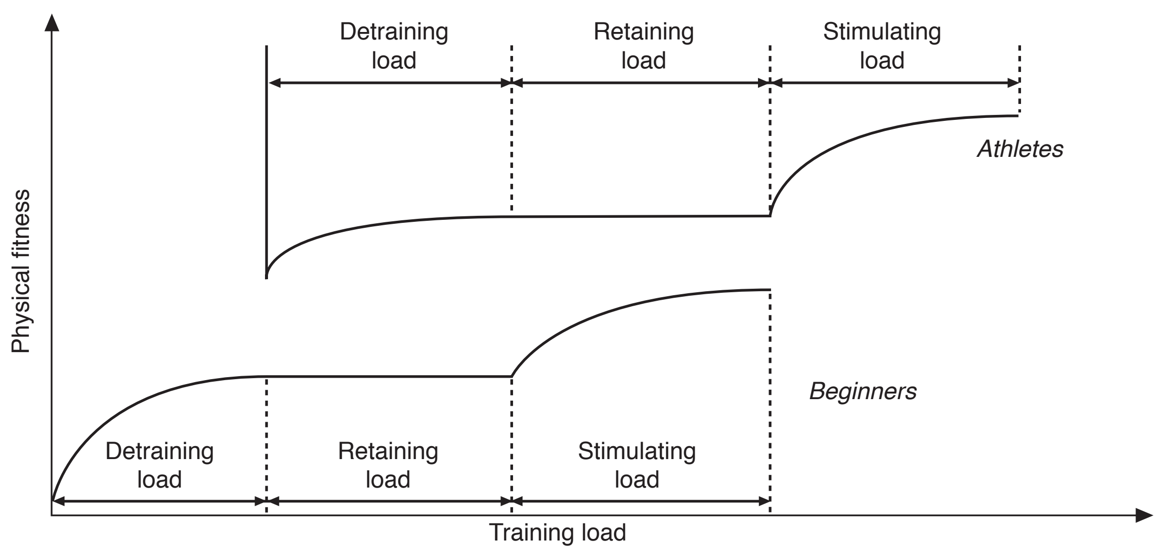


**FIGURE 1.1** Relationship between training load (detraining, retaining, stimulating) and level of physical fitness. Rectangles indicate the neutral zones (retaining loads) corresponding to small fluctuations in the training load at which the level of fitness is basically not changed. Note the stepladder effect showing a change in the adaptation curve with a change in the training stimulus. A training load that leads to the detraining of high-level athletes may be extremely high for beginners.

## Overload Example

Identical triplets possessed equal levels of strength; each was able to lift a 57.5-kg barbell one time. They began to exercise with a 50-kg barbell, lifting the barbell in 1 set until failure five times. After a period of time, the athletes adapted to the training routine, their preparedness improved, and they were able to lift a 60-kg barbell one time. However, despite continued training, they did not make further gains in performance because they accommodated to the training program.

At this stage, the three athletes made different decisions. Athlete A decided to increase the training load (weight lifted, number of **repetitions** in a set, number of sets) or change the exercise. The new load was a stimulating one for this athlete and performance improved. Athlete B continued to employ the previous routine and performance results were unchanged (retaining load). Athlete C decreased the training load and strength performance declined (detraining load).

elite athletes cannot afford complete passive rest for more than 3 days in a row (typically only 1 or 2 days).

Training loads can be roughly classified according to their magnitude as

- **stimulating**, in which the magnitude of the training load is above the neutral level and positive adaptation may take place;
- **retaining**, in which the magnitude is in the neutral zone where the level of fitness is maintained; and
- **detraining**, in which the magnitude of the load leads to a decrease in performance results, in the functional capabilities of the athlete, or both.

