

Strength Training Basics

Designing Workouts to Meet Patients' Goals

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Exercise

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Series

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In Brief: Dramatic advances in the prescription of anaerobic exercise, especially over the past 15 years, have led to better strength training programs. Grounded in fundamental principles of specificity, progressive overload, and variation of training, an anaerobic exercise prescription for strength development is individualized to meet training goals. Physicians who know the basic principles can prescribe exercise to effectively build muscle strength in active patients.

The many benefits of regular physical exercise have been supported by research related to human health. Research in exercise physiology has increased markedly over the past 50 years, and strength development has more recently become an integral part of most health and fitness programs. Too often, training myths and pseudoscience have fostered inappropriate training practices that are neither factual nor optimal in their results. Armed with better research methods and physiologic measurement techniques, physiologists have discovered a wealth of information about responses and adaptations to high-intensity training and identified the most important considerations for designing effective strength training programs.

The first article in this series (see "[What Is Exercise?: A Primer for Practitioners](#)") described the complete range of human power production capabilities and the differences among the physiologic responses to different intensities of exercise. The second article (see "[Aerobic Exercise and Endurance: Improving Fitness for Health Benefits](#)") addressed the responses and adaptations to aerobic exercise performed at the lower levels of muscle power production to build endurance. Anaerobic exercise is performed at the highest levels of force and power production to develop muscle strength (figure 1).

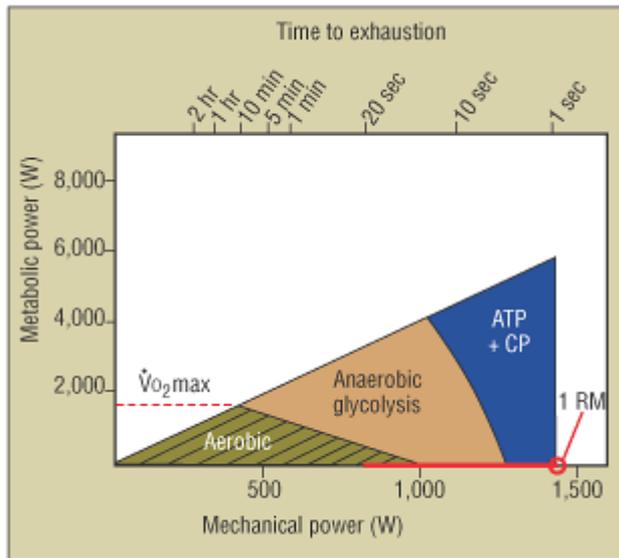


FIGURE 1. Relationship of metabolic power produced in skeletal muscle to mechanical power as measured at constant velocity on a cycle ergometer shows the contributions of the different processes. Times to exhaustion are shown on the upper coordinate. Anaerobic exercise occurs over the upper 40% of the scale (red bar). Strength exercise is performed at the very highest levels. The 1 RM (1,350 W) relies totally on ATP and CP, while exercise at lower power (750 to 1,000 W) relies principally on anaerobic glycolysis.

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1 RM = one repetition maximum; ATP = adenosine triphosphate; CP = creatine phosphate

In the context of exercise training, figure 1 shows the relationship of metabolic power to mechanical power. Strength training exercise takes place somewhere between 50% and 100% of maximal power production. The one repetition maximum (1 RM) noted in figure 1 is specific to a cycle ergometer exercise when only one revolution can be performed. In typical strength training exercises, 1 RM represents the maximal weight that can be lifted for one repetition. In 1987, Knuttgen and Kraemer¹ proposed that strength be defined as "the maximal force a muscle or muscle group can generate at a specified velocity." Using this definition, a variety of force production testing conditions can be employed (eg, static and dynamic). Several basic principles are fundamental to an understanding of the underlying scientific basis for exercise prescription in strength training.

Fundamental Principles

A number of important principles provide the basis for designing a workout program and prescribing strength training.

Individualization is key to formulating training goals that are matched to each person's needs. Pretraining (baseline) testing information is needed to monitor the training goal, optimize progression, and evaluate the success of the exercise prescription. Frequently, training time is wasted if baseline information is lacking. Optimal training programs are designed to meet realistic, specific, and individualized goals. The magnitude and rate of improvement observed with training depend on genetic endowment, training status (ie, how much prior strength training has been performed), and effectiveness of the exercise prescription. Therefore, expectations for improvements must be framed within the physiologic context that each person brings to the training program. Finally, training programs must change as program goals are attained, and this makes exercise prescription a dynamic process.

