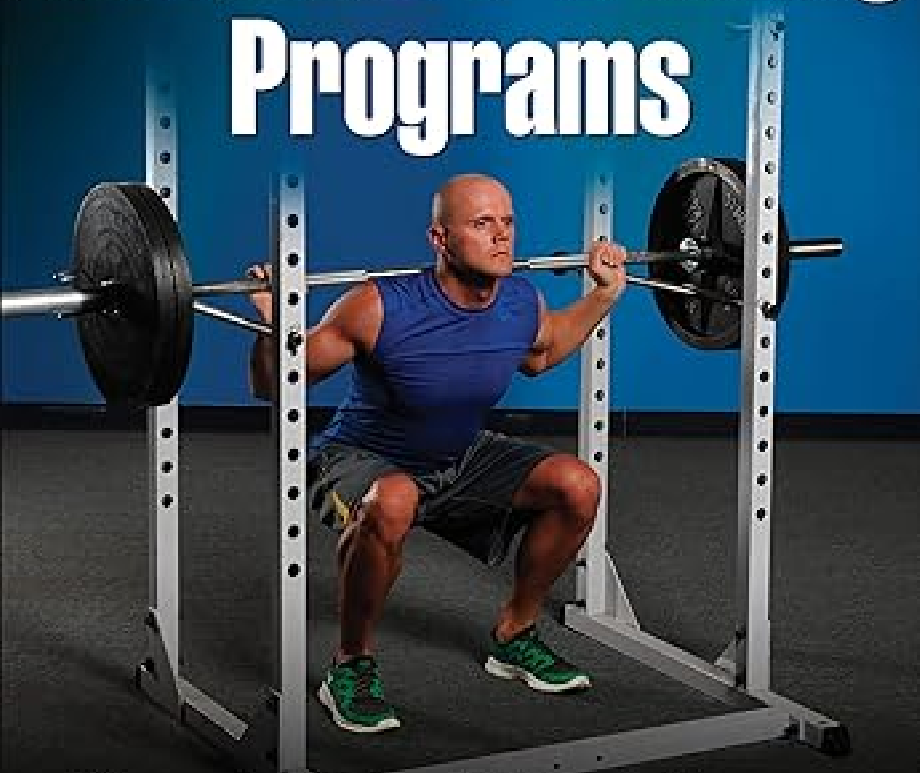
Fourth Edition

Designing Resistance Training Programs



Steven J. Fleck • William J. Kraemer

Get Complete eBook Download Link below for instant download

https://browsegrades.net/documents/286751/ebook-payment-link-for-instant-download-after-payment

Follow the Instructions for complete eBook Download by email.

Designing Resistance Training Programs

FOURTH EDITION

Steven J. Fleck, PhD
University of Wisconsin–Parkside

William J. Kraemer, PhD
University of Connecticut

Human Kinetics

Get complete eBook Order by email at eztutorsource@hotmail.com

CONTENTS

1

Basic Principles of Resistance Training and Exercise Prescription

After studying this chapter, you should be able to

1. define basic terms commonly used in the design of resistance training programs,
2. demonstrate the three types of muscle actions,
3. explain the use of voluntary muscle actions and their role in bringing about optimal gains in strength or muscle hypertrophy,
4. discuss principles of program design, including intensity, training volume, rest periods, specificity, periodization, and progressive overload, and
5. discuss the importance of safety, including proper spotting, breathing, technique, range of motion, and equipment.

Resistance training, also known as strength or weight training, has become one of the most popular forms of exercise for enhancing physical fitness as well as for conditioning athletes. The terms *strength training*, *weight training*, and *resistance training* have all been used to describe a type of exercise that requires the body's musculature to move (or attempt to move) against an opposing force, usually presented by some type of equipment. The terms *resistance training* and *strength training* encompass a wide range of training modalities, including body weight exercises, the use of elastic bands, plyometrics, and hill running. The term *weight training* typically refers only to resistance training using free weights or some type of weight training machine.

The increasing number of health club, high school, and college resistance training facilities attests to the popularity of this form of physical conditioning. Those who participate in resistance training programs expect them to produce certain health and fitness benefits, such as increased strength, increased fat-free mass, decreased body fat, and improved physical performance in either a sporting activity or daily life activities. Other health benefits, such as changes in resting blood pressure, blood lipid profile, and insulin sensitivity, can also occur. A well-designed and consistently performed resistance training program can produce all of these benefits while emphasizing one or several of them.

The fitness enthusiast, recreational weight trainer, and athlete all expect gains in strength or muscle size (muscle hypertrophy) from a resistance training program. Many types of resistance training modalities (e.g., isokinetic, variable resistance, isometric, plyometric) can be used to accomplish these goals. In addition, a variety of training systems or programs (i.e., combinations of sets, repetitions, and resistances) can produce significant increases in strength or muscle hypertrophy as long as an effective training stimulus is presented to the neuromuscular system. The effectiveness of a specific type of resistance training system or program depends on its efficacy and proper use in the total exercise prescription or program. Fitness gains will continue as long as the training stimulus remains effective, which requires increasing the difficulty (i.e., progressive overload) in some manner and using periodized programs.

Most athletes and fitness enthusiasts expect the gains in strength and power produced by a resistance training program to result in improved sport or daily life activity performance. Resistance training can improve motor performance (e.g., the ability to sprint, throw an object, or climb stairs), which can lead to better performance in various games, sports, and daily life activities. The amount of carryover from a resistance training program to a specific physical task depends on the specificity of the program. For example, multijoint exercises, such as clean pulls from the knees, have greater carryover to vertical jump ability than isolated single-joint exercises, such as knee extensions and leg curls. Both multijoint and single-joint exercises increase the strength of the quadriceps and hamstring muscle groups. However, the greater similarity of biomechanical movement and muscle fiber recruitment patterns between a multijoint exercise and most sporting or daily life activities results in greater specificity and carryover. In general, multijoint exercises have a greater specificity and carryover to motor performance tasks than single-joint exercises do.

Body composition change is also a goal of many fitness enthusiasts and athletes engaged in resistance training programs. Normally, the changes desired are a decrease in the amount of body fat and an increase in fat-free mass. However, some people also desire a gain or loss in total body weight. Body composition changes are associated with not only increases in physical performance, but also health benefits. Fitness enthusiasts, and to a lesser extent athletes, may also be interested in the health benefits of weight training, such as adaptations that reduce the risk for disease. For example, decreased resting blood pressure is associated with a decreased risk for cardiovascular disease. The success of any program in bringing about a specific adaptation depends on the effectiveness of the training stimulus produced by that program. All of the preceding changes can be achieved by a properly designed and performed resistance training program.

Resistance training can produce the changes in body composition, strength, power, muscle hypertrophy, and motor performance that many people desire, as well as other health benefits. To achieve optimal changes in these areas, people must adhere to some basic principles that apply regardless of the resistance modality or the type of system or program.

Different people desire different changes from a resistance training program. Bodybuilders mostly desire increased fat-free mass and decreased percent body fat. Other athletes may desire improved power or motor performance, and fitness enthusiasts often desire the aforementioned changes as well as health benefits such as decreased blood pressure and positive changes to the blood lipid profile.

Basic Definitions

Before discussing the principles of resistance training, we will define some basic terms commonly used in describing resistance training programs and principles. Having multiple meanings for the same term leads to misunderstanding. This is why terminology is so important when communicating with others interested in strength and conditioning.

- When a weight is being lifted, the major muscles involved are shortening, or performing a **concentric muscle action** (see figure 1.1*a*). During a concentric muscle action, force is developed and shortening of the muscle occurs; therefore, the word *contraction* is also appropriate for this type of muscle action.
- When a weight is being lowered in a controlled manner, the major muscles involved are developing force and lengthening in a controlled manner; this is termed an **eccentric muscle action** (see figure 1.1*b*). Muscles can only shorten or lengthen in a controlled manner; they cannot push against the bones to which they are attached. In most exercises, gravity pulls the weight back to the starting position. To control the weight as it returns to the starting position, the muscles must lengthen in a controlled manner; otherwise, the weight will fall abruptly.
- When a muscle is activated and develops force, but no visible movement at the joint occurs, an **isometric muscle action** takes place (see figure 1.1*c*). This can occur when a weight is held sta-

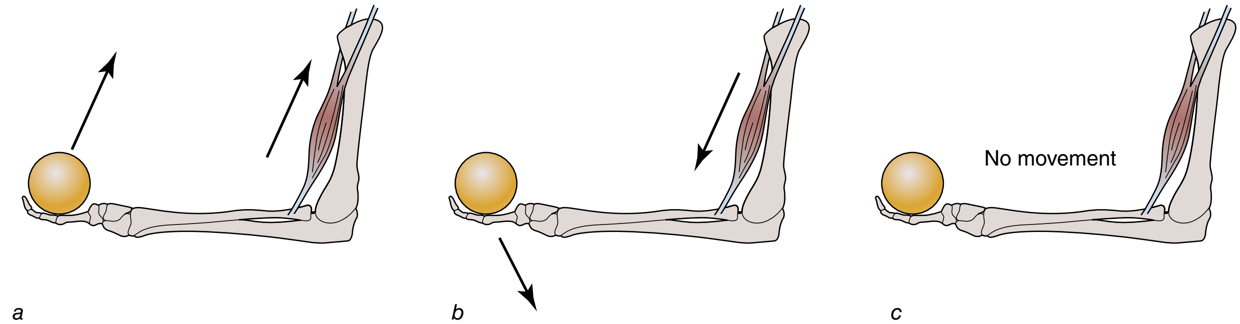


FIGURE 1.1 Major types of muscle actions. *(a)* During a concentric muscle action, the muscle shortens. *(b)* During an eccentric muscle action, the muscle lengthens in a controlled manner. *(c)* During an isometric muscle action, no movement of the joint occurs, and no shortening or lengthening of the total muscle takes place.

tionary or when a weight is too heavy to lift any farther. Maximal isometric action force is greater than maximal concentric force at any velocity of movement, but less than maximal eccentric force at any movement velocity.

- A **repetition** is one complete motion of an exercise. It normally consists of two phases: the concentric muscle action, or lifting of the resistance, and the eccentric muscle action, or lowering of the resistance. However, in some exercises a complete repetition may involve several movements and thus several muscle actions. For example, a complete repetition of the power clean requires concentric muscle actions to accelerate the weight so it can be caught at a shoulder-height position, eccentric muscle actions as the knees and hips flex to drop underneath the weight, and then concentric actions to assume a full standing position.

- A **set** is a group of repetitions performed continuously without stopping or resting. Although a set can consist of any number of repetitions, sets typically range from 1 to 15 repetitions.

- A **repetition maximum, or RM,** is the maximal number of repetitions per set that can be performed in succession with proper lifting technique using a given resistance. Thus, a set at a certain RM implies that the set is performed to momentary voluntary fatigue usually in the concentric phase of a repetition. The heaviest resistance that can be used for one complete repetition of an exercise is called 1RM. A lighter resistance that allows completion of 10, but not 11, repetitions with proper exercise technique is called 10RM.

- A **repetition training zone** is a range of typically three repetitions (e.g., 3-5, 8-10). When performing the repetitions in a repetition training zone, the resistance used can allow the person to perform the desired number of repetitions with relative ease or can result in momentary voluntary failure. If the resistance used results in momentary voluntary failure, the repetition training zone is termed an **RM training zone**. However, using an RM training zone does not necessarily result in a set to failure. For example, using an 8- to 10RM training zone for 8 repetitions is not training to failure; performing 10 repetitions may bring the person close to failure.

- **Power** is the rate of performing work (see box 1.1). During a repetition, power is defined as the weight lifted multiplied by the vertical distance the weight is lifted divided by the time to complete the repetition. Power can be increased by lifting the same weight the same vertical distance in a shorter period of time. Power can also be increased by lifting a heavier resistance the same vertical distance in the same period of time as a lighter resistance. Normally, factors such as arm and leg length limit the ability to increase power by moving a weight a greater distance. Thus, the only ways to increase power are to increase movement speed or lift a heavier resistance with the same or greater movement speed than one would use with a lighter resistance.

- **Maximal strength** is the maximal amount of force a muscle or muscle group can generate in a specified movement pattern at a specified velocity (Knuttgen and Kraemer 1987). In an exercise such as the bench press, 1RM is a measure of strength at a relatively slow speed. The classic strength–velocity curve indicates that as the concentric velocity increases, maximal strength decreases (see chapter 3). On the other hand, as eccentric

BOX 1.1 **PRACTICAL QUESTION**

What Is the Difference Between Work and Power?

Work is defined as force multiplied by the distance a weight or resistance is moved. Power is the rate of doing work, or work divided by time. Work can be increased by increasing the distance a weight is moved or increasing the weight or resistance being moved. Power can be increased the same way work is increased, or by decreasing the time in which a certain amount of work is performed. If the time to perform a certain amount of work is decreased by half, power doubles. Work and power can be calculated for a resistance training exercise and are normally calculated for the concentric phase of a repetition. If 100 kg (220 lb) is lifted 0.9 m vertically in two seconds during a bench press, the work performed is 90 kg $\cdot$ m^{-1} (100 kg $\times$ 0.9 m) or 882.9 joules (1 kg $\cdot$ m^{-1} = 9.81 joules). The average power during the concentric phase is 45 kg $\cdot$ m^{-1} $\cdot$ sec^{-1} (100 kg $\times$ 0.9 m / 2 sec) or 441.5 watts (1 watt = 1 joule $\cdot$ s^{-1}). During weight training exercises high-speed video recording or some other means is needed for accurately determining the time and distance a weight is moved to accurately determine work and power. In some exercises, such as the bench press as in this example, ignoring the mass of the body parts moved results in little error in calculating work and power. But in other exercises, such as a squat, in which the mass of the body parts moved is high, not including the mass of the body parts moved does result in a significant amount of error when calculating work and power.

velocity increases, maximal strength increases and then plateaus.

Maximal Voluntary Muscle Actions

Maximal voluntary muscle actions, or performing sets to failure, appears to be an effective way to increase muscular strength (see the discussion of dynamic constant external resistance training in chapter 2). This does not mean that the maximal resistance possible for one complete repetition (1RM) must be lifted. Performing **maximal voluntary muscle actions** means that the muscle generates as much force as its present fatigue level will allow. The force a partially fatigued muscle can generate during a maximal voluntary muscle action is not as great as that of a nonfatigued muscle. The last repetition in a set to momentary concentric failure is thus a maximal voluntary muscle action, even though the force produced is not the absolute maximum because the muscle is partially fatigued.

Many resistance training systems use momentary concentric failure, or RM resistance, to ensure the performance of maximal voluntary muscle actions. This does result in increases in strength, power, or local muscular endurance (see chapter 2). As a result of daily variation in strength due to a variety of factors (e.g., fatigue from other types of training, a poor night's sleep), many programs use repetition training zones or RM training zones to prescribe training resistances for a set.

A training zone encompasses a small number of repetitions, such as a 4-6 zone or an 8-10 zone, and does not necessarily result in momentary concentric failure. An RM training zone also encompasses a small range of repetitions, but does result in momentary concentric failure. One rationale to use training zones instead of RM training zones is that always carrying sets to failure may result in less than optimal increases in power (see chapter 6). Training zones and RM training zones allow for day-to-day variations in strength, whereas prescribing a true repetition maximum, such as 6RM, requires that the lifter perform exactly six repetitions. The lifter can be instructed to perform a minimum of six repetitions or more if possible, or as close to six repetitions as possible. Prescribing the number of repetitions per set in this manner results in prescribing an RM training zone or sets to momentary voluntary fatigue.

Maximal increases in strength can occur without maximal voluntary muscle actions or sets carried to failure in all training sessions or even no training sessions. This is true for seniors (Hunter et al. 2001) as well as healthy adults (Izquierdo et al. 2006). In seniors equivalent strength and fat-free mass gains occur when performing maximal voluntary muscle actions during all three training sessions per week and during only one of three training sessions per week. In healthy adults, not performing sets to failure resulted in equivalent maximal strength gains as well as greater power gains after a peaking training phase compared to carrying sets to failure (see chapter 6). Thus, performing sets to voluntary fatigue is not a prerequisite for strength gains. However, how far from failure (the number of repetitions prior to being unable to continue) a set can be terminated and still result in optimal maximal strength gains is not known. So generally, it is recommended that sets be carried at least close to failure at some point in a training program.