The need for a constant increase in training loads, considered necessary for positive adaptation, leads to **progressive resistance training**: When strength levels improve, larger training loads are used. Because the preparation of elite athletes usually lasts 8 to 12 years, their progressive resistance training leads to extremely demanding training programs. The training load of elite athletes is roughly 10 times greater than that of beginners having 6 months of training experience. Elite weightlifters lift approximately 5,000 tons/year, while the load for novices is only 1/10 or 1/12 this level. The same is true for other sports. For instance, the year-round training mileage of elite cross-country skiers is between 8,000 and 12,000 km. For beginners, it is about 1,000 km.

### Accommodation

If athletes employ the same exercise with the same training load over a long period of time, performance improvement (gain) decreases (see figure 1.2). This is a manifestation of **accommodation**, often considered a general law of biology. According to this law, the response of a biological object to a constant stimulus decreases over time. By definition, accommodation is the decrease in response of a biological object to a continued stimulus.

In training, the stimulus is physical exercise and the response is performance gain as a result of adaptation, a process known as **transformation**. With an increase in training volume or duration, the magnitude of adaptations diminishes—the **principle of diminishing returns**. In beginning athletes,

## A Bizarre Bank Metaphor

Banks usually pay higher interest rates to the customers who deposit money for longer periods of time or make large contributions. Imagine a bank—the bizarre bank—that adopts the opposite policy: The longer you keep the money in the bank and the larger the deposit, the smaller the interest. Most likely a bank with this policy would soon be out of business. However, this is exactly how our body works. Over long periods of training or when athletes increase the training load, they will see a decrease in the performance improvement per unit of training load, or the interest on their capital.

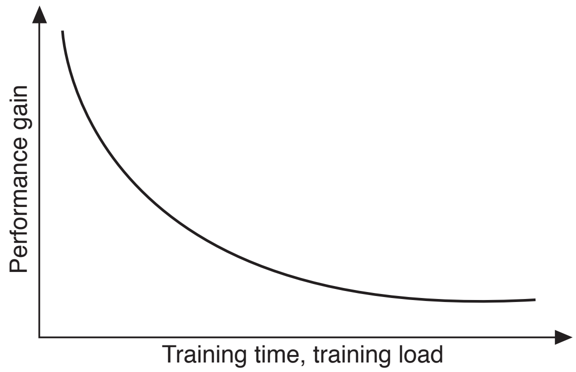


**FIGURE 1.2** Dependence of performance improvement (gain) on time of training or training load. As a result of accommodation, the gain decreases.

relatively small training loads may lead to large performance improvements, while in athletes with multiyear experience, even heavy training routines may result in no performance changes. This is due to the lack of an adaptive window for change, which is typically dictated by the individual's genetic ceiling for a given characteristic being trained.

Because of accommodation, it is inefficient to use standard exercises or a standard training load over a long period of time. Training programs must vary. At the same time, because of the specificity of training adaptations, the training exercises should be as close as possible to the main sport exercise in muscular coordination and physiological demand. The highest transfer of training result occurs with the use of **sport-specific exercises**. These two requirements lead to one of the main conflicts in training elite athletes: Training programs should be both variable, to avoid accommodation, and stable, to satisfy the demand for specificity.

To avoid or decrease the negative influence of accommodation, training programs are periodically modified. In principle, there are two ways to modify training programs:

- Quantitative—changing training loads (for instance, the total amount of weight lifted)
- Qualitative—replacing the exercises

Qualitative changes are broadly used in the training of elite athletes, at least by those who are creative.

## Specificity

Training adaptations are highly specific. It is well known that strength training increases both muscle mass and strength, while endurance training induces other changes such as increases in aerobic capacity. Because of adaptation **specificity**, the exercises and training in various sports are different.

Specificity may be described in another way, as an issue of **transfer of training results**. Imagine, for example, a group of young athletes who have trained over a certain period of time with one exercise: exercise A, barbell squats. Ultimately, their performances improve. Let's suppose that the gain is the same for all the athletes, say 20 kg. What will happen with the performances of these athletes in other exercises, such as the standing vertical jump, sprint dash, or freestyle swimming (exercises B, C, and D)? We may predict that the results in these exercises will improve to different degrees. The gain may be substantial in the standing jump, relatively small in sprint running, and next to nothing in swimming. In other words, the transfer of training results from exercise A to exercises B, C, and D is variable.