Specificity is one of the seminal principles in strength training and has a dramatic influence on almost all exercise responses and training adaptations. A high degree of task specificity is involved in human movement, acute physiologic responses, and chronic adaptations to exercise. The specific exercise stimulus is related to the: (1) muscle actions involved, (2) speed of movement, (3) range of motion, (4) muscle groups trained, (5) energy systems involved, and (6) intensity and volume of training. Although there are some general carryover effects, most of the chronic adaptations are specific to the exercise stimuli used. Effective strength training programs are designed to stimulate muscles in a specific manner related to these different variables.²

Recruitment of motor units depends on the magnitude of the external resistance used in an exercise. Aerobic exercise is performed by motor units composed of type 1 (slow-twitch) muscle fibers. Heavier resistances will also recruit motor units made up of type 2 (fast-twitch) muscle fibers. The greater the resistance used, the greater the need for more muscle tissue to be activated; therefore, a training program uses heavy loading to activate all of the muscle tissue in a

specific exercise.

Progressive overload refers to the need for heavier resistances to stimulate continued adaptation and improved force production. Progressive resistance exercise is a classic principle that was established by the research of DeLorme and Watkins.^{3,4} After World War II, they demonstrated the importance of progressive resistance exercise for increasing muscle strength in the physical rehabilitation of military casualties.

Physiologic demands in a strength training program can be increased in several ways.⁵ The load (resistance), number of sets (completion of an exercise to its RM constitutes a single set), or volume of exercise may all be increased. The repetition speed can be altered with submaximal loads according to goals. Rest periods may be lengthened to enhance force production in strength and power training or reduced to improve local muscle endurance. Optimal results in a training program depend on proper management of the progression of physical demands.

Repetition maximum allows the prescription of a targeted number of repetitions for each exercise. The external resistance at which an individual can perform only one repetition, but not two, is the 1 RM. RM also refers to other specific numbers of repetitions limited by a specific resistance (eg, 5 RM, 10 RM, 15 RM).¹ The resistance that limits the individual to 10 repetitions is the 10 RM. As resistance increases, fewer repetitions can be performed (figure 2). As the athlete gets stronger, the resistance seems lighter, and the number of repetitions will increase. The RM system has been used for more than 50 years to prescribe resistance exercise intensity.^{3,4}

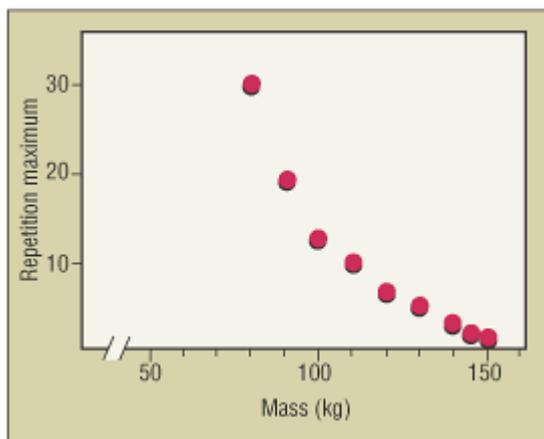


FIGURE 2. An exercise prescription for strength training is based on the relationship between an individual's endurance capability and the amount of weight used while performing repetitive maneuvers. In this example, the subject can do fewer repetitions of the bench press to exhaustion as the weight (mass) increases.

Adapted with permission from Knuttgen HG, Kraemer WJ: Terminology and measurement in exercise performance. *J Appl Sports Sci Res* 1987;1(1):1-10

More than 20 years ago, Atha's literature review⁶ established that heavier resistances result in greater strength development than lighter resistances. Thus, the RM continuum is associated with the expected gains made in 1-RM strength development. Prescription of resistance can therefore be tied to an RM target (eg, 12 RM) or, in more practical terms, an RM training zone (eg, 8 to 10 RM). The resistance used in each set and the number of repetitions performed are recorded to establish the amount of weight used in each workout. As the strength of the lifter gradually increases over time, the resistance is adjusted so that either a true RM target or RM training zone resistance is used. An RM training zone consists of a three-repetition range (eg, 8 to 10 RM). This approach reduces the need to exercise to failure on every set, which can create additional stress (eg, joint compression and soreness), especially among the older patient population.

Variation means that the resistance starts out light, with the volume of exercise high, and systematically progresses over time to heavier resistances with lower volumes. Periodization means that the volume of the training stimulus and intensity of training vary, and planned rest periods are incorporated. Using periodization successfully in strength training programs has underscored the importance of variation in training stimuli.⁷ Planned periods of rest to enhance recovery and eliminate any possible overtraining are a key component in periodization theory. Periodized training is superior to programs in which the target RM or RM zone remains the same⁷ (see "[More About Periodization](#)").

Creating a Workout

A workout comprises a selected combination of variables that produce a specific exercise stimulus.⁸ Termed the "acute program variables," the choices made for each variable define the physiologic demands of the workout. The training adaptations that occur will be specific to the choices made for each variable.