In some exercises, performance of maximal voluntary muscle actions does not necessarily mean that the last repetition in a set is not completed. For example, when some muscle fibers become fatigued during power cleans, the velocity of the bar decreases and the weight is not pulled as high as it could be during the first repetition of a set even though the trainee is exerting maximal effort. Because the trainee developed maximal force in a partially fatigued state, by definition this is a maximal voluntary muscle action.

Some resistance training machines have been specifically designed to force the muscle to perform maximal voluntary muscle actions either through a greater range of motion or for more repetitions in a set. Developments in equipment such as variable resistance, variable variable resistance, and isokinetic equipment (see chapter 2) attest to a belief in the necessity for close to maximal voluntary muscle actions in training. All competitive Olympic weightlifters, powerlifters, and bodybuilders use maximal voluntary muscle actions at some point in their training programs. They recognize the need for such actions at some point in the training process to bring about optimal gains in strength or muscle hypertrophy. However, strength gains and hypertrophy can clearly occur without carrying sets to absolute failure.

Intensity

The **intensity** of a resistance training exercise is estimated as a percentage of the 1RM or any RM resistance for the exercise. The minimal intensity that can be used to perform a set to momentary voluntary fatigue in young, healthy people to result in increased strength is 60 to 65% of 1RM (McDonagh and Davies 1984; Rhea et al. 2003). However, progression with resistances in the 50 to 60% of 1RM range may be effective and may result in greater 1RM increases than the use of heavier resistances in some populations (e.g., in children and senior women; see chapters 10 and 11). Additionally, approximately 80% of 1RM results in optimal maximal strength gains in weight-trained people (Rhea et al. 2003). Performing a large number of repetitions with a very light resistance will result in no or minimal strength gain. However, the maximal number of repetitions per set of an exercise that will result in increased strength varies from exercise to exercise and from muscle group to muscle group. For example, the maximal number of repetitions possible at 60% of 1RM by trained men in the leg press is 45.5 and for the arm curl is 21.3 (see table 1.1).

In addition, training level may also affect the number of repetitions performed in a weight machine exercise; trained men and women typically perform more repetitions at a given percentage of 1RM than untrained men and women do (Hoeger et al. 1990). *Trained* was defined very heterogeneously as having two months to four years of training experience. Thus, it appears that when using a percentage of 1RM resistance, the

TABLE 1.1 **Number of Repetitions to Concentric Failure at Various Percentages of an Exercise**

Hoeger et al. 1990	Leg press 60% of 1RM	Leg press 80% of 1RM	Bench press 60% of 1RM	Bench press 80% of 1RM	Arm curl 60% of 1RM	Arm curl 80% of 1RM
Untrained	33.9	15.2	19.7	9.8	15.3	7.6
Trained	45.5	19.4	22.6	12.2	21.3	11.4
Shimano et al. 2006	**Squat 60% of 1RM**	**Squat 80% of 1RM**	**Bench press 60% of 1RM**	**Bench press 80% of 1RM**	**Arm curl 60% of 1RM**	**Arm curl 80% of 1RM**
Untrained	35.9	11.8	21.6	9.1	17.2	8.9
Trained	29.9	12.3	21.7	9.2	19.0	9.1

The average number of repetitions possible at percentages of 1RM in machine exercises and free weight barbell exercises.

number of repetitions possible is higher with larger muscle groups and in trained people when using weight machines. However, not all studies confirm that the number of repetitions possible at a percentage of 1RM increases with training; the percentage of 1RM used for a 10RM in machine exercises was generally unchanged in previously untrained women after 14 weeks of training (Fleck, Mattie, and Martensen 2006).

When trained men perform barbell free weight exercises, more repetitions per set are also possible with large-muscle-group exercises (squat and bench press) than with small-muscle-group exercises (arm curl). However, cross-sectional data indicate that trained men may perform fewer repetitions at given percentages than untrained men in the squat but not in other exercises (table 1.1). Also, 12 weeks of weight training of American football players did not increase the number of repetitions possible at 60, 70, 80 and 90% of 1RM in the bench press (Brechue and Mayhew 2009), but did increase the number of repetitions possible at 70% of 1RM in the squat (Brechue and Mathew 2012). On average, similar free weight and machine exercises, such as barbell and machine arm curls, produce similar results in the number of repetitions possible at a specific percentage of 1RM except for the squat, in which typically fewer repetitions than the leg press were performed by trained and untrained men, probable due to less low back use in the leg press.

Thus, RMs or RM training zones vary from exercise to exercise, between men and women, between similar machine and free weight exercises and possibly with training status. It is also important to note that a great deal of individual variation exists in the number of repetitions possible at a percentage of 1RM in all exercises (as shown by the large standard deviations in the aforementioned studies). These factors need to be considered when the percentage of 1RM or RM training zones are used to prescribe training intensity and volume.

Lower intensities, with resistance moved at a fast velocity, are used when training for power (see chapter 7). This is in large part because, in many exercises, lower intensities (light resistance) allow faster velocities of movement and result in higher power output than other combinations of intensity and velocity of movement. This is true for both multijoint and single-joint exercises (Komi 1979), but typically, multijoint exercises are used when training for power.

Unlike the intensity of endurance exercise, the intensity of resistance training is not estimated by heart rate during the exercise. Heart rate during resistance exercise does not consistently vary with the exercise intensity (see figure 1.2). Heart rate attained during sets to momentary voluntary fatigue at 50 to 80% of 1RM can be higher than heart rate attained during sets with 1RM or sets performed to momentary voluntary fatigue at higher percentages of 1RM (Fleck and Dean 1987). Heart rate during training is different with various types of weight training programs (Deminice et al. 2011). Maximal heart rate attained during a training session using three sets of 10RM and 90-second rest periods between sets and exercises, and performing all the arm exercises followed by all the leg exercises, results in a mean heart rate of 117 beats per minute (60% of maximal heart rate). Performing the same exercises for the same number of sets with the same resistance with an alternating arm–leg exercise order with little rest between exercises results in a mean heart rate of 126 beats per minute (65% of maximal heart rate). In both training sessions the same intensity, number of sets, and repetitions were performed. The difference in heart rate was due to the use of exercise order and rest period lengths and not to differences in training intensity or volume, which is the next concept discussed. Recovering between sets and exercises to a specific heart rate, however,

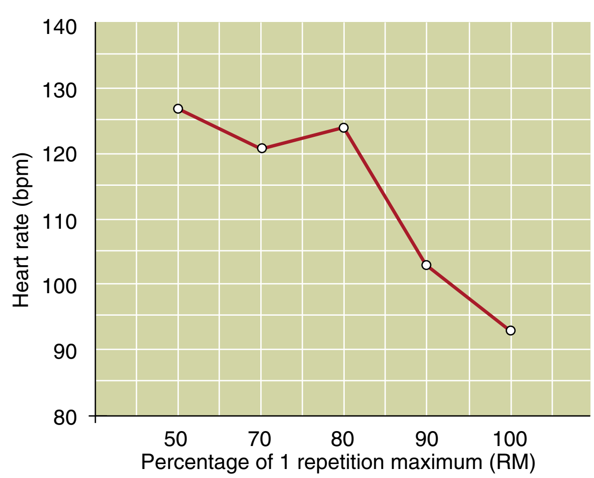


FIGURE 1.2 Maximal heart rate of a moderately trained group of males during knee extension sets to momentary voluntary fatigue at various percentages of 1RM. The heart rate does not reflect the intensity (% of 1RM) of the exercise.

Based on Fleck and Dean 1987.

has been used to determine the rest period length between sets and exercises (Piirainen et al. 2011).

Training Volume

Training volume is a measure of the total amount of work (in joules) performed in a training session, a week of training, a month of training, or some other period of time. Training frequency (number of training sessions per week, month, or year), training session duration, number of sets, number of repetitions per set, and number of exercises performed per training session all have a direct impact on training volume. The simplest method to estimate volume is to add the number of repetitions performed in a specific time period, such as a week or a month of training. Volume can also be estimated by the total amount of weight lifted. For example, if 100 lb (45 kg) are used to perform 10 repetitions, the volume of training is 1,000 lb (450 kg) (10 repetitions multiplied by 100 lb, or 45 kg).

Training volume is more precisely determined by calculating the work performed. Total work in a repetition is the resistance multiplied by the vertical distance the weight is lifted. Thus, if 100 lb (45 kg or 445 N) is lifted vertically 3 ft (0.9 m) in a repetition, the volume or total work is 100 lb multiplied by 3 ft or 300 ft · lb (445 N × 0.9 m = 400 J). Training volume for a set of 10 repetitions in this example is 300 ft · lb (400 J) per repetition multiplied by 10 repetitions, which equals 3,000 ft · lb (4,000 J). The calculation of training volume is useful in determining the total training stress.

A relationship exists between higher training volumes and training outcomes, such as muscle hypertrophy, decreased body fat, increased fat-free mass, and even motor performance. Larger training volumes may also result in a slower loss of strength gains after cessation of training (Hather, Tesch et al. 1992). Thus, training volume is a consideration when designing a resistance training program (see box 1.2).

Rest Periods

Rest periods between sets of an exercise, between exercises, and between training sessions allow recovery and are important for the success of any program. The rest periods allowed between sets and between exercises during a training session are in large part determined by the goals of the training program. Rest period length affects recovery and blood lactate, a measure of acidity, as well as the hormonal responses to a training session (see chapter 3). The rest periods between sets and exercises, the resistance used, and the number of repetitions performed per set all affect the design and goals of the program (see chapter 5). In general, if the goal is to emphasize the ability to exhibit maximal strength, relatively long rest periods (several minutes), heavy resistances, and

BOX 1.2 **RESEARCH**

Training Volume Affects Strength Gains

Strength gains are affected by total training volume. Several meta-analyses have concluded that training programs that use multiple sets of an exercise result in greater increases in strength than single-set programs do (Peterson et al. 2004; Rhea et al. 2003; Wolfe, LeMura, and Cole 2004). But increasing the number of sets performed is only one way of increasing training volume. Training volume is also affected by other training variables, such as training frequency. Performing nine exercises during six weeks of training for either three days per week with two sets of 10 repetitions (10RM) or two days per week with three sets of 10 repetitions (10RM) results in the same total training volume (six sets of 10 repetitions of each exercise per week). The only difference between the programs is training frequency. No significant difference in 1RM bench press or back squat was shown between training programs. The authors concluded that total training volume is more important than other training variables, such as training frequency and number of sets, to bring about maximal strength gains (Candow and Burke 2007).

Candow, D.G., and Burke, D.G. 2007. Effect of short-term equal-volume resistance training with different workout frequency on muscle mass and strength in untrained men and women. *Journal of Strength and Conditioning Research* 21: 204-207.

one to six repetitions per set are suggested. When the goal is to emphasize the ability to perform high-intensity exercise for short periods of time, rest periods between sets should be less than one minute. Repetitions and resistance can range from 10 to 25 repetitions per set, depending on the type of high-intensity ability the person wishes to enhance. If enhancement of long-term endurance (aerobic power) is the goal, then circuit-type resistance training with short rest periods (less than 30 seconds), relatively light resistances, and 10 to 15 repetitions per set is one training prescription.

Shorter rest period lengths do result in an overall shorter training session. If the same session is performed with one-minute rest periods rather than two-minute rest periods between sets and exercises, the session is completed in about half the time. This may be important for trainees with limited time in which to train. However, other training variables, such as the number of repetitions per set, may be affected (see box 1.3). Trainees must also make sure that exercise technique is not compromised by short rest periods; greater fatigue levels can result in improper technique, which may increase the potential for injury.

Many fitness enthusiasts and some athletes allow one day of recovery between resistance training sessions for a particular muscle group. This

BOX 1.3 **RESEARCH**

Shorter Rest Periods Significantly Affect Training Volume

Short rest periods between sets and exercises offer the advantage of completing a training session in less time. Fatigue as the training session progresses decreases training volume as indicated by a decrease in number of repetitions possible with a specific intensity. Figure 1.3 presents the number of repetitions possible at 8RM as a training session progresses. Three-minute rest periods allow significantly more repetitions per set than one-minute rest periods. The number of repetitions possible in a set decreases substantially in successive sets of an exercise and particularly when two exercises involving the same muscle groups are performed in succession. Rest periods as well as exercise order affect training volume by affecting the number of repetitions performed per set.

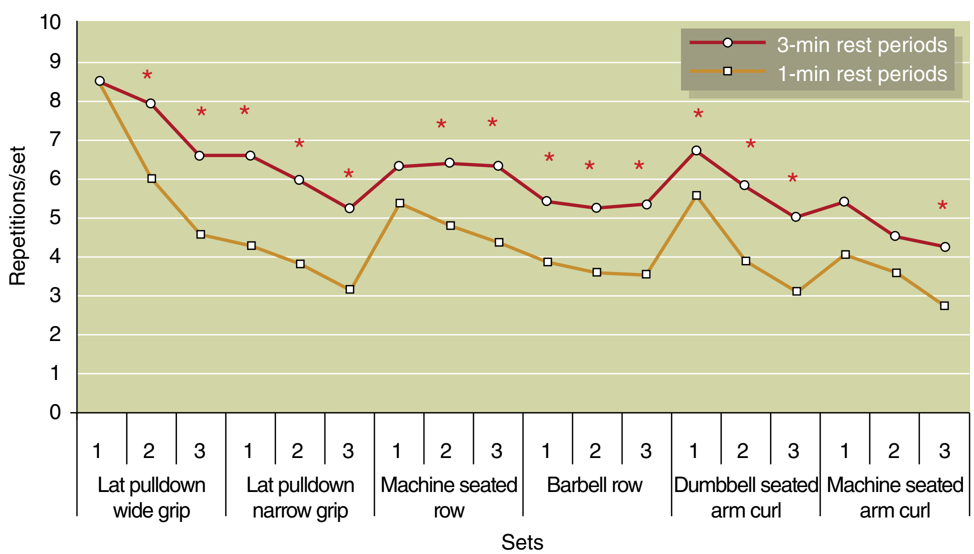


FIGURE 1.3 The number of repetitions possible in a training session with one- and three-minute rest periods between sets and exercises.

* = significant difference in repetitions with one- and three-minute rest periods in the same set.

Adapted, by permission, from R. Miranda, S.J. Fleck, et al., 2007, "Effect of two different rest period lengths on the number of repetitions performed during resistance training," *Journal of Strength and Conditioning Research* 21:1032-1036.

is a good general rule, although some evidence indicates that other patterns of training sessions and recovery periods are equally or even more beneficial (see the discussion of rest periods between workouts in chapter 5 and the discussion of two training sessions per day in chapter 7). A practical indication of the need for more rest between training sessions is residual muscular soreness. When muscular soreness interferes with performance in the following training session, the rest between training sessions was probably insufficient.

Velocity Specificity

Many coaches and athletes maintain that some resistance training should be performed at the velocity required during the actual sporting event. For many sporting events this means a high velocity of movement. **Velocity specificity** is the concept that resistance training produces its greatest strength and power gains at the velocity at which the training is performed (see chapter 7 for a discussion of movement speed and power development). However, if the training goal is to increase strength at all velocities of movement and only one training velocity is to be used, an intermediate velocity is the best choice. Thus, for someone interested in general strength, an intermediate training velocity is generally recommended. However, training at a fast velocity against light resistance and training at a slower velocity against heavy resistance both demonstrate velocity-specific strength gains. Thus, velocity-specific training to maximize strength and power gains at velocities needed during competition is appropriate for athletes at some point in their total training programs. If strength and power need to be maximized across velocities ranging from slow to very fast, training at several velocities of movement should be performed.

Muscle Action Specificity

If a person trains isometrically and progress is evaluated with a static muscle action, a large increase in strength may be apparent. However, if progress is evaluated using concentric or eccentric muscle actions, little or no increase in strength may be demonstrated. This is termed muscle action specificity or testing specificity. **Muscle action specificity** indicates that gains in strength are in part specific to the type of muscle action used in training (e.g., isometric, variable resistance, isokinetic). **Testing specificity** is a similar term referring to the fact that strength increases are higher when tested using an exercise or muscle action performed during training and less when tested using an exercise or muscle action involving the same muscle groups, but not performed during training. Testing specificity is also apparent when testing and training are performed using the same exercise but different types of equipment, such as training with a machine bench press and testing with a free weight bench press.

