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Foreword

The second edition of Science and Practice of Strength Training brings together as authors two individuals I consider colleagues in the research and practice of strength training. Throughout their professional careers, both have distinguished themselves as strength training scientists and practitioners. Dr. Zatsiorsky has extensive experience in strength training from the former Soviet Union and Eastern Bloc countries while Dr. Kraemer has extensive experience from the American perspective on strength training. This text represents a unique melding of these two experts’ knowledge of strength and conditioning. This work is in part a result of their collaborative teaching of an advanced class on the practice and theory of strength training at Pennsylvania State University. The serendipitous opportunity to teach a class together on strength training allowed the exchange of ideas and information in the area of strength training from two very successful perspectives. Both authors not only have extensive research experience in strength training, they also have extensive experience as coaches and practitioners. Thus the text is a unique blend of the science as well as the art of designing all aspects of successful strength training programs.

This work is for the serious strength coach, athlete, or fitness enthusiast who desires to think about and develop an individualized strength training program that will result in successful long-term strength, fitness, and performance gains. It is not for the individual who desires a cookie-cutter approach to training and to be told exactly what exercises, number of sets, and number of repetitions per set to perform in their training program. All aspects of the strength training field including program design; periodization; specific exercises; and training specific populations such as women, youth, and older athletes are covered in detail. No matter how experienced you are in strength training, you will find provocative concepts that will affect your ideas and planning of strength training programs. I highly recommend this text to all people who are serious about strength conditioning.

Steven J. Fleck, PhD
Colorado College
Preface

We are excited to present the second edition of *Science and Practice of Strength Training*. We were former colleagues for almost 10 years at Pennsylvania State University where we taught the theory class in strength training, and our collaboration on this second edition has renewed our mutual interest in the topic. The result is a second edition that builds on the previous text and expands on the principles and concepts for training athletes. This new text includes updated information, as well as additional chapters on training special populations.

As with the previous edition, this textbook is for readers who are interested in muscular strength and ways to enhance its development. Thus it is for coaches, students who plan to become coaches, and athletes who want to be self-coaches. The textbook has been developed from the vast experience that we both bring to the text, with documented experiences of more than 1,000 elite athletes ranging from Olympic, world, continental, and national champions and record holders. Dr. Kraemer also brings experience in coaching from the junior high school to the college levels. His work on training studies with collegiate and professional athletes brings an additional dimension to the textbook that expands its conceptual relevance.

*Science and Practice of Strength Training* is designed for serious readers who are willing not only to remember and repeat but also to understand and put information to use. On more than one occasion a coach or athlete has asked both of us what is the best exercise, method, or training program to develop strength. Answers to such questions are difficult as no one program works for all athletes at all times or under all conditions. The individual needs of each athlete will vary and what works at one point in time may not work at another time. Thus there is no single best program, and 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 in order to make decisions on what might be an appropriate program design for an athlete. 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 to take under specific circumstances. While we offer some program examples, this book is not meant to be a "cookbook," as such an approach is fraught with pitfalls. Thus, we use program examples to demonstrate some of the principles and concepts that have been discussed in the book.

Strength training research has been growing dramatically each year and gives further credibility to concepts that were for many years only anecdotal in nature. Yet the design and practice of strength training programs will never be led step by step with scientific studies. 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 Dr. Zatsiorsky's Eastern European experience, predominantly in the former Soviet Union, former East Germany (German Democratic Republic), and Bulgaria. Dr. Kraemer brings to the book concepts and ideas from an American perspective as a high school and collegiate strength coach. This integration of perspectives over the past 20 years has yielded much success and has allowed many hybrids of training theory to be put forth.
This book is intended to be comprehensive, including additional chapters on training special populations (women, young athletes, and older athletes) and expanded sections in each of the previous chapters. Concepts that have been shown to be outdated or 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 addresses the basic concepts of training theory, such as the role of adaptation in training and generalized theories of training. Task-specific strength is discussed in chapter 2 and athlete-specific strength is discussed in chapter 3. Part II deals with the methods of strength conditioning. Training intensity and the methods of strength training are discussed in chapter 4. The topic of chapter 5 is timing in strength training. Strength exercises, including the selection of strength training drills for beginning and qualified athletes, are considered in chapter 6. Chapter 7 deals with injury prevention during strength training. Goal-specific strength training is addressed in chapter 8. Part III deals with training for specific populations. Chapter 9 outlines gender differences and important considerations when training women. Chapter 10 allows the reader to make the proper decisions when training young athletes in order to optimize physical development. Chapter 11 discusses the aging process and necessary considerations in developing optimal strength training programs for the older athlete.