Choice of exercise. Typically matched to the biomechanical characteristics of each sports-related skill, the choice of exercise is determined by the need to:

- Use each of the major muscle groups (eg, legs, thighs, lower back, abdomen, chest, upper back, shoulders, and arms);
- Exercise both sides of each joint; and
- Include structural closed-kinetic-chain, whole-body exercises (eg, squats).

It is especially important to include structural multiple-joint exercises in a strength training program, because most sports and functional activities in everyday life depend on such movements. The use of concentric (ie, shortening muscle), eccentric (ie, forced stretch), and isometric (ie, unchanged length) muscle actions in resistance training will yield different adaptations. However, greater improvements can be made when a repetition includes both the concentric and eccentric components.⁹

The equipment used can also dictate how the muscles are trained and the type of muscle action used.² The choice of exercise must address the principle of specificity of training for the greatest carryover to targeted goals (eg, power requires explosive training with whole-body movements, such as power cleans) for enhanced physical development and performance.²

Sequence of exercise. The order in which exercises are performed during a workout affects muscle fatigue. Exercising the larger muscle groups first allows the use of heavier resistance in a given exercise. Working the large muscle groups before the small muscle groups creates a more effective training stimulus for strength development.

The sequence of exercises will affect the intensity used during the workout. Care must be taken to optimize the load being lifted for a specific exercise. This is especially important in a circuit-training workout when choosing whether to proceed from an arm exercise to another arm exercise (arm-to-arm) or from an arm exercise to a leg exercise (arm-to-leg). However, because lighter resistances are typically used in circuit training (40% to 60% of 1 RM), strength development is not the only training goal. Tolerant of the training session becomes a more important concern in circuit training, because lactate concentrations can be much higher (eg, 10 to 15 mmol/L). Beginners may not be able to tolerate arm-to-arm or leg-to-leg sequences; the resistance used may be much less than when using an arm-to-leg sequence.

The sequence of exercises is based on individual training goals and is highly dependent on energy metabolism and the amount of fatigue that is acceptable in a given workout. Therefore, exercise order needs to correspond to the training status and training goals of the individual. When the intensity is important, the large-muscle-group exercises must be placed early in the workout sequence.

Number of sets. First, not all exercises in a training session need to be performed for the same number of sets. The number of sets is one of the factors in any volume of exercise equation (eg, sets 2 reps). The preponderance of evidence indicates that multiple-set systems work best for the development of strength and local muscle endurance.^{5,6,10,11} No study has shown that single-set training is superior to multiple-set training in either trained or untrained individuals. It appears that, while both programs may be similar for increasing strength in untrained subjects during short-term training periods (6 to 12 weeks), multiple-set systems are required for optimal progress over longer training periods. However, the need for variation also becomes critical for continued improvement, and lower-volume training programs can be used for certain phases of the overall training cycle. The key factor is the periodization of training volume rather than the number of sets, which are only one factor in a volume and intensity periodization model.

The importance of the exercise volume (sets 2 repetitions 2 intensity) is a vital concept of training progression.⁵ This is especially true in individuals who have already achieved a basic level of

strength fitness. The interaction of the number of sets with the principle of variation in training or, more specifically, periodized training, may also help augment an individual's training adaptations.²

Rest periods. The influence of rest periods on the stress of the workout and the amount of resistance that can be used for an exercise has been a topic of study for the past 15 years. Rest periods between sets and exercises determine how much of the adenosine triphosphate/creatine phosphate energy source is resynthesized and how high lactic acid concentrations become in the muscles and blood.^{2,12} Lactate and hydrogen ion concentrations dramatically contribute to muscle fatigue and loss of force-production capabilities. The length of the rest period significantly influences the metabolic, hormonal, and cardiovascular responses to an acute bout of resistance exercise, as well as performance of subsequent sets.²

Rest periods span a continuum from very short to long (table 1). When training for absolute strength or power, rest periods of at least 3 to 5 minutes are recommended. Shorter rest periods (less than 2 minutes) produce dramatic increases in muscle and blood lactic acid levels and perceptions of fatigue. Incorporating gradual reductions in rest periods in a strength training program requires about 6 to 8 weeks to improve tolerance to high muscle and blood lactate concentrations, improve local muscle endurance, and stimulate anabolic hormones. If such adaptations are vital to a sport (eg, wrestling or 400- to 800-m track events), the length of rest periods between sets and exercises in training may enhance performance in those sports. Careful manipulation of rest periods is essential to avoid needless stress during training.