The specificity of strength gains is caused by neural adaptations resulting in the ability to recruit the muscles in the most efficient way to perform a particular type of muscle action or exercise (see the discussion of nervous system adaptations in chapter 3). Generally, fitness gains are evaluated with an exercise performed during training, and the training program for a specific sport or activity should include the types of muscle actions encountered in that sport or activity. For example, isometric muscle actions are frequently performed while wrestling, so it is beneficial to incorporate some isometric training into the resistance training program of wrestlers.

Muscle Group Specificity

Muscle group specificity simply means that each muscle group requiring strength gains or other adaptations to the training program must be trained. In other words, the muscle tissue in which adaptations are desired must be activated or recruited by the exercises performed during training (see chapter 3). If an increase in strength is desired in the flexors (biceps group) and extensors (triceps) of the elbow, exercises for both muscle groups need to be included in the training program. Exercises in a training program must be specifically chosen for each muscle group in which a training adaptation such as increased strength, power, endurance, or hypertrophy is desired.

Energy Source Specificity

Energy source specificity refers to the concept that physical training may bring about adaptations of the metabolic systems predominantly used to supply the energy needed by muscles to perform a given physical activity. There are two anaerobic sources and one aerobic source of energy for muscle actions. The anaerobic sources of energy supply the majority of energy for high-power, short-duration events such as sprinting 100 m, whereas the aerobic energy source supplies the majority of energy for longer-duration, lower-power events, such as running 5,000 m. If an increase in the ability of a muscle to perform anaerobic exercise is desired, the bouts of exercise should be of short duration and high intensity. To increase aerobic capability, training bouts should be of longer duration and lower intensity. Resistance training is most commonly used to bring about adaptations of the anaerobic energy sources; however, resistance training can cause increases in aerobic capability as indicated by increases in maximal oxygen consumption (see chapter 3). The number of sets and repetitions, the length of rest periods between sets and exercises, and other training variables need to be appropriate for the energy source in which training adaptations are desired (see chapter 5).

Periodization

Periodization, planned variation in the training volume and intensity, is extremely important for continued optimal gains in strength, as well as other training outcomes (see chapter 7). Additionally, changes in other training variables, such as exercise choice (e.g., performing more power-oriented exercises at some point in the training program) and rest period length between sets and exercises can also be made on a regular basis in a periodized fashion.

Variations in the position of the feet, hands, and other body parts that do not affect the safety of the lifter affect muscle fiber recruitment patterns and can also be used as training variations. The use of several exercises to vary the conditioning stimulus of a particular muscle group is also a valuable way to change muscle fiber recruitment patterns to produce continued increases in strength and muscle fiber hypertrophy (see the discussion of motor unit activation in chapter 3). Periodization is needed for achieving optimal gains in strength and power as training progresses (American College of Sports Medicine 2009; Rhea and Alderman 2004). Considering the factors that can be manipulated, there are an infinite number of possibilities for periodization of resistance training; however, in terms of research, training volume and intensity are the most commonly manipulated variables (see box 1.4).

Progressive Overload

Progressive overload is the practice of continually increasing the stress placed on the body as force, power, or endurance capabilities increase as a result of training. **Progressive resistance** is a similar term that applies specifically to resistance training; the stress of resistance training is gradually increased as fitness gains are achieved with training. The term was developed by physician Capt. Thomas

BOX 1.4 PRACTICAL QUESTION

Can the Same Training Volume and Intensity Be Used to Create Two Different Periodization Plans?

Training volume and intensity are the most commonly manipulated training variables in research examining the effects of periodized resistance training. These variables are also commonly changed by strength and conditioning professionals when creating programs for athletes or clients. The same average intensity and volume can be used to create very different programs. If three training zones of 12- to 15RM, 8- to 10RM, and 4- to 6RM are used each for one month of training in succession (linear periodization; see chapter 7) with three training days per week, a total of 12 training sessions are performed with each RM training zone. If the same RM training zones are performed one day per week for three months of training (nonlinear periodization), there are also 12 training sessions performed with each of the three training zones. Although the arrangement of training volume and intensity is quite different in these two programs, the total training volume and intensity are equivalent.

Delorme after World War II when he demonstrated in a series of studies that resistance training was an effective medical treatment for rehabilitating wounded soldiers from war-related injuries. Not knowing what to call this form of resistance training in which he carefully increased the resistance used over time, his wife during a dinner conversation on the topic said, "Why don't you call it progressive resistance training," and so the term was created (oral communication with Dr. Terry Todd, University of Texas at Austin). For example, at the start of a training program the 5RM for arm curls might be 50 lb (23 kg), which is a sufficient stimulus to produce an increase in strength. As the program progresses, five repetitions with 50 lb (23 kg) would not be a sufficient stimulus to produce further gains in strength because the trainee can now easily perform five repetitions with this weight. If the training stimulus is not increased in some way at this point, no further gains in strength will occur.

Several methods are used to progressively overload muscles (American College of Sports Medicine 2009). The most common is to increase the resistance to perform a certain number of repetitions. The use of RMs or RM training zones automatically provides progressive overload because as a muscle's strength increases, the resistance necessary for performing an RM or staying within an RM training zone increases. For example, a 5RM or a 4- to 6RM training zone may increase from 50 lb (23 kg) to 60 lb (27 kg) after several weeks of training. However, as discussed earlier, performing sets to failure is not needed to cause increased strength. As long as the resistance used is gradually increased, progressive overload is occurring.

Other methods to progressively overload the muscle include increasing the total training volume by increasing the number of repetitions, sets, or exercises performed per training session; increasing the repetition speed with submaximal resistances; changing the rest period length between exercises (i.e., shortening the rest period length for local muscular endurance training); and changing the training frequency (e.g., performing multiple training sessions per day for a short period of time). To provide sufficient time for adaptations and to avoid overtraining, progressive overload of any kind should be gradually introduced into the training program; sufficient time is needed for the trainee to become accustomed to the training and make physiological adaptations to it.

Safety Aspects

Successful resistance training programs have one feature in common—safety. Resistance training has some inherent risk, as do all physical activities. The chance of injury can be greatly reduced or completely removed by using correct lifting techniques, spotting, and proper breathing; by maintaining equipment in good working condition; and by wearing appropriate clothing.

The chance of being injured while performing resistance training is very slight. Among college American football players (Zemper 1990) the weight room injury rate was very low (0.35 per 100 players per season). Weight room injuries accounted for only 0.74% of the total reported time-lost injuries during the football season. This injury rate may be reduced to even lower levels through more rigorous attention to proper procedures in the weight room (Zemper 1990), such as proper exercise technique and the use of collars with free weight bars. Injury rates in a supervised health and fitness facility that included resistance training as part of the total training program were also very low (0.048 per 1,000 participant-hours) (Morrey and Hensrud 1999). A review of the U.S. Consumer Product Safety Commission National Electronic Injury Surveillance System indicates that 42% of resistance training injuries occur at home (Lombardi and Troxel 1999), and 29 and 16% of resistance training injuries occur at sport facilities and schools, respectively. Muscle sprains and strains during weight training are common injuries in children as well as adults, but increase in frequency with age from 8-13 years to 23-30 years of age (Meyer et al. 2009). Accidental injury is highest in children and decreases with increasing age.

These results indicate that lack of supervision contributes to injury. Exercise techniques involving the shoulder complex also need special attention because 36% of documented resistance training injuries involve the shoulder complex (Kolber et al. 2010). The injury rate even in competitive male and female powerlifters is low compared to that in other sports. The rate of injury in powerlifters was only 0.3 injuries per lifter per year (1,000 hours of training = 1 injury) (Siewe et al. 2011). The rate of injury in the powerlifters increased with age, and women had more injuries than men. Interestingly, the use of weight belts actually increased the rate of lumbar spine injuries most likely due to an overestimation of the degree of protection to the low back weight belts provide when lifting maximal loads. So, although resistance training is a very safe activity, all proper safety precautions should be taken, and supervision should always be present.

Spotting

Proper spotting is necessary for ensuring the safety of the participants in a resistance training program. **Spotting** refers to the activities of people other than the lifter that help ensure the safety of the lifter. Spotters serve three major functions: to assist the trainee with the completion of a repetition if needed, to critique the trainee's exercise technique, and to summon help if an accident does occur. Briefly, the following factors should be considered when spotting:

- Spotters must be strong enough to assist the trainee if needed.
- During the performance of certain exercises (e.g., back squats), more than one spotter may be necessary to ensure the safety of the lifter.
- Spotters should know proper spotting technique and the proper exercise technique for each lift for which they are spotting.
- Spotters should know how many repetitions the trainee is going to attempt.
- Spotters should be attentive at all times to the lifter and to his or her exercise technique.
- Spotters should summon help if an accident or injury occurs.

Following these simple guidelines will aid in the avoidance of weight room injuries. A detailed description of spotting techniques for all exercises is beyond the scope of this text, but spotting techniques for a wide variety of resistance training exercises have been presented elsewhere (Fleck 1998; Kraemer and Fleck 2005).

Breathing

A **Valsalva maneuver** is holding one's breath while attempting to exhale with a closed glottis. This maneuver is not recommended during resistance training exercises because blood pressure rises substantially (see the discussion of acute cardiovascular responses in chapter 3). Figure 1.4 depicts the intra-arterial blood pressure response to maximal isometric muscle actions during one-legged knee extensions. The blood pressure response during an isometric muscle action in which breathing was allowed is lower than the response observed during either an isometric action performed simultaneously with a Valsalva maneuver or during a Valsalva maneuver in the absence of an isometric muscle action. This demonstrates that the elevation of blood pressure during resistance training is lower when the person breathes during the muscle action compared to when a Valsalva maneuver is performed during the muscle action. Elevated blood pressure increases the afterload on the heart; this requires the left ventricle to develop more pressure to eject blood, which makes the work of the left ventricle more difficult.

Exhaling during the lifting of the resistance and inhaling during the lowering of the resistance are normally recommended, although little difference in the heart rate and blood pressure response during resistance training is observed between that and inhaling during lifting and exhaling during lowering (Linsenbardt, Thomas, and Madsen 1992). During an exercise using 1RM or during the

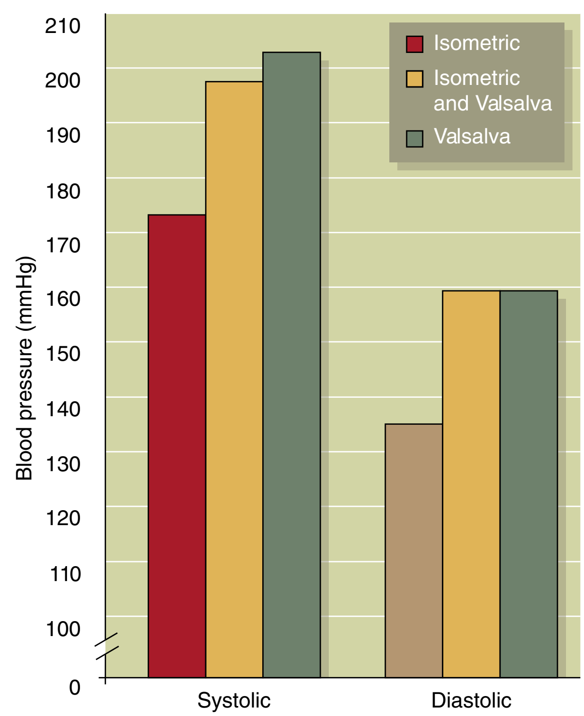


FIGURE 1.4 Systolic and diastolic blood pressure during an isometric action only, simultaneous isometric action and Valsalva maneuver, and Valsalva maneuver only.

N = 6.

Unpublished data of authors.

last few repetitions of a set performed to momentary voluntary fatigue, the Valsalva maneuver will occur. However, excessive breath holding should be discouraged.

Proper Exercise Technique

Proper technique for resistance training exercises is partially determined by anatomy and the specific muscle groups being trained. Altering the form of an exercise causes other muscle groups to assist in the movement. This decreases the training stimulus on the muscles normally associated with a particular exercise. Proper technique is altered in several advanced resistance training techniques (e.g., the forced repetition technique), but these techniques are not recommended for beginning resistance trainees (see chapter 6).

Proper technique is also necessary for preventing injury, especially in exercises in which improper technique exposes the low back to additional stress (e.g., squat, deadlift) or in which the resistance can be "bounced" off a body part (e.g., free weight bench press). Improper form often occurs when the lifter performs an exercise with resistances that exceeds his or her present strength capabilities for a certain number of repetitions. If exercise technique deteriorates, the set should be terminated. Proper exercise technique for a large variety of exercises has been described elsewhere (Fleck 1998; Kraemer and Fleck 2005).

Full Range of Motion

Full range of motion refers to performing an exercise with the greatest possible range of movement. Exercises are normally performed with the full range of motion allowed by the body's position and the joints involved. Although no definitive studies are available to confirm this, it is assumed that to develop strength throughout the joint's full range of motion, training must be performed throughout that range. Studies demonstrating joint-angle specificity with isometric training indicate that when training is performed only at a specific joint angle, strength gains are realized in a narrow range around that specific joint angle and not throughout the joint's range of motion (see chapter 2). In advanced training programs joint-angle specificity is used to increase strength and power in a range of motion to increase motor performance (e.g., using quarter squats to develop jumping ability). Some advanced training techniques (e.g., partial repetitions) intentionally limit the range of motion (see chapter 6). However, generally, exercises are performed throughout a full range of motion to ensure strength gains throughout that range.

Resistance Training Shoes

A safe shoe for resistance training does not have to be one specifically designed for Olympic-style lifting or powerlifting, but should have good arch support, a nonslip sole, proper fit, and a sole that is not shock absorbing. The first three of these factors are for safety reasons. The last is important for a simple reason: Force produced by the leg muscles to lift the weight should not be wasted in compressing the shoe's sole. Additionally, if the heel area is very compressible, such as in a running shoe, in some exercises, such as back squats, compression of the heel area during the lift may result in a loss of balance. Shoes designed for cross-training offer all of these characteristics and are appropriate for all but the advanced fitness enthusiast, strength or power athlete, Olympic-style lifter, or powerlifter.

Resistance Training Gloves

Gloves for resistance training cover only the palm area. This protects the palms from catching or scraping on free weight and machine handles, but allows a good grip of the bar or handle with the fingers. Gloves help prevent blisters and the ripping of calluses on the hand. However, they are not mandatory for safe resistance training.

Training Belts

Training belts have a wide back portion that supposedly helps support the lumbar area or low back. They do help support the low back, but not because of the wide back area. Instead, the belt gives the abdominal muscles an object to push against. This helps to raise intra-abdominal pressure, which supports the lumbar vertebrae from the anterior side (Harman et al. 1989; Lander, Hundley, and Simonton 1992; Lander, Simonton, and Giacobbe 1990). Increased intra-abdominal pressure prevents flexion of the lumbar vertebrae, which aids in maintaining an upright posture. Strong abdominal musculature helps to maintain intra-abdominal pressure. When intra-abdominal pressure increases, weak abdominal musculature protrude anteriorly. This results in decreased intra-abdominal pressure and so less support for the lumbar vertebrae. A training belt can be used for exercises that place significant stress on the lumbar area, such as squats and deadlifts. However, it is not necessary for the safe performance of these exercises and should not be used to alleviate technique problems caused by weak abdominal or low back musculature.

Many lifters use weight training belts in inappropriate situations (e.g., lifting light weights or performing exercises not related to low back stress; Finnie et al. 2003). As noted earlier, the use of weight training belts has been shown to increase the injury rate to the lower spine possibly as a result of the belief that they protect competitive lifters as they push their ability with maximal or supramaximal weights in preparation for competition (Siewe et al. 2011). In addition, electromyographic activity of the lumbar extensor musculature is higher when wearing a belt during squats at 60% of 1RM compared to without a belt. This suggests that a belt does not reduce stress on the low back when using relatively light resistance and therefore should not be used with such resistances (Bauer, Fry, and Carter 1999). If exercises placing a great deal of stress on the low back are to be performed, exercises to strengthen the low back and abdominal regions need to be included in the training program.