We do not address drug use in sports, which, as of the writing of this textbook, has continued to receive worldwide attention. We both 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 optimize 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 taken by us in the writing of this second edition. With the knowledge base of the field of strength training expanding each year, we provide references to books, reviews, and position stands to allow you to gain more background reading 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.
Numerous people helped us in preparing the manuscript for this book. With the completion of the first edition of this book, V.Z. is most grateful to Dr. Richard C. Nelson. The first edition of the book would not have been written without his invaluable support and help. Special thanks go to Dr. Robert J. Gregor (currently at Georgia Tech, Atlanta) and Dr. Benno M. Nigg (University of Calgary), for inviting V.Z. as a visiting researcher at their laboratories. The first edition of the book was written in part during this time.

For the genesis of the second edition of the book we both are thankful and indebted to the many professionals at Human Kinetics who have put in a great deal of effort to bring this book to completion. Most notably, Dr. Mike Bahrke was pivotal in bringing two former colleagues together again in a new collaboration on this topic of mutual interest and synergistic perspectives. The authors would like to thank Ms. Maggie Schwarzentraub, our developmental editor, for all her exceptional professionalism and hard work in bringing this book to completion. We also thank our past and present colleagues and students at Pennsylvania State University and the University of Connecticut who have fostered our interest and excitement about this area of study to the present day. W.J.K. is very indebted to Dr. Steven J. Fleck (Colorado College) for his support of this project and continuous collaboration in this scientific study and research in resistance training. Finally, we acknowledge 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, of which many are found in the pages of this book. Thank you.
## Symbols and Abbreviations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW</td>
<td>Body weight</td>
</tr>
<tr>
<td>$CF_{mn}$</td>
<td>Maximum competition weight</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>EMS</td>
<td>Electrical stimulation of muscles</td>
</tr>
<tr>
<td>ESD</td>
<td>Explosive strength deficit</td>
</tr>
<tr>
<td>$F$</td>
<td>Force</td>
</tr>
<tr>
<td>$F_m$</td>
<td>Maximal force attained when the magnitude of a motor task parameter is fixed</td>
</tr>
<tr>
<td>$F_{mn}$</td>
<td>Maximum maximorum force attained when the magnitude of a motor task parameter is altered</td>
</tr>
<tr>
<td>FT</td>
<td>Fast-twitch muscle fibers</td>
</tr>
<tr>
<td>$g$</td>
<td>Acceleration due to gravity</td>
</tr>
<tr>
<td>GH</td>
<td>Growth hormone</td>
</tr>
<tr>
<td>IAP</td>
<td>Intra-abdominal pressure</td>
</tr>
<tr>
<td>IES</td>
<td>Index of explosive strength</td>
</tr>
<tr>
<td>IGF</td>
<td>Insulin-like growth factor</td>
</tr>
<tr>
<td>LBPS</td>
<td>Low back pain syndrome</td>
</tr>
<tr>
<td>MSD</td>
<td>Muscle strength deficit</td>
</tr>
<tr>
<td>MU</td>
<td>Motor unit</td>
</tr>
<tr>
<td>N</td>
<td>Newton; the unit of force</td>
</tr>
<tr>
<td>$P_n$</td>
<td>Maximal performance attained when the magnitude of a motor task parameter is fixed</td>
</tr>
<tr>
<td>$P_{mn}$</td>
<td>Maximum maximorum performance attained when the magnitude of a motor task parameter is altered</td>
</tr>
<tr>
<td>RC</td>
<td>Reactivity coefficient</td>
</tr>
<tr>
<td>RFD</td>
<td>Rate of force development</td>
</tr>
<tr>
<td>RM</td>
<td>Repetition maximum</td>
</tr>
<tr>
<td>ST</td>
<td>Slow-twitch muscle fibers</td>
</tr>
<tr>
<td>$T_m$</td>
<td>Time to peak performance</td>
</tr>
<tr>
<td>$TF_{mn}$</td>
<td>Maximum training weight</td>
</tr>
<tr>
<td>$V_n$</td>
<td>Maximal velocity attained when the magnitude of a motor task parameter is fixed</td>
</tr>
<tr>
<td>$V_{mn}$</td>
<td>Maximum maximorum velocity attained when the magnitude of a motor task parameter is altered</td>
</tr>
</tbody>
</table>
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 methods of strength training. 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 main 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.
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. 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 worsens due to fatigue. Nobody expects to become stronger after 1 set of drills or a single training session. So, why do multiple training sessions and performance improvement? Improvement happens because the body adapts to the training load.