TABLE 1. Recommendations for Correlating Length of Rest Period With Resistance Used in Strength Training

Rest Period	RM Resistances	
<1	min >13	RM
1-2	min 11-13	RM
2-3	min 8-10	RM
3-5	min 5-7	RM
>5 min	<5 RM	

RM = repetition maximum

Intensity. The amount of resistance used for a specific exercise is one of the key variables in any strength training program.⁶ Again, using either the RM or RM training zone is probably the easiest method for determining the correct resistance. Some exercises (eg, power cleans) that rely on recruitment of many muscles across several joints are better suited to using a percent of the 1 RM. The repetition continuum from heavy resistances to lighter resistances allows one to predict the primary training outcome based on the intensity used. It appears that RM resistances of 6 or less have the greatest effect on muscle size, strength, and power, and those of 20 or more show the greatest effect on muscle endurance. This continuum makes it possible to develop a particular feature of muscle performance to varying degrees over a range of RM resistances.

Strength Training Summary

Anaerobic exercise, performed with high resistance, develops strength and explosive power. An exercise prescription for strength training is based on scientific principles and decisions about individual responses and quantifiable data (eg, baseline testing, training logs, subsequent evaluation). An effective program is individualized, engages multiple joints, and measures progress toward meeting both the demands of a sport and the goals of the individual. The development of a periodized training program starts with the design of each workout by selecting the appropriate exercise stimuli and sequence of the acute program variables. Effective training over time requires variation in the exercise stimuli as well as planned periods of rest and recovery.

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Suggested Readings

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More About Periodization

Periodization is a training theory that was developed in the former Eastern Bloc countries in the late 1950s and early 1960s based on the pioneering stress studies of Canadian endocrinologist Hans Selye, MD, PhD, DSc.¹ Selye put forth the basic concepts of the general adaptation syndrome: A new stress creates an alarm reaction, adaptation to a given stressor can be tolerated only for a given period of time, and change or removal of the stressor must be prescribed to eliminate organism failure or death. Even though the general nature of stress has been subsequently discounted scientifically in favor of a specific "fingerprint" for each stressor, the basic concepts put forth by Selye were applied to training theory and have remained viable.

Periodization uses specific cycles of training and periods of rest and recovery to optimize the adaptations of a resistance training program.² Exercise prescriptions are designed to include a variety of exercises done at different intensities to achieve maximum gains. The priority of each training cycle or set of cycles is established based on the fitness level, training goals, and competition schedule for each athlete.

Periodization models have been developed that use a host of different combinations of variables and training cycles. The concept of nonlinear periodization has received the most attention over the past 2 years and has been used successfully in training individuals from beginners to skilled athletes (eg, the University of Connecticut's women's basketball team).

The nonlinear program enables variation in intensity and volume within each 14-day training

cycle by rotating different exercise protocols. Training frequency is either 3 or 4 days a week, depending on fitness level and targeted goals. During a single workout, only one characteristic (ie, strength, power, or local muscle endurance) is trained on a given day. In addition to rest days between workouts, rest periods of 1 to 3 weeks are typically allowed at the end of each 3-month cycle before the sequence of workouts starts again.

This type of periodization permits the flexibility of using different workouts on different days to create a rapid response that optimizes training. A planned workout can be easily altered without disrupting the entire training sequence. For example, a coach may implement an especially hard morning practice, thus making a heavy strength workout in the afternoon almost impossible because of dramatic residual fatigue. Rather than implementing a workout that the athletes could not perform well, the coach could substitute a rest period or a "light" training session focused on local muscle endurance. The next heavy strength training workout would be saved for another day in the 14-day cycle.

For the average fitness enthusiast, varying the workout volume each day decreases boredom and maintains compliance in the training program. The nonlinear model has been shown to be superior to using the same repetition maximum for every workout.³⁻⁵

Workouts designed to meet training priorities, match sport requirements, and meet individual needs can be rotated during a 2-week training cycle (table A). The success of the nonlinear training approach appears to be based on creating very specific exercise stimuli in each workout, allowing muscles to rest and recover with some lighter workouts, and providing variation to improve the psychological aspects needed for high-quality training. Workouts should be unique and create different exercise stimuli to provide variation and challenge in a nonlinear training sequence.

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TABLE A. Protocols for a 14-Day Periodized Strength Training Regimen

Type of Training Day*	Goal	No. of Sets	Repetition Maximum (RM)	Rest Period Between Sets			
Very Heavy	Maximal development using major muscle groups	1	RM	strength	3-5	2-4	>4 min
Moderate	Strength hypertrophy; some local muscle endurance		development;		3	8-10	2-3 min
Power Training	Development of mechanical power† of 1 RM		of maximal		3-6	3 reps at 30%-50%	3-4 min
Very Light	Local muscle endurance				2	15-17	<1 min
High Lactic	Toleration of pH reductions		in		3	8-10	1-2 min

Acid muscles and
 blood; high-intensity local muscle
 endurance

* The intensity of exercise should vary from the previous session, with a rest day between workouts (training 3-4 dy/wk). Some types of training days will be used more than once in 14 days, depending on schedule demands and goals of the training program.

† Using structural multiple-joint exercises (eg, power cleans, hanging pulls), medicine ball throws, and plyometric jumps and drills.

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