Wearing a tightly cinched belt during an activity increases blood pressure (Hunter et al. 1989), which can result in increased cardiovascular stress. Thus, a tightly cinched training belt should not be worn during activities such as riding a stationary bike or during exercises in which the lumbar area is not significantly stressed. Belts should normally not be worn when performing exercises that do not require back support or when using light to moderate resistances (i.e., RMs higher than 6RM or low percentages of 1RM).

Equipment Maintenance

Maintaining equipment in proper operating condition is of utmost importance for a safe resistance training program. Pulleys and cables or belts should be checked frequently for wear and replaced as needed. Equipment should be lubricated as indicated by the manufacturer. Cracked or broken free weight plates, dumbbells, or plates in a machine's weight stack should be retired and replaced. Upholstery should be disinfected daily. The sleeves on Olympic bars and other free weight bars should revolve freely to avoid tearing the skin on a lifter's hands. Equipment in a facility that is not in working order needs to be clearly marked as such. An injury resulting from improper equipment maintenance should never happen in a well-run resistance training facility or program.

Summary

Understandable and clear definitions of terminology are important to any field of study. Clear definitions of weight training terms are necessary for accurate communication and an exchange of ideas among fitness enthusiasts and strength and conditioning professionals. Proper safety precautions, such as spotting and proper exercise technique, are a necessity of all properly designed and implemented resistance training programs. An understanding of the basic terminology and safety aspects of weight training is important when examining the topic of the next chapter, the types of strength training.

SELECTED READINGS

Deminice, R., Sicchieri, T., Mialich, M., Milani, F., Ovidio, P., and Jordao, A.A. 2011. Acute session of hypertrophy-resistance traditional interval training and circuit training. *Journal of Strength and Conditioning Research* 25: 798-804.

Fleck, S.J. 1998. *Successful long-term weight training.* Chicago: NTP/Contemporary Publishing Group.

Fleck, S.J. 1999. Periodized strength training: A critical review. *Journal of Strength and Conditioning Research* 13: 82-89.

Kraemer, W.J., and Fleck, S.J. 2005. *Strength training for young athletes* (2nd ed.). Champaign, IL: Human Kinetics.

Meyer, G.D., Quatman, C.E., Khoury, J., Wall, E.J., and Hewitt, T.E. 2009. Youth versus adult "weightlifting" injuries presenting to United States emergency rooms: Accidental versus non-accidental injury mechanisms. *Journal of Strength and Conditioning Research* 23: 2064-2080.

2

Types of Strength Training

After studying this chapter, you should be able to

1. define isometric, dynamic constant external resistance, variable resistance, variable-variable resistance, isokinetic, and eccentric training,
2. describe what is known from research concerning the optimal training frequency, volume, and intensity to cause strength increases, motor performance increases, hypertrophy increases and body composition changes with the various types of training,
3. describe considerations unique to each type of training,
4. discuss how the various types of training compare in causing strength increases, motor performance increases, hypertrophy increases and body composition changes, and
5. define and discuss specificity of training factors such as joint angle specificity, velocity specificity, and testing specificity.

Most athletes and fitness enthusiasts perform strength training as a portion of their overall training program. The main interest for athletes is not how much weight they can lift, but whether increased strength and power and changes in body composition brought about by weight training result in better performances in their sports. Fitness enthusiasts may be interested in some of the same training adaptations as athletes, but also in health benefits such as decreased blood pressure and changes in body composition, as well as the lean, fit appearance brought about by weight training.

There are several factors to consider when examining a type of strength training. Does this type of training increase motor performance? Vertical jump tests, a 40 yd sprint, and throwing a ball or medicine ball for distance are common motor performance tests. Is strength increased throughout the full range of motion and at all velocities of movement? Most sports and daily life activities require strength and power throughout a large portion of a joint's range of motion. If strength and power are not increased throughout a large portion of the range of motion, performance may not be enhanced to the extent that it could be. The majority of athletic events require strength and power at a variety of movement speeds, particularly at fast velocities. If strength and power are not increased over a wide variety of movement velocities, once again, improvements in performance may not be optimal.

Other questions to consider when examining types of strength training include the following: To what extent does the type of training cause changes in body composition, such as the percentage of body fat or fat-free body mass? How much of an increase in strength and power can be expected over a specified training period with this type of training? How does it compare with other training types in the preceding factors?

A considerable amount of research concerning types of resistance training exists. The emergence of conclusions from this research, however, is hampered by several factors. The vast majority of studies have been of short-term duration (8 to 12 weeks) with sedentary or moderately trained people. This makes the direct application of their results to long-term training (years) and highly trained fitness enthusiasts or athletes questionable.

As an example, following one year of training, elite Olympic-style weightlifters show an increase in 1RM snatch ability of 1.5% and in 1RM clean and jerk ability of 2%; they also exhibit an increase in fat-free body mass of 1% or less and a decrease in percent body fat up to 1.7% (Häkkinen, Komi et al. 1987; Häkkinen, Pakarinen et al. 1987b). Following two years of training, elite Olympic-style weightlifters show an increase in their lifting total (total = 1RM snatch + 1RM clean and jerk) of 2.7%, an increase in fat-free body mass of 1%, and a decrease in percent body fat of 1.7% (Häkkinen et al. 1988b). These changes are much smaller than those shown by untrained or moderately trained people in strength and body composition (see table 3.3 in chapter 3) over much shorter training periods. This indicates that causing changes in strength and body composition in highly fit people, such as athletes and advanced fitness enthusiasts, is more difficult than in untrained or moderately trained people. The idea that it is more difficult to increase strength in highly trained people is supported by a meta-analysis of research studies (Rhea et al. 2003) and clearly shown in figure 2.1.

Other factors that can affect gains in strength are the training volume (number of muscle actions or sets and repetitions) performed and the training intensity (% 1RM) used in training. These factors vary considerably from study to study and make interpretation of the results difficult. Additionally, training volume (four vs. eight sets per muscle group for untrained people and athletes, respectively) and training intensity (60 vs. 85% of 1RM for untrained people and athletes, respectively) may not be the same in all populations to bring about maximal strength gains (Peterson, Rhea, and Alvar 2004). Another factor making interpretations and comparisons of studies difficult is the fact that strength increases in different muscle groups do not necessarily occur at the same rate or to the same magnitude with identical training programs (Willoughby 1993). Ultimately, the outcome of any comparison of strength training types depends on the efficacy of the programs used in the comparison.

A comparison of the optimal dynamic constant external resistance training program to a very ineffective isokinetic program will favor the former. Conversely, a comparison of the optimal isokinetic program to a very ineffective dynamic constant external resistance training program will favor the isokinetic program. Ideally, any comparison of strength training types would be of long duration and use the optimal programs, which may change over time. Unfortunately, comparisons of this nature do not exist. Enough research has been conducted, however, to reach some tentative conclusions concerning the types of strength training and how to use them in a training program. This chapter addresses the major research studies and their conclusions.

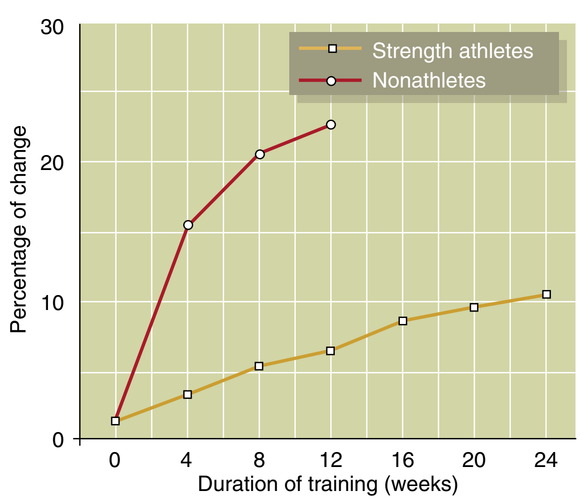


FIGURE 2.1 The percentage of change in maximal squat ability from the pretraining value depends on the pretraining status of the trainees and the duration of training.

Adapted, by permission, from K. Häkkinen, 1985, "Factors influencing trainability of muscular strength during short-term and prolonged training," *National Strength and Conditioning Association Journal* 7: 33.

Isometric Training

Isometric training, or static resistance training, refers to a muscular action during which no change in the length of the total muscle takes place. This means that no visible movement at a joint (or joints) takes place. Isometric actions can take place voluntarily against less than 100% of maximal voluntary action, such as voluntarily holding a light dumbbell at a certain point in an exercise's range of motion or voluntarily generating less than maximal force against an immovable object. An isometric action can also be performed at 100% of maximal voluntary muscle action (MVMA) against an immovable object.

Isometric training is most commonly performed against an immovable object such as a wall or a weight machine loaded beyond the person's maximal concentric strength. Isometrics can also be performed by having a weak muscle group act against a strong muscle group—for example, activating the left elbow flexors maximally to try to flex the left elbow while simultaneously resisting the movement by pushing down on the left hand with the right hand with just enough force to stop any movement at the left elbow. If the left elbow flexors are weaker than the right elbow extensors, the left elbow flexors would perform an isometric action at a 100% of MVMA. Isometric actions can also be performed after a partial range of motion of a dynamic action in some exercises (see the chapter 6 section Functional Isometrics).

Isometrics came to the attention of the American public in the early 1950s, when Steinhaus (1954) introduced the work of two Germans, Hettinger and Muller (1953). Hettinger and Muller concluded that gains in isometric strength of 5% per week were produced by one daily 66% maximal isometric action performed for six seconds. Gains in strength of this magnitude with such little training time and effort seemed unbelievable. A subsequent review concluded that isometric training leads to static strength gains, and that the gains can be substantial and variable over short duration training periods (Fleck and Schutt 1985; also see table 2.1).

Increases in strength from isometric training may be related to the number of muscle actions performed, the duration of the muscle actions, whether the muscle actions are maximal, and the frequency of training. Because most studies involving isometric training manipulate several of these factors simultaneously, it is difficult to evaluate the importance of any one of them. Enough research has been conducted, however, to suggest

TABLE 2.1 **Effects of 100% Maximal Voluntary Contractions on Isometric Strength**

Reference	Duration of contraction(s)	Contractions per day	Duration × contractions per day	Number of training days	MVIC increase (%)	MVIC increase % per day	Muscle
Bonde-Peterson 1960	5	1	5	36	0	0	Elbow flexors
Ikai and Fukunaga 1970	10	3	30	100	92	0.9	Elbow flexors
Komi and Karlsson 1978	3-5	5	15-25	48	20	0.4	Quadriceps
Bonde-Peterson 1960	5	10	50	36	15	0.4	Elbow flexors
Maffiuletti and Martin 2001	4	12	48	21	16	0.7	Quadriceps
Alway et al. 1989	10	5-15	50-150	48	44	0.9	Triceps surae
McDonagh, Hayward, and Davies 1983	3	30	90	28	20	0.71	Elbow flexors
Grimby et al. 1973	3	30	90	30	32	1.1	Triceps
Davies and Young 1983	3	42	126	35	30	0.86	Triceps surae
Carolyn and Cafarelli 1992	3-4	30	90-120	24	32	1.3	Quadriceps
Garfinkel and Cafarelli 1992	3-5	30	90-150	24	28	1.2	Quadriceps
Kanehisa et al. 2002	6	12	48	30	60	2.0	Elbow extensors

MVIC = maximal voluntary isometric contraction.

With kind permission from Springer Science+Business Media: *European Journal of Applied Physiology* "Adaptive responses of mammalian skeletal muscle to exercise with high loads," 52: 140, M.J.N. McDonagh and C.T.M. Davies, table 1, copyright 1984; Additional data from Garfinkel and Cafarelli 1992; Carolyn and Cafarelli 1992; Alway et al. 1989; Kanehisa et al. 2002.

recommendations and tentative conclusions concerning isometric training.

Maximal Voluntary Muscle Actions

Increases in isometric strength can be achieved with submaximal isometric muscle actions (Alway, Sale, and McDougall 1990; Davies, Greenwood, and Jones 1988; Davies and Young 1983; Folland et al. 2005; Hettinger and Mueller 1953; Kanehisa et al. 2002; Kubo et al. 2001; Lyle and Rutherford 1998; Macaluso et al. 2000). However, contradictions exist concerning the need for MVMAs because they have been shown to be superior to submaximal voluntary isometric muscle actions in causing strength increases (Rasch and Morehouse 1957; Ward and Fisk 1964), and no difference in strength increases between maximal and submaximal actions have been shown (Kanehisa et al. 2002). There may be adaptational differences depending on how a maximal voluntary isometric action is performed (Maffiuletti and Martin 2001).

Isometric actions can be performed in such a way that maximal force is developed as quickly as possible or that force increases and reaches maximal in a specified time period, such as four seconds. Both types of training result in significant and similar increases in maximal isokinetic and isometric force capabilities. However, electromyographic (EMG) and electrically evoked twitch contractile properties indicate that training in which maximal force is developed in four seconds results in modifications of the nervous system in the periphery (i.e., muscle membrane electrical activity), whereas training by developing maximal force as quickly as possible results in adaptations in contractile muscle properties (i.e., excitation–contraction coupling).

As with other types of resistance training, the effect of the "quality" of the muscle action needs to be further investigated. Generally, MVMAs are used in training healthy people, and submaximal isometric actions are used in rehabilitation programs or remedial strength training programs in which maximal muscular actions are contraindicated.

Number of Muscle Actions and Duration

Hettinger and Muller (1953) proposed that only one 6-second muscle action per day was necessary to produce maximal strength gains. As shown in table 2.1, many combinations in the number and duration of MVMAs result in significant strength gain. The majority of MVMA studies used isometric actions 3 to 10 seconds in duration, with 3 being the least number of muscle actions resulting in a significant strength gain. Similarly, many combinations in the number and duration of submaximal isometric actions can result in increased isometric strength. For example, four sets of six repetitions of two seconds in duration at 50% MVMA (adductor pollicis) and four muscle actions each 30 seconds in duration at 70% MVMA (quadriceps) have resulted in significant increases of isometric strength (Lyle and Rutherford 1998; Schott, McCully, and Rutherford 1995). It is important to note that, generally, these studies used healthy, but non-weight-trained people as subjects.

The duration of the muscle action and the number of training muscle actions per day individually show weaker correlations to strength increases than do duration and number combined (McDonagh and Davies 1984). This means that the total length of the isometric actions performed is directly related to increased strength. It also indicates that optimal gains in strength are the result of either a small number of long-duration muscle actions or a high number of short-duration muscle actions (Kanehisa et al. 2002). As an example, seven daily one-minute muscle actions at 30% of MVMA or 42 three-second MVMAs per training day over a six-week training period both result in about a 30% increase in isometric MVMA (Davies and Young 1983).

However, some information indicates that longer-duration isometric actions may be superior to short-duration actions in causing strength gains (Schott, McCully, and Rutherford 1995). Training the quadriceps at 70% of MVMA with four 30-second actions and four sets of 10 repetitions each three seconds in duration both result in significant isometric strength gains. Even though the total duration of the isometric muscle actions (120 seconds per training session) was identical between the two training programs, the longer-duration isometric actions resulted in a significantly greater increase in isometric strength (median 55 vs. 32% increase). The longer-duration isometric actions resulted in a significant increase in isometric strength after two weeks of training, whereas eight weeks of training was necessary before a significant increase in strength was achieved with the short-duration isometric actions. This indicates that longer-duration submaximal isometric actions may be more appropriate when a quick increase in strength is desired.

During isometric actions, blood flow occlusion does occur and may in part be responsible for increased metabolite concentrations and acidity; this could be a stimulus for greater strength gains from long-duration isometric actions than from short-duration ones (see the section in chapter 6, Vascular Occlusion). The possible role of occlusion as a stimulus for strength gains is shown in studies by Takarada and colleagues. They found that training using 20 to 50% of 1RM while blood flow is occluded results in increased metabolite concentrations, acidity, and serum growth hormone concentrations (Takarada et al. 2000a, 2000b). Training at 30 to 50% of 1RM with blood flow occlusion resulted in a significantly higher blood lactate concentration compared to training at 50 to 80% of 1RM without occlusion, indicating greater concentrations of intramuscular metabolites (Takarada et al. 2000b). Over 16 weeks of training, both programs resulted in significant, but similar, increases in strength. This indicates that blood flow occlusion and the resulting increase in intramuscular metabolites do affect strength increases.