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

### 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).

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 around 5,000 tons/year, while the load for novices is only 1/10th or 1/12th of 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 improvement as a result of adaptation. With an increase in training volume or duration, the magnitude of adaptations diminishes—the **principle of diminishing returns**. In beginning athletes, relatively small training loads...
may lead to large performance improvements, while in athletes with multyear experience even heavy training routines may result in no performance changes.

**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.

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 results occur with the use of **specific exercises**. These two requirements lead to 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.

**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.

**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, squattling with a barbell. Finally, 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.
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?

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 1.3a), the strength gains in all joint 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 1.3b), 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 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 [(Post-training 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. 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 by squating with a barbell. Elite athletes should use more specific exercises and training methods to increase competitive preparedness.

### Calculating the Transfer of Training Results

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Before</th>
<th>After</th>
<th>Gain of performance</th>
<th>Result gain</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Group 1 (isometric training at an angle of 70°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force at an angle 70°, N</td>
<td>1310 ± 340</td>
<td>1720 ± 270</td>
<td>410 ± 170</td>
<td>410 / 340 = 1.2</td>
<td></td>
</tr>
<tr>
<td>Squatting, kg</td>
<td>95.5 ± 23</td>
<td>107 ± 21</td>
<td>11.5 ± 5.4</td>
<td>11.5 / 23 = 0.5</td>
<td>0.5 / 1.2 = 0.42</td>
</tr>
<tr>
<td><strong>Group 2 (isometric training at an angle of 130°)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force at an angle 130°, N</td>
<td>2710 ± 618</td>
<td>3270 ± 642</td>
<td>560 ± 230</td>
<td>560 / 618 = 0.91</td>
<td></td>
</tr>
<tr>
<td>Squatting, kg</td>
<td>102 ± 28</td>
<td>110 ± 23</td>
<td>7.5 ± 4.7</td>
<td>7.5 / 28 = 0.27</td>
<td>0.27 / 0.91 = 0.30</td>
</tr>
</tbody>
</table>

**Note the results:**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Superior group</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain of performance in trained exercise</td>
<td>Second</td>
<td>560 vs. 410 N</td>
</tr>
<tr>
<td>Result gain in trained exercise</td>
<td>First</td>
<td>1.2 vs. 0.91 SD</td>
</tr>
<tr>
<td>Transfer of training results</td>
<td>First</td>
<td>0.42 vs. 0.30</td>
</tr>
<tr>
<td>Gain of performance in nontrained exercise</td>
<td>First</td>
<td>11.5 ± 5.4 vs. 7.5 ± 4.7 kg</td>
</tr>
</tbody>
</table>

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

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 a 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. The best known example is muscle glycogen depletion after hard anaerobic 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 decreases (see figure 1.5a). If the rest intervals between consecutive workouts are the right length, and if the next training session coincides in time with the supercompensation phase, the athlete’s preparedness advances (figure 1.5b). Finally, in the case of very long intervals between sessions, an athlete’s physical abilities do not change