The transfer of training gains can differ greatly even in very similar exercises. In an experiment, two groups of athletes performed an isometric knee extension at different joint angles, 70° and 130° (a complete leg extension corresponds to 180°). The maximal force values, $F_m$, as well as the force gains, $\Delta F_m$, observed at different joint angles were varied (figure 1.3).

The strength gains at various joint positions were different for the two groups. For the subjects in the first group, who exercised at the 70° knee-joint angle (see figure 1.3*a*), the strength gains in all joint

### Avoiding Accommodation in Olympic Cycles

Several elite track and field athletes, who were successful at three Olympic Games in a row, avoided accommodation. How? None of them used the same training program every year; instead, they varied the training routines. Some of the athletes used the drills that they believed were most efficient (for instance, overhead throwing of a 3-kg shot by a javelin thrower) only during an Olympic season, or one time in a 4-year period. This was done to avoid accommodation.

## Transfer of Training Results: Why Is It Important?

The first books about athlete preparation, published in the 19th century, make interesting reading. The preparation for competition consisted of the main sport exercise and nothing else. If one competed in the 1-mi run, workouts consisted of only 1-mi runs.

However, coaches and athletes soon understood that such preparation was not sufficient. To run a mile successfully, an athlete must not only have stamina but must also possess appropriate sprinting abilities, good running technique, and strong and flexible muscles and joints. It is impossible to develop these abilities by running the same fixed distance repeatedly. As a consequence of this realization, training strategies were changed. Instead of multiple repetitions of a single exercise, many auxiliary exercises were adopted into training programs to improve the abilities specific to a given sport. The general concept of training changed.

The question then arises: How do you choose more efficient exercises that result in a greater transfer of training effect from the auxiliary to the main sport movement? Consider the following problems:

1. Is long-distance running a useful exercise for endurance swimmers? For cross-country skiers? For race walkers? For bicyclists? For wrestlers?
2. To improve the velocity of fast pitches, a coach recommends that pitchers drill with baseballs of varying weight, including heavy ones. What is the optimal weight of the ball for training?
3. A conditioning coach planning a preseason training routine for wide receivers must recommend a set of exercises for leg strength development. The coach may choose one of several groups of exercises or combine exercises from different groups. The exercise groups are
    - one-joint isokinetic movements, such as knee extension and flexion, on exercise apparatuses,
    - similar one-joint drills with free weights,
    - barbell squats,
    - isometric leg extensions,
    - vertical jumps with additional weights (heavy waist belts),
    - uphill running, and
    - running with parachutes.

Which exercise is most effective? In other words, when is the transfer of training results greater?

positions were almost equal. The transfer of training results from the trained body posture (70°) to untrained positions (other joint angles) was high. In the athletes of the second group, who trained at the 130° knee-joint angle (see figure 1.3*b*), transfer of training gains was limited to the neighboring joint angles: The strength gain was low for small joint angles (compare strength gains in angles 130° and 90°). The same held true for barbell squats. In the first group, the strength gain in the trained body posture was 410 ± 170 N and in squatting it was 11.5 ± 5.4 kg. In the second group, the strength in the trained posture increased by 560 ± 230 N; however, in spite of such a high gain, the barbell squat performance improved by only 7.5 ± 4.7 kg. The strength gain in the trained posture in the second group was higher (560 ± 230 N versus 410 ± 170 N), but the improvement in the barbell squats was lower (7.5 ± 4.7 kg versus 11.5 ± 5.4 kg) due to minimal transfer of training results.