Many studies using isometrics give subjects several seconds to increase the force of the muscle action until they reach the desired percentage of MVMA. This is in part done for safety reasons. Some information, however, indicates that a rapid increase in the isometric force results in significantly greater increases in strength at the training joint angle (Maffiuletti and Martin 2001). During seven weeks of training, some subjects performed isometric actions of the knee extensors by increasing muscle force as rapidly as possible (the action lasted approximately one second), and others increased force to a maximal over four seconds. They experienced an increase in MVMA of 28 and 16%, respectively. Similar and comparable increases in strength were shown at knee angles different from the training angle, and during eccentric and concentric isokinetic testing. Thus, increasing force as quickly as possible during training revealed a significantly greater increase in strength only at the training joint angle.

Collectively, these studies indicate that many combinations of maximal and submaximal isometric muscle action durations and numbers can bring about isometric strength gains. However, in typical training settings with healthy people, perhaps the most efficient use of isometric training time is to perform a minimum of 15 MVMAs or near MVMAs of three to five seconds in duration for three sessions per week as discussed in the next section on training frequency.

Training Frequency

Three training sessions per week using either maximal or submaximal isometric actions result in a significant increase in isometric MVMA (Alway, MacDougall, and Sale 1989; Alway, Sale, and MacDougall 1990; Carolyn and Cafarelli 1992; Davies et al. 1988; Folland et al. 2005; Garfinkel and Cafarelli 1992; Lyle and Rutherford 1998; Macaluso et al. 2000; Maffiuletti and Martin 2001; Schott, McCully, and Rutherford 1995; Weir, Housh, and Weir 1994; Weir et al. 1995). Increases in isometric MVMA over 6 to 16 weeks of training ranged from 8 to 79% in these studies. However, whether three training sessions per week cause maximal increases in strength is not fully substantiated. Hettinger (1961) calculated that alternate-day isometric training is 80% and that once-a-week training is 40% as effective as daily training sessions. Hettinger also concluded that training once every two weeks does not cause increases in strength, although it does serve to maintain strength. Daily training with isometrics is superior to less frequent training (Atha 1981), although the exact percentage of strength superiority is debated and may vary by muscle group and other training variables (e.g., muscle action duration, number of muscle actions). To increase maximal strength, daily isometric training may be optimal; however, two or three training sessions per week will bring about significant increases in maximal strength. Three sessions per week is the routine most frequently used in studies.

Muscle Hypertrophy

Increases in limb circumferences have been used to determine muscle hypertrophy and have been shown to occur as a result of isometric training (Kanehisa and Miyashita 1983a; Kitai and Sale 1989; Meyers 1967; Rarick and Larson 1958). More recently, technologies (computerized tomography, magnetic resonance imaging [MRI]) that more accurately determine muscle cross-sectional area and muscle thickness (ultrasound) have been used to measure changes in muscle hypertrophy due to isometric training.

It is clear that isometric training can result in significant hypertrophy (Wernbom, Augustsson, and Thomee 2007). Quadriceps cross-sectional area (CSA) increases on average 8.9% (range 4.8-14.6%) after 8 to 14 weeks of isometric training (Wernbom, Augustsson, and Thomee 2007). Likewise, significant gains in elbow flexor CSA up to 23% have been shown following isometric training. Increases in CSA are typically accompanied by increases in maximal strength. For example, 12 weeks of training resulted in a significant increase of 8% in knee extensor CSA and a 41% increase in isometric strength (Kubo et al. 2001). As with other training types, strength increases are due to a combination of neural adaptations and hypertrophy as indicated by studies showing significant (Garfinkel and Cafarelli 1992) and nonsignificant (Davies et al. 1988) correlations between increases in strength and CSA.

Whether hypertrophy occurs and the extent to which it occurs may vary from muscle to muscle and by muscle fiber type. Type I and II muscle fiber diameters in the vastus lateralis did not change after isometric training at 100% of MVMA (Lewis et al. 1984). Type I and II fiber areas increased in the soleus approximately 30% after isometric training with either 30 or 100% of MVMA (Alway, MacDougall, and Sale 1989; Alway, Sale, and MacDougall 1990), whereas only the type II fibers of the lateral gastrocnemius increased in area 30 to 40% after an identical isometric training program.

Longer-duration muscle actions may result in greater gains in CSA than shorter-duration muscle actions (Schott, McCully, and Rutherford 1995). Muscle CSA was determined (via computerized tomography) before and after training with four 30-second actions and four sets of 10 repetitions each three seconds in duration. Even though the total duration of the isometric muscle actions (120 seconds per training session) was identical between the two groups, the longer-duration isometric actions resulted in a significant increase in quadriceps CSA (10-11%), whereas the shorter-duration muscular actions resulted in nonsignificant increases (4-7%) in quadriceps CSA. Additionally, maximal MVMAs may result in significantly greater hypertrophy than 60% MVMAs over 10 weeks of training (Kanehisa et al. 2002). This comparison was between 12 muscle actions at 100% MVMA with each action lasting six seconds and four actions at 60% MVMA with each action lasting 30 seconds. So total isometric action duration per training session was equivalent (120 seconds) between the two training programs. However, when training volume is expressed as the total duration of isometric actions per training session or as the product of training intensity times total duration, no apparent relation between volume and rate of CSA increase was apparent (Wernbom, Augustsson, and Thomee 2007). This indicates that a variety of training intensity and volume can result in significant hypertrophy.

Muscle protein synthesis in the soleus after an isometric action at 40% of MVMA to fatigue (approximately 27 minutes) increases significantly by 49% (Fowles et al. 2000). This finding supports the efficacy of isometric actions inducing muscle hypertrophy. Collectively, this information indicates that muscle hypertrophy of both the type I and type II muscle fibers can occur from isometric training with submaximal and maximal muscle actions of varying durations. Table 2.2 describes guidelines to bring about muscle hypertrophy with various intensities of isometric training.

Joint-Angle Specificity

Gains in strength occur predominantly at or near the joint angle at which isometric training is performed; this is termed **joint-angle specificity**. The majority of research indicates that static strength increases from isometric training are joint-angle specific (Bender and Kaplan 1963; Gardner 1963; Kitai and Sale 1989; Lindh 1979; Meyers 1967; Thepaut-Mathieu, Van Hoecke, and Martin 1988; Weir, Housh, and Weir 1994; Weir et al. 1995; Williams and Stutzman 1959), although lack of joint-angle specificity strength gains have also been shown (Knapik, Mawdsley, and Ramos 1983; Rasch and Pierson 1964; Rasch, Preston, and Logan 1961). Several factors may affect the degree to which joint-angle specificity occurs, including the muscle group(s) trained, the joint angle at which the training is performed, and the intensity and duration of the isometric actions. Joint-angle specificity is normally attributed to neural adaptations, such as increased muscle fiber recruitment at the trained angle and the inhibition of the antagonistic muscles at the trained angle.

Carryover of significant isometric strength increases to other joint angles can vary from 5 to 30 degrees on either side of the joint angle trained depending on the muscle group and joint angle trained (Kitai and Sale 1989; Knapik, Mawdsley, and Ramos 1983; Maffiuletti and Martin 2001;

TABLE 2.2 **Guidelines to Increase Hypertrophy With Isometric Training**

Training variable	Low intensity	High intensity	Maximal intensity
Intensity	30-50% MVIA	70-80% MVIA	100% MVIA
Repetitions	1	1	10
Sets	2-6 per exercise Progress from 2 to 4-6 sets per muscle group	2-6 per exercise Progress from 2 to 4-6 sets per muscle group	1-3 per exercise Progress from 1 to 3 sets per muscle group
Repetition duration	40-60 sec, and to muscular failure during the final 1-2 sets	15-20 sec, and to muscular failure during the final 1-2 sets	3-5 sec
Rest between repetitions and sets	30-60 sec	30-60 sec	25-30 sec and 60 sec
Training frequency	3-4 sessions per muscle group per week	3-4 sessions per muscle group per week	3 sessions per muscle group per week

MVIA = maximal voluntary isometric action

Adapted from Wernbom, Augustsson, and Thomee 2007.

Thepaut-Mathieu, Van Hoecke, and Martin 1988). Joint-angle specificity (see figure 2.2) may be most marked when the training is performed with the muscle in a shortened position (25-degree angle) and occurs to a smaller extent when the training occurs with the muscle in a lengthened position (120-degree angle) (Gardner 1963; Thepaut-Mathieu, Van Hoecke, and Martin 1988). When training occurs at the midpoint of a joint's range of motion (80-degree angle), joint-angle specificity may occur throughout a greater range of motion (Kitai and Sale 1989; Knapik, Mawdsley, and Ramos 1983; Thepaut-Mathieu, Van Hoeke, and Martin 1988). In addition, twenty 6-second muscle actions result in greater carryover to other joint angles than six 6-second muscle actions do (Meyers 1967). This indicates that the longer the duration of isometric training per training session (i.e., the number of muscle actions multiplied by the duration of each muscle action), the greater the carryover to other joint angles.

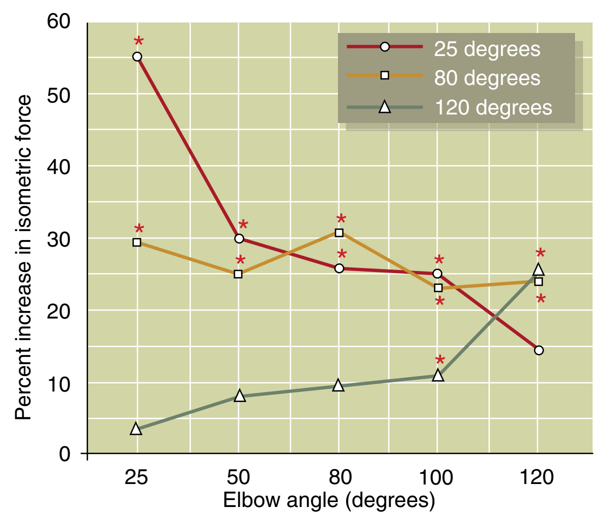


FIGURE 2.2 Percentage gain in the isometric strength of elbow flexors due to isometric training at various elbow angles.

* = significant increase ($p < .05$).

Data from Thépaut-Mathieu et al. 1988.

Isometric training at one joint angle may not result in dynamic power increases. Isometric training of the knee extensors at one joint angle results in inconsistent and for the most part nonsignificant changes in isokinetic torque across a wide range of movement velocities (Schott, McCully, and Rutherford 1995). However, it has also been reported that isometric training at one joint angle results in significant force increases in dynamic (isokinetic) eccentric and concentric actions (Maffiuletti and Martin 2001) and increases peak power at 40, 60, and 80% of normal weight training 1RM (Ullrich, Kleinoder, and Bruggemann 2010). Thus, isometric training at one joint angle may not always result in increased force and power throughout the joint's range of motion. However, isometric training of the elbow flexors and knee extensors at four different joint angles increases static strength at all four joint angles and significantly increases the dynamic power and force (isokinetic) throughout the range of motion at several velocities (45, 150, and 300 degrees per second) (Folland et al. 2005; Kanehisa and Miyashita 1983a). Thus, to ensure an increase in dynamic power and strength throughout a joint's range of motion, a trainee must perform isometric training at several points in a joint's range of motion.

This information on joint-angle specificity offers some practical guidelines for increasing strength and power throughout the entire range of motion. First, the training should be performed at joint-angle increments of approximately 10 to 30 degrees. Second, the total duration of isometric training (the duration of each muscle action multiplied by the number of muscle actions) per session should be long (three- to five-second actions, 15 to 20 actions per session). Third, if isometric actions cannot be performed throughout the entire range of motion, it may be best to perform them with the muscle(s) in a lengthened position rather than a shortened position. It is also possible to use isometric training's joint-angle specificity to increase dynamic strength lifting ability by performing isometric actions at the sticking point of an exercise (see the section Functional Isometrics in chapter 6).

Motor Performance

Maximal isometric strength has shown significant correlations to performance in sports such as basketball (Häkkinen 1987), rowing (Secher 1975), and sprinting (Mero et al. 1981), as well as to countermovement and static jump ability (Häkkinen 1987; Kawamori et al. 2006; Khamoui et al. 2011; Ugarkovic et al. 2002) and dynamic force in a mid-thigh clean pull (Kawamori et al. 2006). However, nonsignificant correlations between maximal isometric strength and dynamic performance have also been shown. A review (Wilson and Murphy 1996) concluded that the relationship between maximal isometric strength and dynamic performance is questionable, even though some studies demonstrated significant correlations between the rate of force development during an isometric test and dynamic performance. Similarly, isometric tests are not sensitive to training adaptations induced by dynamic activity nor do they consistently discriminate among athletes of differing caliber in the same sport or activity (Wilson and Murphy 1996). The isometric rate of force development (first 50 and 100 ms) in a clean high pull does correlate to peak velocity in a clean high pull, and isometric peak force per kilogram of body mass correlates with vertical jump height and vertical jump peak velocity (Khamoui et al. 2011). All of these correlations, although significant, were moderate (r = .49-.62); however, they do indicate that isometric force development in a multijoint movement does correlate to vertical jump and clean pull ability. Thus, although isometric testing may not be the best modality for monitoring changes in dynamic motor performance, if it is used in this manner, an isometric multijoint movement appears to be most appropriate. This information may also indicate that when isometric training is used to increase dynamic motor performance, such as sprinting or vertical jumping, the training should be multijoint in nature. Isometric training and testing is, however, of substantial value if the sport involves a significant amount of isometric action, such as rock climbing (see box 2.1).

BOX 2.1 **RESEARCH**

Rock Climbing and Isometric Strength

Rock climbers use numerous isometric actions—in particular, while gripping a handhold, which involves flexion of the fingers. Maximal isometric force per kilogram of body mass of the fingers is significantly correlated to rock climbing ability (Wall et al. 2004). Additionally, this same measure is significantly greater in climbers of higher ability than in climbers of lesser ability. Climbers perform isometric actions of the fingers when training by gripping handholds (finger board). Isometric actions of the fingers are also recommended to climbers for rehabilitation after an injury to the fingers (Kubiac, Klugman, and Bosco 2006). This is clearly one sport in which isometric actions are very important for successful performance and for rehabilitation after injury.

Kubiak, E.N., Klugman, J.A., and Bosco, J.A. 2006. Hand injuries in rock climbers. *Bulletin of the NYU Hospital for Joint Diseases* 64: 172-177.

Wall, C., Byrnes, W., Starek, J., and Fleck, S.J. 2004. Prediction of performance in female rock climbers. *Journal of Strength and Conditioning Research* 18: 77-83.

Isometric training at one joint angle has been shown to increase motor performance in the novel task of one-legged jumping using only plantar flexion (Burgess et al. 2007); however, it does not consistently increase dynamic motor performance (Clarke 1973; Fleck and Schutt 1985). The lack of any or a consistent increase in motor performance may be due to the inconsistent changes in the rate of force or power, as discussed previously, and the lack of an increase in the limb's maximal velocity of movement with little or no resistance (DeKoning et al. 1982) with isometric training at one joint angle. Other factors that may inhibit isometric strength gains from affecting dynamic motor performance include differences in muscle fiber recruitment patterns between isometric and dynamic actions and mechanical differences, such as little, if any, stretch-shortening cycle during in an isometric action.

Maximal isometric force varies throughout the range of motion of a movement. The correlation between dynamic bench press ability and isometric strength varies drastically with the elbow angle at which the isometric test is performed (Murphy et al. 1995). This has led to the suggestion that isometric testing should be performed at the point within the range of motion at which maximal force is developed. However, the use of such an angle may not demonstrate the highest correlation between isometric strength and dynamic motor performance (Wilson and Murphy 1996). Thus, the exact angle at which isometric strength should be assessed to monitor isometric training to increase motor performance or train to increase motor performance remains unclear.