![Figure 1.4 Time course of the restoration process and athlete's preparedness after a workout according to the supercompensation theory. The vertical axis is both for the amount of substance and for the level of preparedness. According to the model, the two curves coincide.](image-url)
Figure 1.5 Supercompensation theory. The vertical axis is both for the amount of substance and for the level of preparedness. There are three situations with rest intervals between sequential training workouts: (a) the intervals are too short and the level of athlete preparedness decreases due to accumulated fatigue; (b) the intervals are optimal and the ensuing workouts match with the supercompensation phase; and (c) the intervals are too long and there is no stable training effect.

Coaches and athletes should avoid time intervals between serial training sessions that are either too short or too long. Instead, they should seek the following:

- Optimal rest intervals between successive training sessions
- An optimal training load in each workout

The aim in selecting these intervals and loads is to ensure that a subsequent training session coincides with the supercompensation phase.

Within the framework of this theory, more sophisticated variations of the training schedule are also acceptable. One variation that is popular among coaches, the overloading microcycle (or impact microcycle), is shown...
in figure 1.6. In this case, after several training sessions with high training loads and short time intervals between sessions, a relatively long period of rest is included. The common belief is that such a training routine produces a final supercompensation that is greater than normal (compare figures 1.5 and 1.6).

For several decades, the supercompensation model has been the most popular training theory. It has been described in many textbooks and is widely accepted by coaches. In spite of its popularity, however, it deserves critical scrutiny.

The very existence of the supercompensation phase for a majority of metabolic substances has never been experimentally proven. For some metabolites, like muscle glycogen, after-exercise depletion has been definitely demonstrated. It is possible to induce glycogen supercompensation by combining a proper training routine with carbohydrate loading. This procedure, however, cannot be reproduced regularly and is used only before important competitions, not for training. The concentrations of other biochemical substrata whose role in muscular activity has been proven to be very important, for example, *adenosine triphosphate (ATP)*, do not change substantially even after very hard exercise. The restoration of initial levels of different metabolic substances requires unequal amounts of time. It is absolutely unclear which criteria (substances) one should use for selecting proper time intervals between consecutive workouts. In general, the theory of supercompensation is too simple to be correct. Over the last few years it has lost much of its popularity.

**Two-Factor Theory (Fitness-Fatigue Theory)**

The **two-factor theory** of training is more sophisticated than the supercompensation theory. It is based on the idea that preparedness, characterized by the athlete's potential sport performance, is not stable but rather varies with time. There are two components of the athlete's preparedness: those that are slow changing and those that are fast changing. The term **physical fitness** is used for slow-changing motor components of the athlete's preparedness. Physical fitness does not vary substantially over several minutes, hours, or even days. However, as a result of fatigue, psychological overstretch, or a sudden illness such as flu, an athlete's disposition toward competition may change quickly. An athlete's preparedness is sometimes thought of as a set of latent characteristics that exist at any time but can be measured only from time to time. According to the two-factor model, the
Immediate training effect after a workout is a combination of two processes:

1. Gain in fitness prompted by the workout
2. Fatigue

After one workout, an athlete's preparedness

- ameliorates due to fitness gain, but
- deteriorates because of fatigue.

The final outcome is determined by the summation of the positive and negative changes (figure 1.7).

The fitness gain resulting from one training session is supposed to be moderate in magnitude but long lasting. The fatigue effect is greater in magnitude, but relatively short in duration. For most crude estimations, it is assumed that for one workout with an average training load, the durations of the fitness gain and the fatigue effect differ by a factor of three: The fatigue effect is three times shorter in duration. This implies that if the negative impact of fatigue lasts, for instance, 24 h, the positive traces from this workout will remain through 72 h.