As performances in different exercises have different modalities (force, time, distance) and are not directly comparable, a dimensionless unit should be employed to estimate the transfer of training result. Such a unit is a result gain expressed in standard deviations:

$$\text{Result gain} = \frac{\text{Gain of performance}}{\text{Standard deviation of performance}}.$$

For instance, if the average performance of a group is 60 ± 10 kg (average ± standard deviation) and the performance of an athlete improves by 15

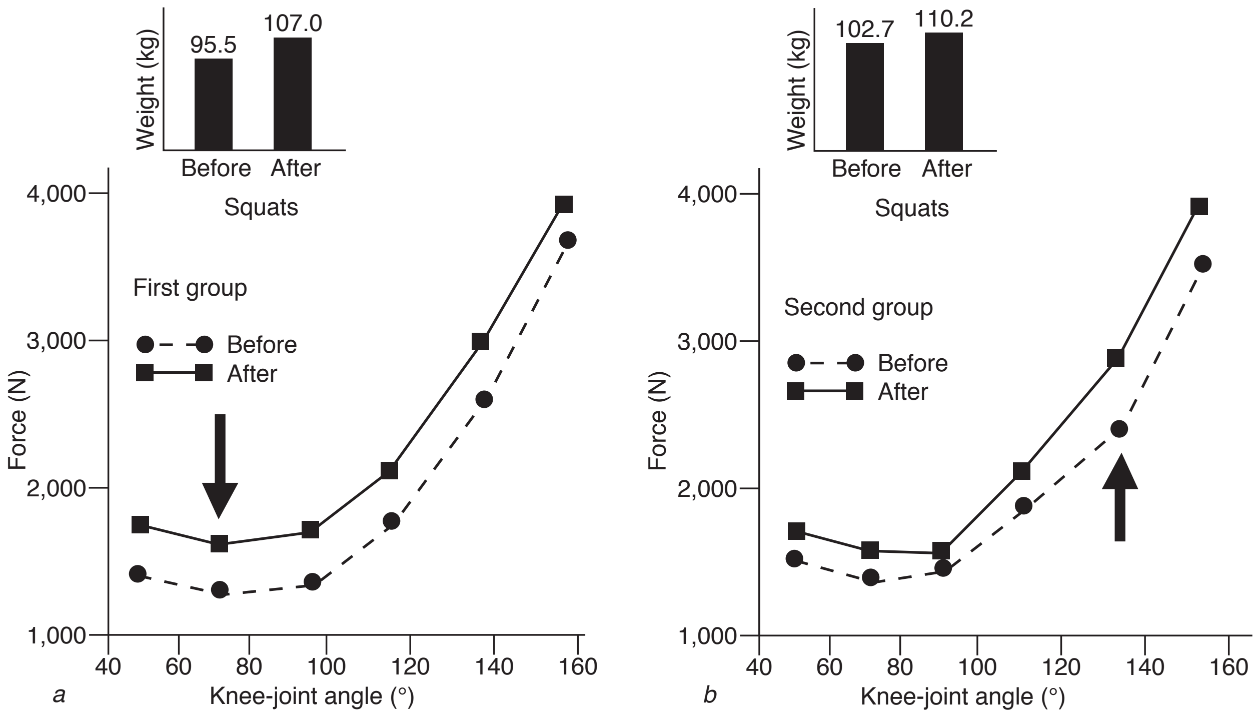


**FIGURE 1.3** Performance improvements (strength gains) in two experimental groups. The vertical arrows show the angles at which isometric training took place. Strength was measured in leg extensions as well as in barbell squats.

Data from W.M. Zatsiorsky and L.M. Raitsin, "Transfer of Cumulative Training Effects in Strength Exercises," *Theory and Practice of Physical Culture* 6 (1974): 7-14.

kg as a result of training, the athlete's personal gain equals 15/10 or 1.5 standard deviation. In scientific literature, the result gain for a group computed as [(Posttraining mean - Pretraining mean) / Pretraining standard deviation] is known as the **effect size**. For the estimation of transfer, a ratio of the gains in nontrained exercises (exercises B, C, and D) and the trained exercise (exercise A) is employed. The coefficient of the transfer of training is, by definition, the following ratio:

$$\text{Transfer} = \frac{\text{Result gain in nontrained exercise}}{\text{Result gain in trained exercise}}.$$