If isometric actions are used to monitor or increase dynamic motor performance, several suggestions seem warranted. First, as discussed earlier, dynamic power can be increased with isometric training if the isometric actions are performed at several points within the range of motion. Thus, performance of isometric actions at 10- to 20-degree intervals throughout the movement's range of motion may aid in carryover of isometric strength gains to dynamic actions. Second, most dynamic motor performance tasks are multijoint and multi-muscle-group in nature. Thus, multijoint, sport-specific isometric movements, such as a leg press or clean pull movement, should be used to monitor or improve dynamic motor performance tasks. Third, if previous research indicates a point within the range of motion that demonstrates a high significant correlation between isometric strength and a motor performance task, isometric strength should be assessed at this point. If previous research does not indicate such a point, the strongest point within the range of motion can be used as the initial position for isometric strength testing. Fourth, the quick development of maximal force (within one second) at one joint angle has been shown to increase peak power (Ullrich, Kleinoder, and Bruggemann 2010); isometric force in 50 to 100 ms has shown significant correlations to vertical jump ability (Khamoui et al. 2011); and although not significant, a trend for significance ($p = .059$) was shown for an increase in one-legged jumping ability with quick force development of the plantar flexors after isometric training (Burgess et al. 2007). Therefore, the quick development of isometric force may help improve motor performance, but this type of training does carry risks for injury.

Combining Isometric With Other Types of Training

Minimal information is available concerning the effect of combining isometric with other types of training. Combining isometric training of the elbow flexors with power training (resistance moved as fast as possible) at 30 and 60% of maximal force resulted in increased peak power, but the increase was not different from what would result from power training alone (Toji and Kaneko 2004). Combining isometric training of the knee extensors and flexors with weight training in which the concentric repetition phase was performed as fast as possible and the eccentric phase was performed in 0.5 second also resulted in increased peak power at 40, 60, and 80% of 1RM; however, again, the increase in power was not different from what resulted from concentric–eccentric or isometric training alone (Ullrich, Kleinoder, and Bruggemann 2010). Thus, although the information is minimal and used only single-joint movements, no advantage was shown for increasing power by combining isometric with power-type training.

Other Considerations

Long-term isometric training decreases resting blood pressure (Taylor et al. 2003). However, as with all resistance training, a Valsalva maneuver may occur, resulting in an exaggerated blood pressure response during training. Performance of a

Valsalva maneuver should be discouraged because it results in higher blood pressure. As duration, intensity (% MVMA), and muscle mass increase during an isometric action, the blood pressure response increases (Kjaer and Secher 1992; Seals 1993). The increased blood pressure response during high-intensity large-muscle-group isometric exercise can decrease left ventricular function (ejection fraction) (Vitcenda et al. 1990). These factors need to be considered when isometric actions are performed by those with compromised, or potentially compromised, cardiovascular function, such as older trainees.

Because they do not lift or move an actual weight, some trainees may experience motivational problems with isometric training. It is also difficult to evaluate whether the trainees are performing the isometric actions at the desired intensity without feedback on force development. Visual feedback of force development, especially during unfamiliar movements, serves as positive feedback and encourages greater force production during isometric actions (Graves and James 1990). EMG feedback during isometric training is beneficial for increasing strength, but there is wide variability in its effect on strength increases (Lepley, Gribble, and Pietrosimone 2011). Feedback equipment may not be practical in many training situations. However, for isometric actions to be optimal, use of a feedback-monitoring system may be warranted.

Dynamic Constant External Resistance Training

Isotonic is a term traditionally used to describe an action in which the muscle exerts constant tension. Free weight exercises and exercises on various weight training machines that are usually considered isotonic are not isotonic according to this definition. The force exerted by muscles in the performance of such exercises is not constant, but rather varies with the mechanical advantage of the joint(s) involved in the exercise and the acceleration or deceleration of the resistance. Two terms, **dynamic constant external resistance** (DCER) and **isoinertial**, more accurately describe resistance training exercise in which the external resistance does not change in the lifting (concentric) or lowering (eccentric) phase. These terms imply that the weight or resistance being lifted is held constant and not that the force developed by a muscle during the exercise is constant.

On many resistance training machines the weight stack or weight plates have constant values. However, the point at which a cable or strap attaches to a movable handle or foot pad on the machine changes the muscular force needed to move the resistance throughout the exercise's range of motion. If the resistance training machine has circular pulleys (as opposed to noncircular pulleys), even though the muscular force needed to lift the resistance through the range of motion changes, the machine is still termed a DCER or isoinertial machine. With free weights and weight training machines, the external resistance or weight lifted is held constant even though the muscular force varies throughout the exercise movement. Thus, *DCER* and *isoinertial* describe this type of resistance training more accurately than the old term *isotonic*.

Number of Sets and Repetitions

The number of sets and repetitions needed for DCER exercises to result in maximal gains in strength and power, and in body composition changes, has received a great deal of attention from personal trainers, strength coaches, and sport scientists. The search for an optimal number of sets and repetitions assumes several factors: that an optimal number of sets and repetitions actually exists; that once found, it will work for all people and exercises or muscle groups; that it will work equally well in untrained and trained people; and that it will promote maximal increases in strength, power, and local muscular endurance, as well as body composition changes for an indefinite period of time. Acceptance of some of these assumptions would mean, among other things, that periodization of training and different programs for different age groups or training statuses are not necessary. Additionally, the optimal number of sets may be different among muscle groups. Researchers reported no difference in upper-body strength gains between people performing one set and people performing three sets. However, previously untrained men experienced significantly greater strength gains with three sets of exercises of the lower body (Ronnestad et al. 2007); increases in bench press and leg press strength of 3 and 9%, respectively, after performing the same training program for eight weeks (Kerrsick et al. 2009); and increases in bench press and leg press strength of 17 and 79%, respectively, after performing the same daily nonlinear program (Buford et al. 2007).

The vast majority of research studies concerning DCER have used novice, college-age subjects and a relatively short duration of training (8 to 12 weeks, with several lasting 20 to 36 weeks). Pretraining status and the duration of the training affect the results of any weight training program. These factors make interpretation of the studies and drawing conclusions concerning long-term training effects difficult. Common to the vast majority of studies concerning DCER is the use of sets carried to or close to volitional fatigue or the use of an RM resistance at some point in the training program (see chapter 6, Sets to Failure Technique).

Perhaps the earliest studies investigating the effect of varying numbers of sets and repetitions were by Berger in the 1960s; they indicated that optimal increases in 1RM in the bench press and back squat can occur with a variety of numbers of sets and repetitions when sets are carried to failure (Berger 1962b, 1962c, 1963a). The point that various combinations of sets and repetitions can bring about increased strength is well supported by research. Using nonperiodized training numbers of sets ranging from 1 to 6 and numbers of repetitions per set ranging from 1 to 20 have resulted in increased strength (see tables 2.3 and 2.4; Bemben et al. 2000; Calder et al. 1994; Dudley et al. 1991; Graves et al. 1988; Häkkinen 1985; Hass et al. 2000; Humburg et al. 2007; Kraemer et al. 2000; Marx et al. 2001; Schlumberger, Stec, and Schmidtbleicher 2001; Staron et al. 1989, 1994; Willoughby 1992, 1993).

Direct comparisons substantiate the assertion that there is no one optimal combination of nonperiodized sets and repetitions for increasing strength. No significant difference in increases in 1RM were found when training consisted of five sets of three at 3RM, four sets of five at 5RM, or three sets of seven at 7RM (Withers 1970); three sets of two to three, five to six, or nine to ten repetitions at the same respective RM resistance (O'Shea 1966); or one, two, or four sets all at 7 to 12RM (Ostrowski et al. 1997). Various combinations of nonperiodized sets and repetitions per set result in strength increases; however, multiple sets do result in greater strength increases than single sets, and the optimal number of sets varies with training status (see Considerations for All Types of Training later in this chapter).

Training Frequency

Training frequency, the number of sets and repetitions, and the number of exercises per training session determine total training volume. The optimal training frequency, therefore, may depend in part on total training volume per training session. The term *training frequency* is normally used to refer to the number of training sessions per week in which a certain muscle group is trained. This definition is important because it is possible to have daily training sessions and train a particular muscle group or body part from anywhere between not at all to seven sessions per week. Training frequency is defined here as the number of training sessions per week in which a certain muscle group is trained or a particular exercise is performed.

The importance of the definition of *training frequency* is made apparent by comparing an upper- and lower-body split program (see chapter 6) to a total-body weight training routine (Calder et al.

TABLE 2.3 **Changes in Bench Press Strength Due to Training**

Reference	Sex of subjects	Type of training	Training duration (wk)	Training days/week	Sets and repetitions	% increase for equipment trained on	Comparative type of equipment	Comparative test % increase
Boyer 1990	F	DCER	12	3	3 wk = 3 × 10RM 3 wk = 3 × 6RM 6 wk = 3 × 8RM	24	VR	23
Brazell-Roberts and Thomas 1989	F	DCER	12	2	3 × 10 (75% of 1RM)	37	—	—
Brazell-Roberts and Thomas 1989	F	DCER	12	3	3 × 10 (75% of 1RM)	38	—	—

>continued

TABLE 2.3 >*continued*

Reference	Sex of subjects	Type of training	Training duration (wk)	Training days/ week	Sets and repetitions	% increase for equipment trained on	Comparative type of equipment	Comparative test % increase
Brown and Wilmore 1974	F	DCER	24	3	8 wk = 1 × 10, 8, 7, 6, 5,4 16 wk = 1 × 10, 6, 5, 4, 3	38	—	—
Calder et al. 1994	F	DCER	20	2	5 × 6- to 10RM	33	—	—
Hostler, Crill et al. 2001	F	DCER	16	2-3	4 wk = 2 × 7RM 4 wk = 3 × 7RM (10 days off) 8 wk = 3 × 7RM	47	—	—
Kraemer et al. 2000	F (college tennis)	DCER	36	3	1 × 8- to 10RM	8	—	—
Kraemer, Häkkinen et al. 2003	F (college tennis)	DCER	36	2 or 3	3 × 8- to 10RM	17	—	—
Marx et al. 2001	F	DCER	24	3	1 × 8- to 10RM	12	—	—
Kraemer, Mazzetti et al. 2001e	F	DCER	24	3	Periodized 3 × 3- to 8RM	37	—	—
Kraemer, Mazzetti et al. 2001e	F	DCER	24	3	Periodized 3 × 8- to12RM	23	—	—
Mayhew and Gross 1974	F	DCER	9	3	2 × 20	26	—	—
Wilmore 1974	F	DCER	10	2	2 × 7-16	29	—	—
Wilmore et al. 1978	F	DCER	10	3	40-55% of 1RM for 30 s	20	—	—
Allen, Byrd, and Smith 1976	M	DCER	12	3	2 × 8, 1 × exhaustion	44	—	—
Ariel 1977	M	DCER	20	5	4 × 3-8	14	—	—
Baker, Wilson, and Carlyon 1994b	M	DCER	12	3	3 × 6	13	—	—
Berger 1962b	M	DCER	12	3	3 × 6	30	—	—
Coleman 1977	M	DCER	10	3	2 × 8- to 10RM	12	—	—
Fahey and Brown 1973	M	DCER	9	3	5 × 5	12	—	—
Gettman et al. 1978	M	DCER	20	3	50% of 1RM, 6 wk = 2 × 10-20 14 wk = 2 × 15	32	IK (12 deg/s)	27
Hoffman et al. 1990	M (college football)	DCER	10	3	4 wk = 4 × 8RM 4 wk = 5 × 6RM 2 wk = 1 × 10, 8, 6, 4, 2RM	2	—	—
Hoffman et al. 1990	M (college football)	DCER	10	4	Same as 3/wk	4	—	—
Hoffman et al. 1990	M (college football)	DCER	10	5	Same as 3/wk	3	—	—
Hoffman et al. 1990	M (college football)	DCER	10	6	Same as 3/wk	4	—	—

Get complete eBook Order by email at eztutorsource@hotmail.com

Reference	Sex of subjects	Type of training	Training duration (wk)	Training days/ week	Sets and repetitions	% increase for equipment trained on	Comparative type of equipment	Comparative test % increase
Hostler, Crill et al. 2001	M	DCER	16	2 or 3	4 wk = 2 × 7RM 4 wk = 3 × 7RM (10 days off) 8 wk = 3 × 7RM	29	—	—
Rhea et al. 2002	M	DCER	12	3	DNLP 1 × 8- to 10RM 1 × 6- to 8RM 1 × 4- to 6RM each 1 day/wk	20	—	—
Rhea et al. 2002	M	DCER	12	3	DNLP 1 × 8- to 10RM 3 × 6- to 8RM 3 × 4- to 6RM each 3 day/wk	33	—	—
Buford et al. 2007	M and F	DCER	9	3	LP 3 wk = 3 × 8 3 wk = 3 × 6 3 wk = 3 × 4	24	—	—
Buford et al. 2007	M and F	DCER	9	3	DNLP 3 × 8 3 × 6 3 × 4 each 1 day/wk	17	—	—
Kerksick et al. 2009	M	DCER	8	4	4 wk = 3 × 10 4 wk = 3 × 8	3	—	—
Marcinik et al. 1991	M	DCER	12	3	1 × 8- to 12RM	20	—	—
Stone, Nelson et al. 1983	M	DCER	6	3	3 × 6RM	7	—	—
Wilmore 1974	M	DCER	10	2	2 × 7-16	16	—	—
Ariel 1977	M	VR	20	5	4 × 3-8	—	DCER	29
Boyer 1990	F	VR	12	3	3 wk = 3 × 10RM 3 wk = 3 × 6RM 6 wk = 3 × 8RM	47	DCER	15
Coleman 1977	M	VR	10	3	1 × 8- to 12RM	—	DCER[a]	12
Lee et al. 1990	M	VR	10	3	3 × 10RM	20	—	—
Stanforth, Painter, and Wilmore 1992	M and F	VR	12	3	3 × 8- to 12RM	11	IK (1.5 s/contraction)	17
Fleck, Mattie, and Martensen 2006	F	VVR	14	3	3 × 10RM	28	—	—
Gettman and Ayres 1978	M	IK (60 deg/s)	10	3	3 × 10-15	—	DCER	11
Gettman and Ayres 1978	M	IK (120 deg/s)	10	3	3 × 10-15	—	DCER	9
Gettman et al. 1979	M	IK	8	3	4 wk = 1 × 10 at 60 deg/s 4 wk = 1 × 15 at 90 deg/s	22	DCER	11
Stanforth, Painter, and Wilmore 1992	M and F	IK (1.5 s/contraction)	12	3	3 × 8- to 12RM	20	VR	11

DCER = dynamic constant external resistance; VR = variable resistance; VVR = variable variable resistance; IK = isokinetic; DNLP = daily nonlinear periodization; LP = linear periodization; RM = repetition maximum; * = values for average training weights.