The time course of the immediate training effect after a single workout can be described by the equation

\[
\text{Preparedness} = P_0 + P_1 e^{-k_1 t} - P_2 e^{-k_2 t},
\]

where

- \( P_0 \) is the initial level of preparedness before the training workout;
- \( P_1 \) is the fitness gain;
- \( P_2 \) is the fatigue effect estimated immediately after the workout;
- \( t \) is time;
- \( k_1 \) and \( k_2 \) are time constraints; and
- \( e \) is the base of the system of natural logarithms, approximately 2.718.

**Figure 1.7** Two-factor theory (model) of training. The immediate effect of a training session is characterized by the joint action of two processes: fitness gain and fatigue. Athlete preparedness improves because of fitness gain and worsens because of fatigue.
One- and Two-Factor Models of Training

These models help coaches to grasp and visualize the timing of workout–rest intervals during preparation of athletes and to view training as an organized process rather than a chaotic sequence of drill sessions and rest periods.

Imagine two coaches with different coaching philosophies. Coach A strictly adheres to the one-factor theory of training and is trying to schedule a training session for when (in his estimation) the supercompensation phase takes place. Coach B prefers the two-factor theory of training and is looking for rest intervals that are long enough for proper restoration and, at the same time, short enough to maintain the acquired physical fitness level. At times the training plans of the two coaches may look similar, but the underlying philosophies are not the same. You would see the greatest differences in plans for tapering, or peaking, periods that take place immediately before important competitions. Coach A would probably recommend that his athletes decrease the number of training sessions (but not the load during the sessions) in order to compete at the climax of the supercompensation phase. For instance, in accordance with the one-factor theory, he has the athletes train only two or three times during the final week before the main competition, with each workout containing a relatively large load. Coach B, on the other hand, prefers that her athletes maintain acquired preparedness, avoid fatigue, and participate in several warm-up-type training sessions. The idea here is to decrease the training load during each session rather than the number of workouts.

According to the two-factor theory of training, the time intervals between consecutive training sessions should be selected so that all the negative traces of the preceding workout pass out of existence but the positive fitness gain persists. This model has become rather popular among coaches and is used predominantly to plan training, especially during the final training days before a competition.

Training Effects

Training effects, that is, changes that occur within the body as a result of training, can be further classified as follows:

- **Acute effects** are the changes that occur during exercise.
- **Immediate effects** are those that occur as a result of a single training session and that are manifested soon after the workout.
- **Cumulative effects** occur as a result of continued training sessions or even seasons of training.
- **Delayed effects** (also called chronic effects) are those manifested over a given time interval after a performed training routine.
- **Partial effects** are changes produced by single training means (e.g., bench press exercise).
- **Residual effects** are defined as the retention of changes after the cessation of training beyond time periods during which adaptation can take place.

Summary

The major objective in training is to induce specific adaptations toward the improvement of athletic performance. In strength training, adaptation means the adjustment of an organism to exercise (physical load). If a training program is properly planned and executed, an athlete’s strength improves as a result of adaptation.

Training adaptation takes place when the training load is above usual or the athlete is not accustomed to an exercise. Training loads
are roughly classified as stimulating, retaining, and detraining loads. In order to induce the adaptation, the following are required:

1. An exercise overload must be applied.
2. The exercises and training protocol must be specific (corresponding to the main sport exercise).
3. Both exercises and training load (intensity, volume) should vary over time periods. When the same exercise with the same training load is employed over a long period of time, performance gains decrease (accommodation).
4. Training programs must be adjusted individually to each athlete. Remember that all people are different.

To plan training programs, coaches use simple models that are based on only the most essential features. These models are known as generalized theories of training.

The theory of supercompensation, or one-factor theory, is based on the idea that certain biochemical substances are depleted as a result of training workouts. After the restoration period, the level of the substance increases above the initial level (supercompensation). If the next workout takes place during the supercompensation phase, the athlete’s preparedness increases. In the fitness-fatigue theory (two-factor theory), the immediate effect after a workout is considered a combination of (a) fitness gain prompted by the workout and (b) fatigue. The summation of positive and negative changes determines the final outcome.

The effects of training can be classified as acute, immediate, cumulative, delayed, partial, or residual.