Both gains are measured in standard deviations (SD). The higher the ratio, the greater the transfer of training results. If the transfer is low, the effect of training is specific. In the example from figure 1.3, the training effects were more specific for the group that performed exercise at the 130° knee-joint angle. Specificity of adaptation increases with the level of sport mastership. The higher an athlete's level of fitness, the more specific the adaptation. The transfer of training gain is lower in good athletes; for beginners, almost all exercises are useful. It is possible to improve the strength, speed, **endurance**, and flexibility of people with extremely low physical fitness through simple calisthenics. The performance of beginning bicyclists can be improved with barbell squats. Elite athletes should use more specific exercises and training methods to increase competitive preparedness.

## Individualization

All people are different. The same exercises or training methods elicit a greater or smaller effect in various athletes. Innumerable attempts to mimic the training routines of famous athletes have proven unsuccessful. The general ideas underlying noteworthy training programs, not the entire training protocol, should be understood and creatively employed. The same holds true for average values derived from training practices and scientific research. Coaches and athletes need to use an average training routine cautiously. Only average athletes, those who are far from excellent, prepare with average methods. Champions are not average; they are exceptional. **Individualization** of training will optimize results and enhance the desired adaptation to the training protocol.

## Calculating the Transfer of Training Results

In the experiment discussed in the text, the following data were recorded (see figure 1.3):

| Test | Before | After | Gain of performance | Result gain | Transfer |
|---|---|---|---|---|---|
| GROUP 1 (ISOMETRIC TRAINING AT AN ANGLE OF 70°) | | | | | |
| Force at an angle 70°, N | 1,310 ± 340 | 1,720 ± 270 | 410 ± 170 | 410 / 340 = 1.2 | |
| Squatting, kg | 95.5 ± 23 | 107 ± 21 | 11.5 ± 5.4 | 11.5 / 23 = 0.5 | 0.5 / 1.2 = 0.42 |
| GROUP 2 (ISOMETRIC TRAINING AT AN ANGLE OF 130°) | | | | | |
| Force at an angle 130°, N | 2,710 ± 618 | 3,270 ± 642 | 560 ± 230 | 560 / 618 = 0.91 | |
| Squatting, kg | 102.7 ± 28 | 110.2 ± 23 | 7.5 ± 4.7 | 7.5 / 28 = 0.27 | 0.27 / 0.91 = 0.30 |

Note the results:

| Characteristics | Superior group | Comparison |
|---|---|---|
| Gain of performance in trained exercise | Group 2 | 560 vs. 410 N |
| Result gain in trained exercise | Group 1 | 1.2 vs. 0.91 SD |
| Transfer of training results | Group 1 | 0.42 vs. 0.30 |
| Gain of performance in nontrained exercise | Group 1 | 11.5 ± 5.4 vs. 7.5 ± 4.7 kg |

Because of the higher transfer of training results, the method used to train the first group better improved the squatting performance.

# Generalized Theories of Training

**Generalized training theories** are very simple models that coaches and experts use broadly to solve practical problems. These models include only the most essential features of sport training and omit numerous others. Generalized theories (models) serve as the most general concepts for coaching. Coaches and athletes use them especially for conditioning and also for planning training programs.

## One-Factor Theory (Theory of Supercompensation)

In the **one-factor theory**, the immediate training effect of a workout is considered as a depletion of certain biochemical substances. The athlete's disposition toward a competition or training, called **preparedness**, is assumed to vary in strict accordance with the amount of this biochemical substance available for immediate use. There is evidence in exercise and sport science literature that certain substances are exhausted as a result of strenuous training workouts. An example is muscle glycogen depletion after high-volume **anaerobic exercise** or long-term aerobic exercise.

After the restoration period, the level of the given biochemical substance is believed to increase above the initial level. This is called supercompensation, and the time period when there is an enhanced level of the substance is the **supercompensation phase** (figure 1.4).

If the **rest intervals** between workouts are too short, the level of an athlete's preparedness