Get complete eBook Order by email at eztutorsource@hotmail.com

TABLE 2.4 **Changes in Leg Press Strength Due to Training**

Reference	Sex of subjects	Type of training	Training duration (wk)	Training days/ week	Sets and repetitions	% increase for equipment trained on	Compara-tive type of equipment	Compara-tive test % increase
Brown and Wilmore 1974	F	DCER	24	3	8 wk = 1 × 10, 8, 7, 6, 5, 4 16 wk = 1 × 10, 6, 5, 4, 3	29	—	—
Calder et al. 1994	F	DCER	20	2	5 × 10- to 12RM	21	—	—
Cordova et al. 1995	F	DCER	5	3	1 × 10, 1 × 6, 2 × as many as possible normally up to 11	50	—	—
Kraemer et al. 2000	F (college tennis)	DCER	36	3	1 × 8- to 10RM	8	—	—
Kraemer, Häkkinen et al. 2003	F (college tennis)	DCER	36	2-3	3 × 8- to 10RM	17	—	—
Marx et al. 2001	F	DCER	24	3	1 × 8- to 10RM	11	—	—
Mayhew and Gross 1974	F	DCER	9	3	2 × 10	48[a]	—	—
Staron et al. 1991	F	DCER (vertical leg press)	18 (8 wk, 1 wk off, 10 wk)	2	3 × 6- to 8RM	148	—	—
Wilmore et al. 1978	F	DCER	10	3	40-55% of 1RM for 30 s	27	—	—
Allen, Byrd, and Smith 1976	M	DCER	12	3	2 × 8 1 × exhaustion	71[b]	—	—
Coleman 1977	M	DCER	10	3	2 × 8- to 10RM	17	—	—
Dudley et al. 1991	M	DCER	19	2	4-5 × 6- to 12RM	26	—	—
Gettman et al. 1978	M	DCER	20	3	50% 1RM, 6 wk = 2 × 10-20 14 wk = 2 × 15	—	IK	43
Pipes 1978	M	DCER	10	3	3 × 8	29	VR	8
Sale et al. 1990	M and F	DCER	11 (3 wk off), 11 more, total 22	3	6 × 15- to 20RM (one-legged training)	30	—	—
Tatro, Dudley, and Convertino 1992	M	DCER	19	2	7 wk = 4 × 10- to 12RM 6 wk = 5 × 8- to 10RM 6 wk = 5 × 6- to 8RM	25 (3RM)	—	—
Wilmore et al. 1978	M	DCER	10	3	40-55% of 1RM for 30 s	7	—	—
Rhea et al. 2002	M	DCER	12	3	DNLP 1 × 8- to 10RM 1 × 6- to 8RM 1 × 4- to 6RM each 1 day/wk	26	—	—

Reference	Sex of subjects	Type of training	Training duration (wk)	Training days/ week	Sets and repetitions	% increase for equipment trained on	Comparative type of equipment	Comparative test % increase
Rhea et al. 2002	M	DCER	12	3	DNLP 1 × 8- to 10RM 3 × 6- to 8RM 3 × 4- to 6RM each 3 day/wk	56	—	—
Buford et al. 2007	M and F	DCER	9	3	LP 3 wk = 3 × 8 3 wk = 3 × 6 3 wk = 3 × 4	85	—	—
Buford et al. 2007	M and F	DCER	9	3	DNLP 3 × 8 3 × 6 3 × 4 each 1 day/wk	79	—	—
Kerksick et al. 2009	M	DCER	8	4	4 wk = 3 × 10 4 wk = 3 × 8	9	—	—
Coleman 1977	M	VR	10	3	1 × 10- to 12RM	—	DCER	18
Gettman, Culter, and Strathman 1980	M	VR	20	3	3 × 8	18[c]	IK	17
Lee et al. 1990	M	VR	10	3	3 × 10RM	6	—	—
Pipes 1978	M	VR	10	3	3 × 8	27	DCER	8
Smith and Melton 1981	M	VR	6	4	3 × 10	—	VR[d]	11
Fleck, Mattie, and Martensen 2006	F	VVR	14	3	3 × 10RM	31	—	—
Cordova et al. 1995	F	IK	5	3	2 × 10 at 60, 180, and 240 deg/s	64	—	—
Gettman et al. 1979	M	IK	8	3	4 wk = 1 × 10 at 60 deg/s 4 wk = 1 × 15 at 90 deg/s	38	DCER	18
Gettman, Culter, and Strathman 1980	M	IK	20	3	2 × 12 at 60 deg/s	42	VR	10
Smith and Melton 1981	M	IK	6	4	Sets to 50% exhaustion at 30, 60, and 90 deg/s	—	VR	10
Smith and Melton 1981	M	IK	6	4	Sets to 50% fatigue at 180, 240, and 300 deg/s	—	VR	7

DCER = dynamic constant external resistance; IK = isokinetic; DNLP = daily nonlinear periodization; LP = linear periodization; VR = variable resistance; VVR = variable variable resistance; RM = repetition maximum; a = values for 10RM; b = values for average training weights; c = values for number of weight plates; d = different type of VR equipment.

1994). Trainees in both programs performed the same exercises and numbers of sets and repetitions per exercise. However, those in the total-body program performed all upper- and lower-body exercises in two training sessions per week, whereas those in the split program performed all of the upper-body exercises two days per week and the lower-body exercises on two other days per week resulting in four training sessions per week. Total training volume was not different between the programs, but training frequency was different (unless it is defined as the total number of training sessions performed per week). The two training programs showed no difference in strength gains during the 10 weeks of training. Additionally, the importance of total training volume when examining training frequency is apparent from a comparison of training untrained people two days per week with three sets of each exercise or three days per week with two sets of each exercise for six weeks; no significant difference in 1RM bench press and squat ability or body composition (DEXA) was noted. Training volume was equal (six sets per week of each exercise) in this comparison (Candow and Burke 2007).

The optimal training frequency may be different for different muscle groups. The American College of Sports Medicine recommends a training frequency of two or three sessions per week for major muscle groups (2011). However, comparisons of training frequency for the bench press and squat concluded that three sessions resulted in greater strength increases than one or two sessions (Berger 1962a; Faigenbaum and Pollock 1997). Graves and colleagues (1990) concluded that one session was equally as effective as two or three sessions per week when training for isolated lumbar extension strength. DeMichele and colleagues (1997) found that two sessions per week was equivalent to three and superior to one when training for torso rotation. These studies indicate that a frequency of three sessions per week is superior to one or two sessions per week when training arm and leg musculature, whereas a frequency of one or two sessions per week results in equivalent gains compared to three sessions per week when training lumbar extension or torso rotation.

In a comparison of varying self-selected training frequencies among collegiate American football players using various body-part training programs over 10 weeks of training (see table 2.5), 1RM bench press ability significantly increased only in the five-sessions-per-week group (Hoffman et al. 1990), and 1RM squat ability significantly increased in the four-, five-, and six-sessions-per-week groups. All training frequencies did result in gains in bench press (2-4%) and squat (5-8%) ability. Examining all of the tests (vertical jump, sum of skinfolds, 2 mi [3.2 km] run, 40 yd sprint, thigh circumference, and chest circumference) pre- and posttraining, the researchers concluded that a frequency of four or five sessions per week results in the greatest overall fitness gains. Note, however, that each muscle group was trained only two or four times per week.

Table 2.6 presents two studies of training frequency. One study (Gillam 1981) compared from one to five training sessions per week. All groups performed a large number of very intense sets (18 sets of 1RM) per training session. Five sessions were shown to be superior in causing increases in 1RM bench press ability compared to the other training frequencies. Additionally, five and three sessions per week showed significantly greater increases than two or one session per week. A study comparing training frequencies of four and three sessions reported significantly greater gains in both sexes with more frequent training sessions (Hunter

TABLE 2.5 **Resistance Training Programs With Three to Six Sessions per Week**

Frequency	Training days	Body parts trained
3	Mon., Wed., Fri.	Total body
4	Mon., Thurs. Tues., Fri.	Chest, shoulders, triceps, neck Legs, back, biceps, forearms
5	Mon., Wed., Fri. Tues., Thurs.	Chest, triceps, legs, neck Back, shoulders, biceps, forearms
6	Mon., Tues., Thurs., Fri. Wed., Sat.	Chest, triceps, legs, shoulders, neck Back, biceps, forearms

Adapted, by permission, from J.R. Hoffman et al., 1990, "The effects of self-selection for frequency of training in a winter conditioning program for football," *Journal of Applied Sport Science Research* 4: 76-82.

1985). Both groups performed all exercises using a 7- to 10RM resistance; the three-sessions-per-week group performing three sets of each exercise per session, and the four-sessions-per-week group performing two sets of each exercise three days per week and three sets one day per week. Thus, total training sets were equivalent between the two groups. Interestingly, the four-sessions-per-week subjects trained two consecutive days twice a week (i.e., Monday and Tuesday, and Thursday and Friday), whereas the three-sessions-per-week subjects trained in the traditional alternate-day method (i.e., Monday, Wednesday, Friday). Results indicate that the necessity of the traditional one day of rest between weight training sessions may not apply to all muscle groups.

Meta-analyses (see box 2.2) of studies in which the majority of subjects trained using DCER concluded that a training frequency of three days per week per muscle group is optimal for untrained people, whereas a frequency of two days per week per muscle group is optimal for recreationally trained nonathletes and trained athletes (Peterson, Rhea, and Alvar 2004, 2005; Rhea et al. 2003). The difference in optimal training frequencies may be due to the higher training volumes used in the studies with trained subjects (Rhea et al. 2003). The results indicate that optimal training frequency may vary with training status and training volume.

Many of the aforementioned studies have design limitations: The majority used beginning resistance exercisers (novice subjects) and examined short training durations (up to 12 weeks), and some studies did not equate the total number of sets and repetitions performed by the various training groups. However, based on the available information, to improve strength, hypertrophy, or local muscular endurance training with DCER, novice trainees should use a total-body program two or three days per week, intermediate trainees

TABLE 2.6 **Effect of Training Frequency on 1RM Bench Press**

Reference	Sex	Days per week of training and % improvement
Gillam 1981	M	Days 1, 2, 3, 4, 5 % improvement 19, 24, 32+, 29, 41*
Hunter 1985	M	Days 3, 4 % improvement 12, 17^
Hunter 1985	F	Days 3, 4 % improvement 20, 33^

* = significantly greater than all other frequencies; + = significantly greater than frequencies 1 and 2; ^ = significantly greater than frequency 3.

? BOX 2.2 PRACTICAL QUESTION

What Is a Meta-Analysis?

A meta-analysis is a statistical method to quantitatively analyze the results of a group of studies concerning the same general question (Rhea 2004)—for example, does the number of repetitions per set affect strength and body composition changes, or does training frequency per week affect strength gains? The basic calculation used in a meta-analysis is effect size, which is a measure of the magnitude of change shown between two time points, such as from pre- to posttesting. There are multiple ways to compute the effect size of a study. For example, the effect size for the change in a single group can be calculated as the posttraining mean minus the pretraining mean divided by the pretraining standard deviation. The effect size comparing two groups can be calculated as the posttraining mean of the treatment group minus the posttraining mean of the control group divided by the pretraining standard deviation of the control group. The pretraining standard deviation is used in both calculations because it is unbiased.

Rhea, M.R. 2004. Synthesizing strength and conditioning research: The meta-analysis. *Journal of Strength and Conditioning Research* 18: 921-923.

should use a total-body program three days per week or a split-body routine four days per week, and advanced lifters should train four to six days per week with a variety of split routines to train one to three muscle groups per session (American College of Sports Medicine 2009).

Motor Performance

It has long been known that DCER exercise can increase motor performance. Studies show significant small increases of several percent or less in the following motor performance tests:

- Vertical jump ability (Adams et al. 1992; Campbell 1962; Caruso et al. 2008; Channel and Barfield 2008; Dodd and Alvar 2007; Kraemer et al. 2000; Kraemer, Mazzetti et al. 2001; Kraemer et al. 2003; Marx et al. 2001; Stone, Johnson, and Carter 1979; Stone, O'Bryant, and Garhammer 1981; Taube et al. 2007)
- Standing long jump (Capen 1950; Chu 1950; Dodd and Alvar 2007; Taube et al. 2007)
- Shuttle run (Campbell 1962; Kusintz and Kenney 1958)
- T-agility test (Cressey et al. 2007)
- Short sprint (Capen 1950; Comfort, Haigh, and Matthews 2012; Deane et al. 2005; Dodd and Alvar 2007; Marx et al. 2001; Schultz 1967)
- Baseball throwing velocity (Thompson and Martin 1965)
- Soccer kick and ball velocity (Young and Rath 2011)
- Shot put (Chu 1950; Schultz 1967; Terzis et al. 2008)

Statistically insignificant changes in short sprint time (Chu 1950; Dodd and Alvar 2007; Hoffman et al. 1990; Jullian et al. 2008; Kraemer et al. 2003; Marx et al. 2001) and in vertical jump ability (Hoffman et al. 1990; Marx et al. 2001; Newton, Kraemer, and Häkkinen 1999; Stone, Nelson et al. 1983) and standing long jump ability (Schultz 1967) have also been demonstrated. Perhaps more important from a training perspective, significant increases in softball throwing velocity (Prokopy et al. 2008); team handball throwing velocity, vertical jump ability, and short sprint ability (Marques and Gonzalez-Badillo 2006); tennis serve, forehand, and backhand ball velocity (Kraemer, Ratamess et al. 2000 Kraemer, Häkkinen et al. 2003); and vertical jump ability have been shown when weight training is incorporated into a total training program (sprint, aerobic, agility, plyometrics; see box 2.3). No significant changes were shown when weight training was incorporated into a total training program for athletes (rugby, basketball)

BOX 2.3 **RESEARCH**

Effects of Resistance Training on Motor Performance

The degree of change in motor performance that occurs in athletes as a result of resistance training is highly variable. Significant changes and nonsignificant changes have been shown in a variety of motor performance tasks when athletes perform weight training in addition to their normal training. How much of a change, if any, depends on a wide variety of factors including the type of weight training program and the specific motor performance task.

In professional team handball players, performance of a 12-week in-season resistance training program increased motor performance and strength (Marques and Gonzalez-Badillo 2006). The program was a multiple-set periodized program performed two or three times per week in addition to sprint, plyometric, and normal skill and technique training. The program resulted in a significant increase in ball-throwing velocity of 6%, in 30 m sprint ability of 3%, and in countermovement jump ability of 13%. Although these changes were significant, they were substantially lower than the significant change in 1RM bench press ability of 27%. This is not unusual given that changes in strength are generally substantially greater than changes in motor performance when resistance training is performed.

Marques, M.C., and Gonzalez-Badillo, J.J. 2006. In-season resistance training and detraining in professional team handball players. *Journal of Strength and Conditioning Research* 20: 563-571.

in short-range (less than 6.25 m) and long-range (more than 6.25 m) basketball shooting ability, vertical jump, and short sprint ability (Gabbett, Johns, and Riemann 2008; Kilinc 2008). Significant changes in job-related motor performance tasks such as a 1RM lift and repetitive box lift have also been demonstrated (Kraemer, Mazzetti et al. 2001).

Similar to strength increases, changes in motor performance tests depend in part on the initial physical condition of the trainee, with smaller increases apparent with better initial physical fitness. Past training history, the type of weight training program, and the duration of training may also affect whether a change in motor performance occurs. The effect of the type of program on a motor performance task is shown by the following examples. Untrained women's vertical jump power and 40 yd sprint ability improved significantly more during six months of training with a multiple-set periodized program compared to a single-set-to-momentary-fatigue program (Marx et al. 2001). Similar results over nine months of training women collegiate tennis athletes have been shown: Vertical jump height and tennis serve velocity showed significant improvements with a multiple-set periodized program and no improvement with a single-set-to-momentary-fatigue program (Kraemer, Ratamess et al. 2000). Over nine months of training (Kraemer et al. 2003) women collegiate tennis athletes performing a multiple-set periodized program and a multiple-set nonperiodized program increased maximal strength similarly. However, the periodized program resulted in significantly greater increases in vertical jump, as well as serve, forehand, and backhand ball velocity. Thus, the type of program can affect whether significant increases in motor performance occur and the magnitude of those increases.

Other program variables may also affect the outcome on motor performance. For example, after weight training for five weeks with 20-second rest periods between sets (15- to 20RM), subjects experienced a significantly greater increase (12.5 vs. 5.4%) in repeat cycle sprint ability than did those training with 80-second rest periods (Hill-Hass et al. 2007). However, greater strength increases (3RM 45.9 vs. 19.6%) occurred in those taking the 80-second rest periods than did those taking the 20-second rest periods. Although conflicting results concerning significant changes in motor performance can be found, as a whole, research supports the contention that DCER exercise can significantly improve motor performance ability.

Training smaller muscle groups may also affect motor performance. For example, significant increases in vertical jump and shot put ability occurred in college-age subjects after training only the toe and finger flexors over a 12-week period (Kokkonen et al. 1988). Dynamic resistance training of the finger flexors also increases rock climbing performance (Schweizer, Schneider, and Goehner 2007).

Many people assume that an increase in strength and power brought about by a training program can be usefully applied to a motor performance task. For this to occur, however, trainees must train all of the muscles involved in the motor performance task, especially the weakest muscles involved in the task, because they may limit the useful application of the strength and power from stronger muscle groups. Additionally, proper technique of the motor task must be trained, because technique may also limit the useful application of increased strength and power. This last point is supported by projects showing that direct practice, alone or combined with resistance training, increases standing long jump ability to a significantly greater extent than resistance training alone in previously untrained subjects (Schultz 1967), and strength training combined with sprint training results in greater changes in sprinting speed than either type of training alone (Delecluse et al. 1997).

Strength Changes

Strength increases in a large variety of muscle groups in both women and men from DCER training are well documented. Tables 2.3, 2.4, and 2.6 present changes in 1RM bench press and leg press ability in both sexes after short-term DCER training. Women demonstrate substantial increases in 1RM bench press ability; increases range from 8% in college tennis athletes after 36 weeks of training (Kraemer et al. 2000) to 47% in untrained women after 16 weeks of training (Hostler, Crill et al. 2001). Similarly, men experience strength increases ranging from 3% in college American football players after 10 weeks of training (Hoffman et al. 1990) to 44% in untrained men after 12 weeks of training (Allen, Byrd, and Smith 1976). Using 1RM as the testing criteria, women have demonstrated increases in leg press ability ranging from 8% in college tennis players after 36 weeks of training (Kraemer et al. 2000) to 148% in untrained women after 18 weeks of training (Staron et al. 1991). Increases in men's leg press ability range from 7% after 6 weeks of training (Stone, Nelson, et al. 1983) to 71% after 10 weeks of training (Allen, Byrd, and Smith 1976). The wide ranges in strength increases are probably related to differences in pretraining status, familiarity with the exercise tests, the duration of training, and the type of program.

Body Composition Changes

The normal changes in body composition as a result of short-term DCER exercise in both sexes are small increases in fat-free mass and small decreases in percent body fat (see table 3.3). The decrease in percent body fat is often due in large part to an increase in fat-free mass rather than a large decrease in fat mass. Many times these two changes occur simultaneously, resulting in little or no change in total body weight.

Safety Considerations

If DCER exercise is performed using free weights, appropriate spotting should be used. For machine DCER exercises, spotting is normally not needed. Because free weights must be controlled in three planes of movement, generally more time is needed to learn proper lifting technique, especially of multijoint or multi-muscle-group exercises, compared to a similar exercise performed using a machine.

Variable Resistance Training

Variable resistance equipment has a lever arm, cam, or pulley arrangement that varies the resistance throughout the exercise's range of motion. One possible advantage of variable resistance equipment is that it can match the increases and decreases in strength (strength curve) throughout an exercise's range of motion. This could result in the muscle exerting near-maximal or maximal force throughout the range of motion, resulting in maximal strength gains.

The three major types of strength curves are ascending, descending, and bell shaped (see figure 2.3). Although the ascending and descending strength curves shown in figure 2.3 are linear, generally they are curvilinear. In exercises such as the squat and bench press, which have an ascending strength curve, it is possible to lift more weight if only the last half or last quarter of the concentric portion of a repetition is performed. If an exercise has a descending strength curve, it is possible to lift more weight if only the first half or first quarter of the concentric repetition phase is performed. An example of such an exercise is upright rowing. An exercise in which it is possible to lift more resistance if only the middle portion of the range of motion is performed has a bell-shaped strength curve. Arm curls, like many single-joint exercises, have a bell-shaped strength curve. To match the three major types of strength curves, variable resistance machines must be able to vary

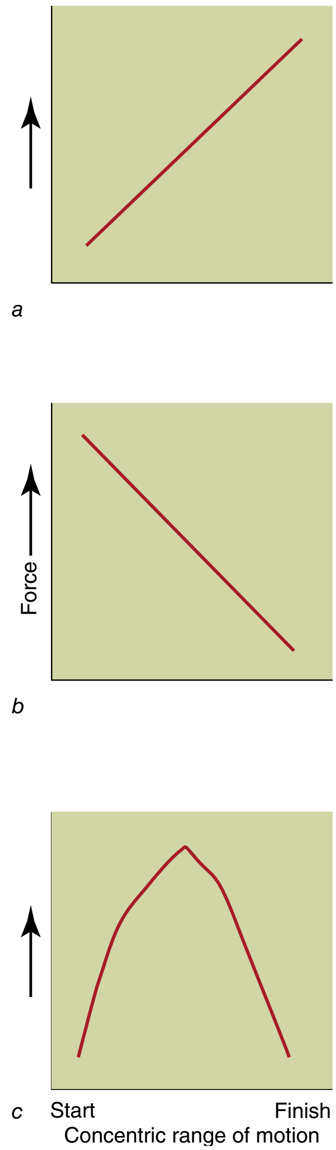


FIGURE 2.3 The three major types of strength curves are *(a)* ascending, *(b)* descending, and *(c)* bell shaped.

the resistance in three major patterns, which most types are not capable of doing (see the section Variable Variable Resistance later in this chapter). Additionally, because of variations in limb length, the point of attachment of the muscle's tendons to the bones, and torso size, it is difficult to conceive of one mechanical arrangement that would match all people's strength curves for a particular exercise.

Biomechanical research indicates that one type of cam variable resistance equipment does not match the strength curves of the elbow curl, multibiceps curl, chest fly, knee extension, knee flexion, and pullover exercises (Cabell and Zebras 1999; Harman 1983; Pizzimenti 1992). The equipment's ability to match the strength curve is especially ineffective at the extreme ranges of an exercise's range of motion (Cabell and Zebras 1999). A second type of cam equipment has been reported to match the strength curves of females fairly well (Johnson, Colodny, and Jackson 1990). However, for females the cam resulted in too great a resistance near the end of the knee extension exercise. The cam also provided too much resistance during the first half and too little during the second half of the elbow flexion and elbow extension exercises. The knee flexion machine matched females' strength curves well throughout the range of motion. The resistance curve of eight variable resistance knee extension machines from six manufacturers also poorly matched the strength curve of young men; the matching of the strength curve was highly variable from machine to machine and significantly less curvilinear than the actual isometric strength curve (Folland and Morris 2008). Thus, in general cam-type variable resistance equipment does not appear to match strength curves of exercises.

Number of Sets and Repetitions

Significant strength gains from short-term (4 to 18 weeks) variable resistance training have been demonstrated in a large variety of muscle groups with various combinations of sets and repetitions. Significant increases in strength have been shown with the following protocols (sets × repetitions):

- 1 × 6- to 10RM (Jacobson 1986)
- 1 × 7- to 10RM (Braith et al. 1993; Graves et al. 1989)
- 1 × 8- to 12RM (Coleman 1977; Hurley, Seals, Ehsani et al. 1984; Keeler et al. 2001; Manning et al. 1990; Pollock et al. 1993; Silvester et al. 1984; Starkey et al. 1996; Westcott et al. 2001)
- 1 × 10- to 12RM (Peterson 1975)
- 1 × 12- to 15RM (Stone, Johnson, and Carter 1979)
- 2 × 10- to 12RM (Coleman 1977)
- 2 × 12 at 50% of 1RM (Gettman, Culter, and Strathman 1980)
- 2 or 3 × 8- to 10RM (LeMura et al. 2000)
- 3 × 6RM (Jacobson 1986; Silvester et al. 1984)
- 3 × 8- to 12RM (Starkey et al. 1996)
- 3 × 15RM (Hunter and Culpepper 1995)
- 6 × 15- to 20RM (Sale et al. 1990)
- 3 × 10RM for three weeks, 3 × 8RM for three weeks, and 3 × 6RM for six weeks (Boyer 1990)
- Four sets with increasing resistance and repetitions decreasing from eight to three in a half-pyramid program (Ariel 1977)

Variable resistance training has also been shown to increase maximal isometric strength throughout the full range of motion of an exercise (Hunter and Culpepper 1995). Thus, various combinations of sets and repetitions can cause significant strength increases.

Strength Changes

Substantial increases in strength have been demonstrated with variable resistance training. For example, after 16 weeks of training males demonstrated an increase of 50% in upper-body strength and 33% in lower-body strength (Hurley, Seals, Ehsani et al. 1984), and females demonstrated an increase of 29% in upper-body strength and 38% in lower-body strength (LeMura et al. 2000). Increases in bench press and leg press strength from variable resistance training are depicted in tables 2.3 and 2.4, respectively. Tests using variable resistance equipment and other types of muscle actions reveal that this type of resistance training can cause substantial increases in strength.

Variable Variable Resistance

One type of variable resistance equipment allows adjustment of the resistance curve of an exercise. **Variable variable resistance** equipment allows an exercise to be performed with an ascending, descending, and bell-shaped strength curves (see figure 2.4). The concept of this type of equipment is to force muscles to use more motor units at different points in the exercise's range of motion by using strength curves that do not match the strength curve of the exercise (e.g., using a bell-shaped and descending curve in addition to an ascending curve in an exercise that has an ascending strength curve). This type of equipment also offers the ability to decrease the force needed in a portion of an exercise's range of motion in which high force output is contraindicated, such as after some types of injuries. Women performing a total-body training program for 14 weeks of three sessions per week showed significant increases in 1RM strength and increased (dual-energy X-ray absorptiometry) lean soft tissue (see table 3.3) and decreased percent fat (Fleck, Mattie, and Martensen 2006). Training consisted of performing one set of 10 repetitions for each of the strength curves (bell-shaped, ascending, and descending) resulting in three sets of each exercise. Their 1RM strength increased significantly (between 25 and 30%) in the leg press, bench press, lat pull-down, and overhead press. Thus, this type of equipment is effective in increasing strength and promoting body composition changes.

Motor Performance

Little information exists concerning changes in motor performance as a result of variable resistance training. American football players who participated in a combined program of in-season football training and total-body variable resistance strength training demonstrated small but greater mean improvements in the 40 yd sprint and vertical jump ability than a control group performing only the in-season football training program (Peterson 1975). Whether the changes were statistically significant or whether a significant difference existed between the groups was not addressed. Although this study showed a slightly greater increase in motor performance with variable resistance training, it offers little concrete evidence of variable resistance training effectiveness in terms of motor performance changes relative to other types of training.

A comparison of a cam-type variable resistance machine and an increasing lever arm–type variable resistance machine showed both types of equipment to increase motor performance (Silvester et

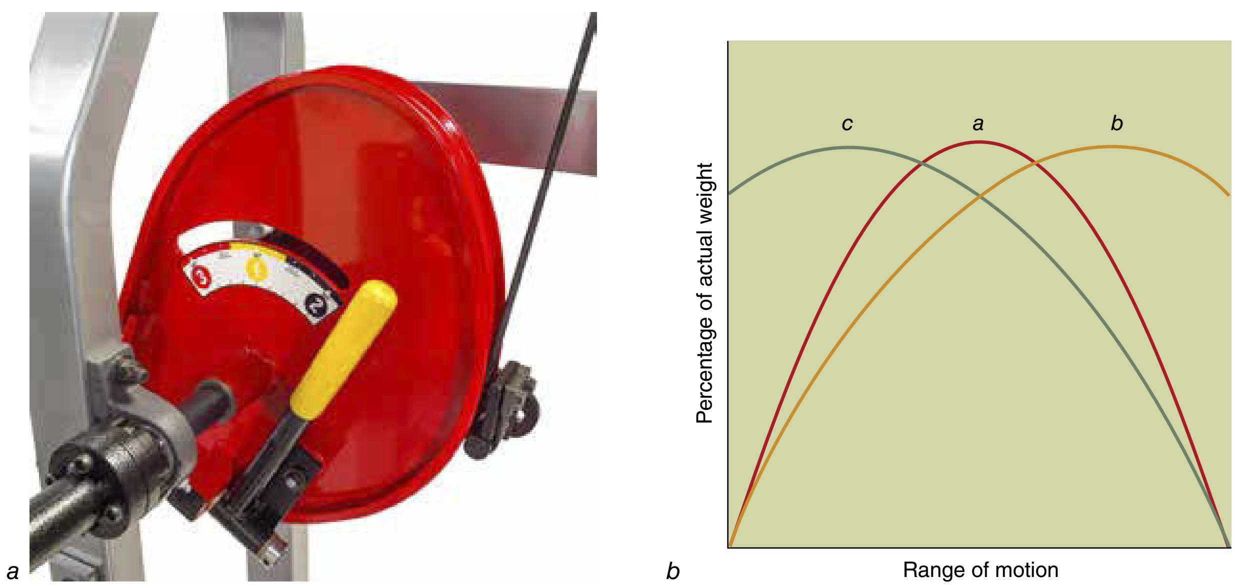


FIGURE 2.4 Variable variable resistance allows the strength curve of an exercise to be varied. *(a)* The handle on variable variable resistance machines rotates the starting position of the cam allowing switching among the three major types of strength curves. *(b)* The three major types of strength curves produced by moving the handle are the *(a)* bell-shaped, *(b)* ascending, and *(c)* descending curves.

Courtesy of Strive Fitness Inc., Cannonsburg, PA.

al. 1984). The cam-type group trained three days per week for six weeks followed by two days per week for five weeks. Participants did knee extensions immediately followed by leg presses and performed each exercise for one set of 12 repetitions to failure. The increasing lever arm–type group trained three days per week for the entire 11-week training period; they performed the leg press for one set of 7 to 10 repetitions followed by one set to concentric failure. No difference in static leg strength gains was demonstrated between the groups. The cam-type and lever arm–type groups increased their mean vertical jumps by 0.3 in. (0.76 cm) and 1.1 in. (2.8 cm), respectively. The increase in vertical jump shown by the lever arm–type group was significantly greater than the increase shown by the cam-type group. So motor performance can increase as a result of variable resistance training, and the increase depends in part on the training protocol, equipment used, or both.

Body Composition Changes

Significant increases in muscle thickness of the quadriceps and knee flexors (hamstrings) have been reported after variable resistance training (Starkey et al. 1996). Increases in fat-free mass and decreases in percent body fat also occur as a result of variable variable resistance training (Fleck, Mattie, and Martensen 2006). These changes in body composition are depicted in table 3.3 and are of the same magnitude as the changes that occur from DCER training.

Safety Considerations

As with all types of weight training machines, safety is not a major concern when using variable resistance or variable variable resistance machines, and a spotter is not normally necessary. Similarly, as with all weight training machines, care must be taken to ensure that the variable resistance machine fits the trainee properly and that the trainee is properly positioned on it. Without proper fit and positioning, proper exercise technique is impossible and risk of injury increases.

Isokinetic Training

Isokinetic refers to a muscular action performed at constant angular limb velocity. Unlike other types of resistance training, isokinetic training has no specified resistance to meet; rather, the velocity of movement is controlled. At the start of each movement, acceleration from 0 degrees per second takes place until the set velocity is achieved. After the set velocity is achieved, further acceleration is not possible and any force applied against the equipment results in an equal reaction force. The reaction force mirrors the force applied to the equipment throughout the range of movement of the exercise, until deceleration starts to occur at the end of the range of motion. It is theoretically possible for the muscle(s) to exert a continual maximal force throughout the movement's range of motion except where acceleration at the start and deceleration at the end of the movement occurs.

The majority of isokinetic equipment found in resistance training facilities allows concentric-only actions, although eccentric and coupled concentric–eccentric isokinetic actions (i.e., the same exercise movement performed in a concentric followed by an eccentric action) are possible on some isokinetic equipment. The emphasis here will be on concentric-only isokinetic training. Advantages of isokinetic training include the ability to exert maximal force throughout a large portion of an exercise's range of motion, the ability to train over a wide range of movement velocities, and minimal muscle and joint soreness. Another characteristic of many types of isokinetic equipment is that they allow only single-joint movements (knee extension, elbow flexion) in unilateral (one leg or arm) as opposed to bilateral (both arms or legs) actions. One major criticism of this type of training is that isokinetic muscle actions do not exist in the real world; this potentially limits the application of isokinetic training to daily life and sport activities.

Strength Changes

The vast majority of studies examining concentric-only isokinetic training have been of short duration (3 to 16 weeks); have examined strength changes of single-joint movements; and have tested for strength gains using isometric, DCER, eccentric-only isokinetic, and concentric-only isokinetic tests. As depicted in table 2.7, programs of 1 to 15 sets at various movement velocities and with various numbers of repetitions and sets cause significant increases in strength.

Significant gains in strength have also been achieved by performing as many repetitions as possible in a fixed period of time, as shown in the following studies: