Fundamentals of Resistance Training: Progression and Exercise Prescription

WILLIAM J. KRAEMER[1] and NICHOLAS A. RATAMESS[2]

[1]*Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, CT; and* [2]*Department of Health and Exercise Science, The College of New Jersey, Ewing, NJ*

ABSTRACT

KRAEMER, W. J., and N. A. RATAMESS. Fundamentals of Resistance Training: Progression and Exercise Prescription. *Med. Sci. Sports Exerc.*, Vol. 36, No. 4, pp. 674–688, 2004. Progression in resistance training is a dynamic process that requires an exercise prescription process, evaluation of training progress, and careful development of target goals. The process starts with the determination of individual needs and training goals. This involves decisions regarding questions as to what muscles must be trained, injury prevention sites, metabolic demands of target training goals, etc. The single workout must then be designed reflecting these targeted program goals including the choice of exercises, order of exercise, amount of rest used between sets and exercises, number of repetitions and sets used for each exercise, and the intensity of each exercise. For progression, these variables must then be varied over time and the exercise prescription altered to maintain or advance specific training goals and to avoid overtraining. A careful system of goal targeting, exercise testing, proper exercise technique, supervision, and optimal exercise prescription all contribute to the successful implementation of a resistance training program. **Key Words:** STRENGTH, MUSCLE, EXERCISE PROGRAM DESIGN, CONDITIONING

Resistance training is a modality of exercise that has grown in popularity over the past two decades, particularly for its role in improving athletic performance by increasing muscular strength, power and speed, hypertrophy, local muscular endurance, motor performance, balance, and coordination (62). Traditionally, resistance training was performed by few individuals (e.g., strength athletes and those who strived to gain muscle hypertrophy such as body builders). However, we now have a better understanding of the health-related benefits of resistance training; resistance training is now a popular form of exercise that is recommended by national health organizations such as the American College of Sports Medicine and the American Heart Association (2,3,65) for most populations including adolescents, healthy adults, the elderly, and clinical populations (e.g., those individuals with cardiovascular disease, neuromuscular disease). The key factor to successful resistance training at any level of fitness or age is appropriate program design. Program design entails proper exercise instruction (e.g., technique, breathing, correct use of equipment), goal setting (so the program can target specific areas of interest), a method of evaluation of training progress toward training goals, the correct prescription of the acute program variables, and the inclusion of specific methods of progression targeting particular areas of muscular fitness. It is important that resistance training should be supervised by qualified professionals for the prevention of injury and for maximizing the health and performance benefits (70). In this article, we will review resistance training program design and the associated factors that need to be considered. In addition, we will consider progression during resistance training in relation to individual training status and goals, and will highlight some of the important concepts of progression recently recommended by the American College of Sports Medicine (3).

RESISTANCE TRAINING INDIVIDUALIZATION/GOAL SETTING

The act of resistance training, itself, does not ensure optimal gains in muscle strength and performance. Rather, it is the magnitude of the individual effort and systematic structuring of the training stimulus that ultimately determines the outcomes associated with resistance training. Thus, resistance-training programs need to be *individualized* (e.g., based on individual goals) in order to maximize the outcomes (29). Program individualization involves several steps. Before the initiation of a resistance training program, it is important that at-risk individuals (e.g., those individuals

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with a physical ailment) obtain medical clearance. This ensures that resistance training is beneficial rather than harmful to those individuals with predisposing injuries or illnesses. Once an individual is deemed healthy to participate, the second step involves goal setting via a *needs analysis*. A needs analysis consists of answering questions based upon the goals of resistance training. Individualized resistance training programs are most effective because they ensure that all goal-oriented issues are included within the design. Some common questions that need to be addressed are (29):

- Are there any health/injury concerns which may limit the exercises performed or the exercise intensity?
- What type of equipment (e.g., free weights, machines, bands/tubing, medicine balls, functional) is available and preferred?
- What is the targeted training frequency and are there any time constraints that may affect workout duration?
- What muscle groups need to be trained (generally all major muscle groups are trained, but some may require prioritization based upon strengths/weaknesses or the demands of the sport or activity)?
- What are the targeted energy systems (e.g., aerobic or anaerobic)?
- What types of muscle actions (e.g., concentric [CON], eccentric [ECC], isometric [ISOM]) are needed?
- If the individual is training for a sport or activity, what are the most common sites of injury?

The program goals must then be determined. Some common goals of resistance training include increases in muscle size, strength, power, speed, local muscular endurance, balance, coordination, and flexibility, reductions in body fat, improvements in general health (e.g., lower blood pressure, strengthen connective tissue, reduce stress), and rehabilitation from injury. Most programs aim to collectively improve several of these components in an integrative approach as opposed to only focusing on one facet. Along with goal setting, the magnitude of improvement and the nature of the program need to be established. Is the program recreational or does "maximal performance" need to be increased? Recreational training involves resistance training for moderate improvements in muscle strength, local muscular endurance, and hypertrophy for general fitness, whereas competitive training involves resistance training to maximize muscle hypertrophy, strength, power, and/or local muscular endurance. Some forms of competitive resistance training include *power lifting* (e.g., competing to maximize muscle strength in specifically the squat, bench press, and deadlift exercises), *weightlifting* (e.g., the Olympic sport that involves maximizing muscle strength and power for performance in the clean and jerk and snatch lifts), *body building* (e.g., using resistance training to optimize muscle hypertrophy, definition, and symmetry while reducing body fat to optimize appearance), *strongman*/woman competitions (e.g., competitions involving numerous events that exemplify muscle strength, power, and local muscular endurance), and *athletics* (e.g., strength training to improve ath-

letic performance). Lastly, *maintenance* programs are also popular. Maintenance training involves resistance work to maintain the current level of muscular fitness rather than to develop further gains. A feature/benefit of maintenance programs is that in the short term, reductions in training volume, frequency, and intensity may be used without a significant reduction in muscular fitness. These programs are used commonly by athletes during the competitive season and in the general fitness setting. However, it is important to note that long-term maintenance training could result in detraining if the training threshold is not met. Therefore, maintenance programs should be included in cyclical fashion and as part of longer programs designed for progression.

RESISTANCE TRAINING PROGRAM DESIGN

The resistance training program is a composite of acute variables that include: 1) muscle actions used, 2) resistance used, 3) volume (total number of sets and repetitions), 4) exercises selected and workout structure (e.g., the number of muscle groups trained), 5) the sequence of exercise performance, 6) rest intervals between sets, 7) repetition velocity, and 8) training frequency (29,62). Altering one or several of these variables will affect the training stimuli and potentially favor conditions by which numerous ways exist to vary resistance training programs and maintain/increase participant motivation. Therefore, proper resistance exercise prescription involves manipulation of each variable specific to the targeted goals.

Muscle actions. Most resistance training programs include primarily dynamic repetitions with both CON and ECC muscle actions, whereas ISOM muscle actions play a secondary role. Greater force per unit of muscle size is produced during ECC actions. Eccentric actions involve less motor unit activation per specific level of tension (55), require less energy per level of force (24), and are critical for optimal hypertrophy, yet may result in more delayed onset muscle soreness (21) as compared with CON actions. Dynamic muscular strength improvements are greatest when ECC actions are included in the training program (20). The role of muscle action manipulation during resistance training is minimal considering that most programs include CON and ECC muscle actions in a given repetition. However, some advanced programs may include different forms of ISOM training (e.g., functional isometrics), the use of supramaximal ECC muscle actions (53), and accommodating resistance devices such as bands and chains in order to maximize gains in strength and hypertrophy. These techniques have not been extensively investigated but are believed to favor improvements in muscular strength.

Exercise selection. Two general types of free weight or machine exercises may be selected in resistance training: single- and/or multiple-joint. *Single-joint exercises* stress one joint or major muscle group, whereas *multiple-joint exercises* stress more than one joint or major muscle group. Both single- and multiple-joint exercises have been shown to be effective for increasing muscular

strength in the targeted muscle groups. Single-joint exercises, e.g., leg extension and leg curl, have typically been used to target specific muscle groups and are thought to pose less risk of injury due to the reduced level of skill and technique involved. Multiple-joint exercises, e.g., bench press, squat, hang pulls, and power clean, involve a more complex neural activation and coordination, and due to the larger muscle mass involvement (and subsequent amount of weight used), these exercises have generally been regarded as the most effective exercises for increasing muscular strength and power (29). In fact, total-body exercises such as the power snatch and power clean have been regarded as the most effective exercises for increasing muscle power because they require fast force production to successfully complete each repetition (31).

Exercises stressing multiple or large muscle groups have shown the greatest acute metabolic responses (9). For example, exercises such as the squat, leg press, leg extension, and bent-over row have been shown to elicit greater rates of oxygen consumption than exercises such as the behind-the-neck shoulder press, bench press, upright row, and arm curl (9). In addition, these exercises have elicited the greatest acute hormonal responses (67). Deadlifts (25), squat jumps (105), and Olympic lifts (67) have produced greater acute 22-kDa growth hormone and testosterone responses compared with exercises such as the bench press and seated shoulder press. Thus, the amount of muscle mass involved in a movement significantly impacts the acute metabolic demands and anabolic hormonal response, which have direct implications for resistance training programs targeting improvements in local muscle endurance, lean body mass, and reductions in body fat.

Exercise order and workout structure. The sequencing of exercises and number of muscle groups trained during a workout significantly affects the acute expression of muscular strength (97). For example, there are three basic workout structures: 1) total-body workouts, 2) upper/lower body split workouts, and 3) muscle group split routines. *Total-body workouts* involve performance of exercises stressing all major muscle groups (i.e., one to two exercises for each major muscle group). They are common among general fitness enthusiasts, athletes, and Olympic weightlifters. *Upper/lower body split workouts* involve performance of upper-body exercises during one workout and lower-body exercises during another. These are common among general fitness enthusiasts, athletes, power lifters, and body builders. *Muscle group split routines* involve performance of exercises for specific muscle groups during the same workout (e.g., a "chest/triceps" workout where all exercises for the chest are performed then all exercises for the triceps are performed). These types of workouts are most popular among body builders or individuals striving to maximize muscle hypertrophy. All three workout structures are effective for improving muscular fitness, and it appears that individual goals, time/frequency, and personal preferences often determines which type of work-

out will be used. The major differences between these structures are the magnitude of specialization observed during each workout (i.e., three to four exercises for a specific muscle group may be performed during a muscle group split routine workout as opposed to one to two exercises for a muscle group in a total-body workout) and the amount of recovery between workouts (i.e., a major muscle group may be trained 1 to $2\times$ wk^{-1} for a split routine, 2 to $3\times$ wk^{-1} for an upper/lower-body split, and 3 or more times per week for a total-body workout during most typical lifting programs). Only one study has compared workout structures and similar improvements in previously untrained women between total-body and upper/lower-body split workouts were found (15). Other studies have compared total-body resistance training to either upper-body-only or lower-body-only training (16,66). We have shown the importance of the total-body resistance training (as opposed to upper-body-only training) in women for improving overall muscular strength, hypertrophy, power, and physical performance (63,66). In the elderly, similar improvements have been observed in lower body strength between total-body and lower-body workouts (of equal volume and intensity) (16).

Upon determination of the workout structure (e.g., muscle groups trained), general recommendations can be made depending on whether one is training for strength, hypertrophy, power, and/or local muscular endurance. Considering that multiple-joint exercises have been shown to increase muscular strength, hypertrophy, and power, maximizing performance of these exercises may be necessary for optimal gains. This recommendation includes performance of these exercises early in the training session when fatigue is minimal. Multiple-joint exercises have been used extensively for power training. The inclusion of these exercises (e.g., power clean, push press, and variations) is necessary as these exercises have been shown to require rapid force production (31). These exercises do require additional time for learning and proper technique is essential. Therefore, these exercises need to be performed initially in the workout when fatigue is minimal. The sequencing of exercises for local muscular endurance training may not be as important in comparison with strength and power training as fatigue is a necessary component of local muscular endurance training. Therefore, similar strategies may be used for local muscular endurance training although variations can also be used. Some sequencing strategies (although others are possible) for strength and power training include:

When training all major muscle groups in a workout:

1. perform large muscle group exercises before small muscle group exercises;
2. perform multiple-joint exercises before single-joint exercises;
3. for power training, perform total-body exercises (from most to least complex) before basic exercises such as the squat or bench press;

4. rotate upper and lower body exercises or opposing (agonist-antagonist relationship) exercises.

When training upper-body muscles on one day and lower-body muscles on a separate day:

1. perform large muscle group exercises before small muscle group exercises;
2. perform multiple-joint exercises before single-joint exercises;
3. rotate opposing exercises (agonist-antagonist relationship).

When training individual muscle groups:

1. perform multiple-joint exercises before single-joint exercises;
2. perform higher-intensity [i.e., higher percent of one-repetition maximum (1 RM)] exercises before lower-intensity exercises.

Loading. Loading describes the amount of weight lifted or the resistance one exercises with and is highly dependent upon other variables such as exercise order, volume, frequency, muscle action, repetition speed, and rest interval length (62). Altering the training load can significantly affect the acute metabolic, hormonal, neural, and cardiovascular responses to training (28,35,58,59,67,93). Load prescription depends upon individual training status and goals. For example, light loads of approximately 45–50% of 1 RM or less may increase dynamic muscular strength in previously untrained individuals (4), as this initial phase of lifting is characterized by improved motor learning and coordination (92). Heavy loads are not required to increase strength at this level of training while the individual is learning correct form and technique. However, greater loading is needed to increase maximal strength as one progresses from intermediate to advanced levels of training. Häkkinen et al. (35) reported that loads greater than 80–85% of 1 RM were needed to produce further neural adaptations during advanced resistance training. This is important because neural adaptations (e.g., enhanced recruitment, rate coding, and synchronization) are crucial to maximal strength development as they precede hypertrophy during intense training periods. Although motor unit activity does increase with fatigue (e.g., the last few repetitions of a set), there appears to be specific motor unit recruitment patterns during the lifting of very heavy or near-maximal loads that does not appear attainable with light-to-moderate loading. Muscle hypertrophy results in lower motor unit activity needed to generate a given force (84). In order to continually recruit these higher-threshold motor units, progressively heavier loads are needed (84). Maximizing strength, power, and hypertrophy may only be accomplished when the maximal numbers of motor units are recruited. Thus, heavy loading in experienced individuals is needed to recruit the high-threshold motor units that may not be activated during light-to-moderate lifting. In addition, other tissues such as bone respond more favorably to heavy loading, and this has implications for resistance training programs designed to improve, for example, bone health (29).

There exists an inverse relationship between the amount of weight lifted and the number of repetitions performed. Several studies have shown that training with loads corresponding to 80–85% of 1 RM and beyond (e.g., 1–6 RM) were most effective for increasing maximal dynamic strength (10,17). This loading range appears to maximally recruit muscle fibers and will specifically increase dynamic 1 RM strength (35). Although significant strength increases have been reported using loads corresponding to ~70–80% of 1 RM (e.g., 6–12 RM) (56), it is believed that this range may not be as effective in increasing maximal strength in advanced resistance-trained individuals compared to heavier loading (e.g., > 85% of 1 RM). The 6–12 RM loading range is typically used in programs that target muscular hypertrophy (61). Although heavy loading is effective for increasing muscle size (17), it has been suggested that the 6–12 RM loading range may provide the best combination of load and volume (62). Loads lighter than this (12–15 RM and lighter) rarely increase maximal strength (4,17) but are very effective for increasing absolute local muscular endurance (17,101). Although each "training zone" has its advantages, devoting 100% of training to one general RM zone or intensity (e.g., 80% of 1 RM) runs a very high risk of the athlete encountering training plateaus or becoming overtrained. It is important to note that intensity is exercise-dependent. For example, Hoeger et al. (45) reported that 80% of 1 RM was a load corresponding to a 10 RM for exercises such as the bench press, leg extension, and lat pulldown; however, this intensity corresponded to only a 6 RM for the leg curl, 7–8 RM for the arm curl, and a 15 RM for the leg press. Therefore, it appears that optimal strength, hypertrophy, and local muscular endurance training requires the systematic use of various loading strategies (27,64,69).

Given that both force and time components are relevant to maximizing power, training to increase muscular power requires two general loading strategies. First, moderate-to-heavy loads are required to recruit high-threshold fast-twitch motor units that are needed for strength. However, as depicted by the force-velocity curve, higher loads are accompanied by slower velocities such that performing heavy resistance training will potentially increase force production but not speed. Thus, the second strategy is to incorporate light-to-moderate loads performed at an explosive lifting velocity. Depending on the exercise in question, this loading range may encompass 30–60% of 1 RM. Wilson et al. (107) reported that 30% of 1 RM was the optimal loading that produced the greatest power output during ballistic jump squat training. However, Baker et al. (7,8) reported a higher loading range (45–60% of 1 RM) was necessary to optimize power during jump squats and the ballistic bench press for power-trained athletes. A recent study has shown that jump squat training with 30% of 1 RM was more effec-

tive for increasing peak power than jump squat training with 80% of 1 RM (71). With ballistic resistance exercise, the load is maximally accelerated either by jumping (e.g., jump squats) or by releasing the weight using specialized equipment (e.g., Plyo Power System) (76,77). However, traditional repetitions result in a "deceleration" phase that limits power development throughout the complete range of motion. During traditional weight training exercises performed at an explosive velocity, a recent study has shown that 40–60% of 1 RM may be most beneficial for the bench press and 50–70% for the squat (98), thereby demonstrating that a slightly higher load is necessary for power training when nonballistic repetitions are performed. Thus, training for maximal power requires various loading strategies performed at high velocity.

Training volume. Training volume is generally estimated from the total number of sets and repetitions performed during a training session. Several systems including the nervous, metabolic, hormonal, and muscular have been shown to be sensitive to training volume (38,39,56,64,68). Altering training volume can be accomplished by changing the number of exercises performed per session, the number of repetitions performed per set, or the number of sets performed per exercise. Typically, heavy loads with low repetitions using moderate-to-high number of sets (i.e., characteristic of strength and power training) (35) are generally considered low-volume programs due to the low number of repetitions performed per set. Without altering the intensity of these programs, volume may be increased by either increasing the number of sets and/or exercises performed or by increasing training frequency. However, care must be taken, because intensity and volume are inversely related; increases in training volume with low-repetition programs should be closely monitored and intensity possibly reduced in order to lower the risk of overtraining (30). Moderate-to-heavy loads, moderate-to-high repetitions, and multiple sets per exercise are characteristic of hypertrophy training (although strength and local muscle endurance are also enhanced with these programs) and are generally regarded as high-volume programs when several exercises are performed per workout (e.g., at least six to eight exercises). Total work, in addition to the forces developed, has been implicated for gains in muscular hypertrophy (75). This has been supported, in part, by greater hypertrophy associated with high-volume, multiple-set programs compared with low-volume, single-set programs in resistance-trained individuals (56,64,69,89). Traditional strength training (high load, low repetition, and long rest periods) has produced significant hypertrophy (17,35,103); however, it has been suggested that the total work involved with traditional strength training may not maximize hypertrophy (29). Very light-to-moderate loads performed for multiple sets of high repetitions (characteristic of local muscular endurance training) are considered to be very high in total volume but not optimal for hypertrophy. Thus, the overall volume selected for the program should be based on individual training status and goals as numerous possibilities exist for effective progression.

Although training volume has been examined in many facets, one facet that has received less attention is the number of sets per muscle group or workout. Indeed, there are few data that directly compare resistance training programs of varying total sets, thus leaving numerous possibilities for the strength and conditioning professional when designing programs. Much of the resistance training literature has examined the number of sets performed per exercise and it has generally been found that two to six sets per exercise produce significant increases in muscular strength in both trained and untrained individuals (10,17,47,56,89). However, similar strength increases have been found in novice individuals who trained using 2 and 3 sets, and 2 and 4 sets (80); 3 sets have also been reported as being superior to one and two (11). Thus, the number of sets selected per exercise should vary depending on the training goals. Typically, three to six sets are most common during resistance training, but more and less have also been used successfully.

Another related issue to training volume that has received considerable attention is the comparison of single- and multiple-set resistance training programs. In most of the studies to date, one set per exercise performed for 8–12 repetitions at an intentionally slow lifting velocity has been compared with both periodized and nonperiodized multiple-set programs. A common criticism of these investigations is that the number of sets per exercise was not separated from other variables such as intensity, frequency, and repetition velocity, therefore making it difficult to ascertain whether the observed differences were the results of the number of sets per exercise or from some other uncontrolled variable. However, the purpose of some of these studies was to make general program comparisons in response to the emergence in popularity of single-set programs and the subsequent claims associated with their efficacy. This concern notwithstanding, comparisons between one popular single-set training program and various multiple-set programs of various intensities have yielded conflicting results. Several studies have reported similar strength increases between single- and multiple-set programs, whereas others reported multiple-set programs superior (11,14,81,102) in previously untrained individuals. These data have prompted the notion that untrained individuals respond favorably to both single- and multiple-set programs. Considering that the early phase of resistance training is characterized by neural adaptations, e.g., improvements in muscle activation and coordination (92), it may be that the overall training volume is not critical during the first 6–12 wk. It has been recently shown that muscle mass may also play a key role in determining strength increases. Paulsen et al. (81) reported that 6 wk of lower-body training with three sets was superior to one set in untrained individuals. However, similar improvements between one and three

sets were observed in selected measures of upper-body strength over the same time period. Nevertheless, single- and multiple-set programs appear beneficial for novice resistance training. However, long-term resistance training studies have predominantly shown that a higher volume of resistance exercise is necessary to generate a higher rate of progression. In resistance-trained individuals, multiple-set programs have been shown to be superior for muscle strength, local muscular endurance, power, and hypertrophy increases in most studies (56,64,87,95). No study has shown single-set training to be superior to multiple-set training in either trained or untrained individuals. Finally, it is important to point out that not all exercises need to be performed with the same number of sets and that emphasis of higher or lower training volume is related to the program priorities as well as the muscle(s) trained in an exercise movement. Low volume programs can provide a solid variation during the larger training cycle (mesocycle), and they therefore have a place when properly incorporated into a conditioning program.

Rest intervals. Rest interval length is dependent upon training intensity, goals, fitness level, and targeted energy system utilization. The amount of rest between sets and exercises significantly affects the metabolic (57), hormonal (58,59), and cardiovascular (28) responses to an acute bout during resistance exercise, as well as performance of subsequent sets (56) and training adaptations (83,90). It has been shown that acute force and power production may be compromised with short (i.e., 1 min) rest periods (56), although these short rest intervals are beneficial for hypertrophy and local muscle endurance training. For example, Kraemer (56) reported differences in performance with 3- versus 1-min rest intervals. All participants were able to perform 10 repetitions with 10 RM loads for 3 sets when 3-min rest periods were used for the leg press and bench press. However, when rest periods were reduced to 1 min, 10, 8, and 7 repetitions were performed, respectively. Strength and power training (e.g., heavy loads, one to six repetitions with long rest intervals) predominantly stress the ATP-PC system, whereas hypertrophy/strength (e.g., moderate-to-heavy loads, 6–12 repetitions with moderate-to-short rest intervals) is supported mostly by energy provided by ATP-PC and glycolysis, with minor contributions from aerobic metabolism. Local muscle endurance training (e.g., high repetition, short rest intervals) involves a higher contribution of energy from aerobic metabolism. Thus, the rest interval influences the relative contribution of the three energy systems.

Longitudinal resistance training studies have shown that greater strength increases result from long when compared with short rest periods between sets, e.g., 2–3 min versus 30–40 s (83,90). When training for absolute strength or power, rest periods of at least 3–5 min are recommended for multiple-joint exercises (3). Robinson et al. (90) reported a 7% increase in squat performance after 5 wk of training when 3-min rest intervals were used compared to only a 2% increase when 30-s rest periods were used. Pincivero et al. (83) reported significantly greater strength gains (5–8%) when 160-s rest intervals were used compared with 40 s. Strength and power performance is highly dependent upon anaerobic energy release, primarily via the phosphagens (ATP-PC). Studies show that the majority of phosphagen repletion occurs within 3 min (26). Therefore, performance of maximal lifts require maximal energy substrate availability before the set with minimal or no fatigue. This emphasizes the importance of recovery during optimal strength and power training. It is important to note that rest interval length will vary according to the goals of that particular exercise, i.e., not every exercise will use the same rest interval. Muscle strength may be increased using short rest periods but at a slower rate compared with long rest periods, thus demonstrating the need to establish goals, i.e., the magnitude of strength improvement sought, before selecting a rest interval.

Stressing the glycolytic and ATP-PC energy systems may enhance training for hypertrophy in addition to heavy resistance exercise. For this aspect of hypertrophy training (e.g., characteristic of body building programs), less rest between sets appears to be effective (1–2 min or less). These rest intervals appear to be a potent anabolic hormone stimulator, stimulator of local blood flow, and result in significant metabolite (e.g., lactate) production (56,57). Recently, the importance of blood flow for increasing muscle protein synthesis has been demonstrated (12). Biolo et al. (12) reported an increase in amino acid transport of 60–120% (depending on the amino acid) 3 h after resistance exercise. Interestingly, arterial amino acid concentrations did not change but the 90% increase in muscle blood flow accounted for much of the increase in amino acid transport. A recent study has shown a greater effect on muscle protein synthesis when amino acids were taken before the workout to optimize amino acid delivery and transport during the workout via greater blood flow (104). Studies that have restricted blood flow and used light loading during resistance exercise (thereby increasing the concentrations of metabolites and the anaerobic nature of the exercise stimulus) have shown prominent increases in muscle hypertrophy comparable with heavier loading, thus demonstrating the utility of blood flow and/or metabolite accumulation during resistance training (91). This may, in part, be one explanation as to the efficacy of body-building programs that use moderate loading, high volume with short rest intervals for increasing muscle hypertrophy. However, considering that heavy resistance exercise has been effective for increasing hypertrophy, it appears maximal hypertrophy may be attained through the combination of strength and hypertrophy training (e.g., variation in rest interval length depending on the loading).

The rest interval selected has a great impact when training for local muscular endurance. Local muscular endurance has been shown to improve during resistance training (4,17,66), with greater effects observed with

absolute muscular endurance (the maximal number of repetitions performed with a specific pretraining load) (4,48) and only limited effects in *relative local muscular endurance* (endurance assessed at a specific relative intensity, or % 1 RM) (70). Training to increase local muscular endurance requires the individual: 1) to perform high repetitions (long-duration sets) and/or 2) minimize recovery between sets. Minimizing recovery between sets is an important stimulus with regards to the adaptations within skeletal muscle necessary to improve local muscular endurance (e.g., increased mitochondrial and capillary number, fiber type transitions, buffer capacity). It has been shown that body builders (who typically train with high volume and short rest periods) demonstrate a significantly lower fatigue rate in comparison with power lifters (who typically train with low-to-moderate volume and longer rest periods) (57). These data demonstrate the benefits of high-volume, short rest interval workouts for improving local muscular endurance.

Another consideration when selecting rest intervals between sets is the number of exercises performed per muscle group during a workout. In our laboratory, we have been using a resistance exercise protocol for a series of studies that consists of four sets of four exercises (squat, bench press, bent-over row, and shoulder press) using 70% of 1 RM for 10 repetitions per set with 2-min rest intervals between all sets. Considering that 70% of 1 RM is less than a 10 RM load, we have observed that 2 min of rest is not enough for some of these multiple-joint exercises to be completed for the full 10 repetitions. In particular, significant reductions in the loading for the shoulder press have been observed in all trials. This appears due to the fact that participants preexhausted their shoulder and triceps muscles previously with the bench press exercise. Thus, loads were significantly reduced and the 2-min rest interval was not sufficient as further load reductions were necessary with each subsequent set. Therefore, rest intervals will vary for each exercise in a workout, and one must consider the fatigue associated with previous exercises when performing exercises later in the workout.

Repetition velocity. The velocity that dynamic repetitions (i.e., cadence) are performed at, affects the neural (23,35,36), hypertrophic (47), and metabolic (9) responses to resistance exercise. Studies examining isokinetic resistance exercise have shown strength increases specific to the training velocity with some carryover above and below the training velocity (e.g., $30°·s^{-1}$) (29). Several investigators have trained individuals between 30 and $300°·s^{-1}$ and reported significant increases in muscular strength (18). It appears that training at moderate velocity ($180–240°·s^{-1}$) produces the greatest strength increases across all testing velocities (51). Data obtained from isokinetic resistance training studies support velocity specificity and demonstrate the importance of training at fast, moderate, and slow velocities to improve isokinetic force production across all testing velocities (29).

Dynamic constant external resistance training poses a different stress when examining repetition velocity. Because force = mass × acceleration, significant reductions in force production are observed when the intent is to perform the repetition slowly. In interpreting this, it is important to note that two types of slow-velocity contractions exist during dynamic resistance training, unintentional and intentional. *Unintentional* slow velocities are used during high-intensity repetitions in which either the loading and/or fatigue are responsible for the velocity of movement. That is, the individual exerts maximal force but due to the heavy loading or onset of fatigue, the resultant velocity is slow. One study has shown that during a 5 RM bench press, the concentric phase for the first three repetitions was approximately 1.2–1.6 s in duration, whereas the last two repetitions were approximately 2.5 and 3.3 s, respectively, due to fatigue (72). These data demonstrate the impact of loading and fatigue on repetition velocity in individuals performing each repetition with maximal effort.

Intentional slow-velocity repetitions are used with submaximal loads where the individual has greater control of the velocity. It has been shown that concentric force production was significantly lower (e.g., 771 vs 1167 N) for an intentionally slow velocity (5-s CON: 5-s ECC) of lifting compared with a traditional (moderate) velocity with a corresponding lower neural activation (53). This suggests that motor unit activity may be limited when intentionally contracting at a slow velocity. Although intentionally slow repetition velocity may provide some benefit for local muscular endurance and hypertrophy training, the lighter loads may not provide an optimal stimulus for improving 1 RM strength in resistance-trained individuals (i.e., although novice individuals may benefit in the initial phases of training). It has recently been shown that when performing a set of 10 repetitions using a very slow velocity (10-s CON: 5-s ECC) compared with a slow velocity (2-s CON: 4-s ECC), a 30% reduction in training load resulted and that this led to significantly less strength gains in most of the exercises tested after 10 wk of training (52). Compared to slow velocities, moderate (1- to 2-s CON: 1- to 2-s ECC) and fast (<1-s CON: 1-s ECC) velocities have been shown to be more effective for enhanced muscular performance, for example, number of repetitions performed, work and power output, volume (74), and for increasing the rate of strength gains (43). Recent studies examining training at fast velocities with moderately high loading have shown this to be more effective for advanced training than traditionally slower velocities (50). This technique requires the individual to accelerate the load maximally throughout the range of motion during the CON action to maximize bar velocity (i.e., the attempt to maximize velocity throughout the movement stresses areas of the range of motion where momentum minimizes the effort needed by the individual to complete the exercise). A major advantage is that this technique can be used with heavy loads (i.e., with small deceleration phases) and is

considered effective, especially for multiple-joint exercises (50).

The repetition velocity is very important for power training. Power production is increased when the same amount of work is completed in a shorter period of time, or when a greater amount of work is performed during the same period of time. Neuromuscular contributions to the development of maximal muscle power may include: 1) maximal rate of force development; 2) muscular strength at slow and fast repetition velocities; 3) stretch-shortening cycle performance; and 4) coordination of movement pattern and skill (29,37,78). In order to maximize power training, heavy resistance training needs to be accompanied by explosive exercises (13). One limitation to performing high-velocity repetitions with free weights is the deceleration phase. The deceleration phase is that point near the end of the CON phase in which bar velocity decreases before completion of the repetition. The length of this phase depends upon the load used and the average velocity as the load is decelerated for a considerable proportion (24–40%) of the concentric movement (22,76). This percentage increases to 52% when performing the lift with a lower percentage (81%) of 1 RM lifted (22) or when attempting to move the bar rapidly in an effort to train more specifically near the movement speed of the target activity (76). Thus, power increases may be most specific only to the initial segment of the range of motion as power/speed development throughout the full range of motion is limited because the load can not be maximally accelerated throughout and safely released. *Ballistic resistance exercise* (explosive movements which enable acceleration throughout the full range of motion) has been shown to limit this problem (71,76). Examples of ballistic resistance exercises include the loaded jump squat, bench throw, and shoulder throw (7,8,19,107). Loaded jump squats with 30% of 1 RM (75) have been shown to increase vertical jump performance more than traditional back squats, plyometrics, and jump squats performed at 80% of 1 RM (71,107). Recently, it has been reported that peak power was significantly greater for the shoulder throw than the shoulder press at both 30 and 40% of 1 RM (19). These studies indicate the importance of minimizing the deceleration phase when maximal power is the training goal and that explosive lifting velocities are critical for developing maximal power.

Training for local muscle endurance, and in some aspects hypertrophy, may require a spectrum of velocities with various loading strategies. Studies examining isokinetic exercise have shown that a fast training velocity, i.e., $180°·s^{-1}$, is more effective than a slow training velocity, i.e., $30°·s^{-1}$, for improving local muscular endurance (1). Thus, fast contraction velocities are recommended for isokinetic training. However, it appears that fast, moderate, and slow velocities are effective for improving local muscular endurance during dynamic constant external resistance training, depending on the number of repetitions performed (17,70). The critical component to local muscle endurance training is to prolong the duration of the set. Two effective strategies used to prolong set duration are 1) moderate repetition number using an intentionally slow velocity and 2) high repetition number using moderate-to-fast velocities. Intentionally slow velocity training with light loads (i.e., 5-s CON: 5-s ECC and slower) places continued tension on the muscles for an extended period and may be more metabolically demanding than moderate and fast velocities when the same number of repetitions are performed. However, it is difficult to perform a large number of repetitions using intentionally slow velocities. Both slow velocity, moderate repetitions and moderate-to-fast velocity, high repetitions training strategies increase the glycolytic and oxidative demands of the stimulus, thereby serving as very effective means of increasing local muscle endurance.

Frequency. The number of training sessions performed during a specific period of time (e.g., 1 wk) may affect subsequent resistance training adaptations. Frequency also includes the number of times certain exercises or muscle groups are trained per week. It is dependent upon several factors such as volume and intensity, exercise selection, level of conditioning and/or training status, recovery ability, nutritional intake, and training goals. For example, training with heavy loads increases the recovery time needed before subsequent sessions especially for multiple-joint exercises involving similar muscle groups. The use of extremely heavy loads, especially when heavy eccentric training is performed, may require 72 h of recovery whereas large and moderate loads may require less recovery time. In particular, it has been shown that untrained women of various ages only recovered approximately 94% of their strength 2 d after a lower-body workout consisting of 5 sets of 10 repetitions with a 10 RM load (34), thus demonstrating that lesser-trained individuals may need longer recovery periods. Numerous resistance-training studies have used frequencies of 2–3 alternating days per week in previously untrained individuals (18,44). This has been shown to be an effective initial frequency whereas $1–2 d·wk^{-1}$ appears to be an effective maintenance frequency for those individuals already engaged in a resistance training program (32). In a few studies: $4–5 d·wk^{-1}$ were superior to 3, $3 d·wk^{-1}$ superior to 1 and 2 d, and $2 d·wk^{-1}$ superior to 1 for increasing maximal strength (32,49).

An increase in training experience does not necessarily require a change in frequency for training each muscle group but may coincide with alterations in other acute variables such as exercise selection, volume, and intensity. Increasing training frequency may enable greater specialization, for example, greater exercise selection and volume per muscle group in accordance with more specific goals. Performing upper/lower body split or muscle groups split routines during a workout are common at this level of training in addition to total-body workouts (29).

Advanced training frequency varies considerably. It has been shown that football players (with varied training backgrounds) training $4–5 d·wk^{-1}$ achieved better results

than those who trained either 3 or 6 d·wk^{-1} (46). Advanced weightlifters and body builders use high frequency training, e.g., four to six sessions per week. The frequency for elite weightlifters and body builders may be even greater. Double-split routines (two training sessions per day with emphasis on different muscle groups) are so common during training (40) that this can result in the completion of 8–12 training sessions per week. Frequencies as high as 18 sessions per week have been reported in Olympic weightlifters. The rationale for this high-frequency training is that frequent short sessions followed by periods of recovery, supplementation, and food intake allow for high-intensity training via maximal energy utilization and reduced fatigue during exercise performance (29). One study reported greater increases in muscle cross-sectional area and strength when training volume was divided into two sessions per day rather than one (42). Elite power lifters typically train 4–6 d·wk^{-1} (29). It is important to note that not all muscle groups are trained specifically per workout using a high frequency. Rather, each major muscle group may be trained 2 to 3× wk^{-1} despite the large number of workouts.

A recent study examined training frequency with a particular focus on resistance training overreaching (86). Overreaching is a short-term training phase in which the volume, frequency, and/or the intensity of resistance exercise is increased above normal. The rationale is to overwork (in order to suppress performance and build up tolerance) and then taper to produce a subsequent "rebound" in performance (30). In our study (86), we trained experienced participants for 4 wk using total-body resistance training consisting of two 2-wk phases of overreaching (phase 1: 3 × 8–12 RM, eight exercises; phase 2: 5 × 3–5 RM, five exercises). Overreaching was achieved by training each major muscle group on consecutive days for 5 d·wk^{-1} (note: the participants had just completed a 4-wk base training phase of 2 d·wk^{-1} so the overreaching program resulted in a large increase in frequency and volume). After the first week, 1 RM squat and bench press significantly decreased (5.2 and 3.4 kg, respectively) in one group of participants who did not ingest an amino acid supplement. However, significant increases in 1 RM squat and bench press were observed after the second, third, and fourth weeks of training. In addition, further increases in strength were observed following a 2-wk reduced volume/frequency phase. These results supported the concept of overreaching and indicated that a large short-term increase in training volume and frequency can produce significant increases in performance. However, it is important to note that overreaching for an extended period of time may lead to overtraining in which significant declines in performance may be observed.

BASIC PRINCIPLES OF PROGRESSION

Ultimately, the goal of a resistance training program is to improve some component of fitness or health until a certain level has been attained. For improvements to occur, the program used must be systematically altered so that the human body is "forced" to adapt to the changing stimuli. Thus, progression may be defined as "the act of moving forward or advancing toward a specific goal" (3). Although it is impossible to continually improve at the same rate over long-term training, the proper manipulation of program variables can limit training plateaus (that point in time where no further improvements takes place) and consequently enable achievement of a higher level of muscular fitness. Three general principles of progression are: 1) progressive overload, 2) variation, and 3) specificity.

Progressive overload. Progressive overload describes the gradual increase of stress placed upon the body during exercise training. Tolerance of increased stress-related overload is of particular concern for the practitioner and clinician monitoring program progression. In reality, the adaptive processes of the human body will only respond if continually required to exert a greater magnitude of force to meet higher physiological demands. Considering that physiological adaptations to a standard resistance exercise protocol (i.e., a protocol with no variation in any program variable) may occur in a relatively short period of time, a systematic increase in the demands placed upon the body is necessary for further improvement. There are several ways in which overload may be introduced during resistance training. For strength, hypertrophy, local muscular endurance, and power improvements, either: 1) load (resistance) may be increased, 2) repetitions may be added to the current load, 3) repetition speed with submaximal loads may be altered according to goals, 4) rest periods may be shortened for local muscular endurance improvements or lengthened for strength and power training, 5) volume may be increased within reasonable limits, and/or 6) any combination of the above. It has been suggested that only small acute increases in training volume (2.5–5%) should be imposed initially until adaptation has occurred (29), but this needs further study as larger increases have been successfully prescribed in advanced athletes.

The importance of progressive overload can be observed when examining the interplay between neural and muscular adaptations during strength and power training. The nervous system plays a significant role in the strength increases observed in the early stages of adaptation to training (92,93). That is, improvements in motor unit recruitment, firing rate, and synchronization take place and account for early increases in strength and subsequent increases in training loads (93). Within a short period of time (i.e., 4–8 wk of training), muscle hypertrophy becomes evident (60,82,99), although changes in the quality of proteins (99), fiber types (60,99), and protein synthetic rates (82) take place much earlier. From this initial phase onward there appears to be an interplay between neural adaptations and hypertrophy in the acute expression of muscular strength (93). In order for further neural adaptations to occur with training, a progressively greater amount of resistance needs to be

lifted (35,84). It has been shown that less muscle mass is recruited during resistance training with a given workload once hypertrophy adaptation has taken place (84). These findings indicate that progressive overload is necessary for maximal muscle fiber recruitment and, consequently, muscle fiber hypertrophy and strength increases. Further evidence for the importance of heavy loads (and neural adaptations) with progression during strength and power training was found with advanced weightlifters who showed significant strength improvements over a 2-yr period with little or no muscle hypertrophy (41). It appears that this interplay is closely related to the training stimulus involved and that progressive overload incorporated into the program design is necessary for maximizing strength, power, hypertrophy, and local muscular endurance.

Specificity. There is a relatively high degree of task specificity involved in human movement and adaptation that encompasses both movement patterns as well as force-velocity characteristics (5). All training adaptations are specific to the stimulus applied. The physiological adaptations to training are specific to the 1) muscle actions involved (20); 2) speed of movement (51); 3) range of motion (54); 4) muscle groups trained (66); 5) energy systems involved (57,96); and 6) intensity and volume of training (17,87,95). For example, if the training goal was to increase vertical jump ability, then the resistance training program would include specific exercises (e.g., squat, jump squat, power clean) that mimic the vertical jump, and these exercises would be performed at a high velocity to maximize power output. Although there is some carryover of training effects (29,54,66), the most effective resistance training programs are those that are designed to target specific training goals.

Variation. Training variation requires that alterations in one or more program variables be made over time to allow for the training stimulus to remain optimal. It has been shown that systematically varying volume and intensity is most effective for long-term progression compared with programs that did not vary any acute program variable (27,100). The concept of variation has been part of program design for many years. The importance of training variation, or *periodization,* became apparent for resistance training as a result of the work of Selye (94). His theory (*general adaptation syndrome*) proposes that the body adapts via three phases when confronted with stress: 1) shock, 2) adaptation, and 3) staleness. *Shock* represents the response to the initial training stimulus in which soreness and performance decrements are produced. Performance then increases during the second stage, *adaptation*, in which the body adapts to the training stimulus. Once the body has adapted, no further adaptations will take place unless the stimulus is altered. This produces the third stage, *staleness*, in which a performance plateau is encountered.

Systematic variation has been used as a means of altering program design to optimize both performance and recovery (38,39,85). However, the use of periodiza-tion is not limited to elite athletes or advanced training but has been used successfully as the basis of training for individuals with diverse backgrounds and fitness levels. In addition to athletics, periodized resistance training has been shown to be effective for health and recreational training goals (100).

Although numerous ways exist in which programs may be varied, two general models have been examined in the literature. One model is the *classic model*, which is characterized by high initial training volume and low intensity (100). As training progresses, volume decreases and intensity increases in order to maximize strength, power, or both (27). Typically, each training phase is designed to emphasize a particular physiological adaptation. For example, hypertrophy is stimulated during the initial high volume phase, whereas strength and power are maximally developed during the later high-intensity phase. Comparisons of classic strength/power periodized models to nonperiodized models have been previously reviewed (27). These studies have shown classic strength/power periodized training superior for increasing maximal strength, e.g., 1 RM squat, cycling power, motor performance, and jumping ability (79,99,106). However, a short-term study (e.g., 12 wk) has shown similar performance improvements between periodized and multiple-set nonperiodized models in resistance-trained individuals (6). It has been shown that longer training periods are necessary to underscore the benefits of periodized training compared with nonperiodized training (106). The results of these studies demonstrate that both periodized and nonperiodized training are effective during short-term training, whereas variation is necessary for long-term resistance training progression.

A second examined model is the *undulating* model. The undulating program enables variation in intensity and volume within each 7- to 10-d cycle by rotating different protocols over the course of the training program. Undulating methods attempt to train the various components of the neuromuscular system within the same 7- to 10-d cycle. During a single workout only one characteristic is trained in a given day, e.g., strength, power, local muscular endurance. For example, in loading schemes for the core exercises in the workout, the use of heavy, moderate, and lighter resistances may be randomly rotated over a training sequence (M, W, F), for example, 3–5 RM loads, 8–10 RM loads, and 12–15 RM loads may used in the rotation. We have recently reported significant improvements in various parameters of muscle fitness using a similar 3 d·wk^{-1} undulated program with each workout dedicated to either power, strength, or hypertrophy in young and older men (78). This model compares favorably with the classical model and nonperiodized multiple-set programs (6). Recently, this model has been shown to be more effective for increasing 1 RM bench press and leg press after 12 wk of training compared with the classic model (88) although more research

is needed. This model has also been shown to have distinct advantages in comparison with nonperiodized, low-volume training in women (64,69).

EFFECT OF TRAINING STATUS AND PROGRESSION

Initial training status plays an important role in the rate of progression during resistance training. Training status reflects a continuum of adaptations to resistance training such that level of fitness, training experience, and genetic endowment each make a contribution. Untrained individuals (those with no resistance training experience or who have not trained for several months to years) respond favorably to most protocols, thus making it difficult to evaluate the effects of different training programs at this level of training (27,33). The rate of strength gain differs considerably between untrained and trained individuals; trained individuals have shown much slower rates of improvement (38–41). A review of the literature reveals that muscular strength increases approximately 40% in "untrained," 20% in "moderately trained," 16% in "trained," 10% in "advanced," and 2% in "elite" over periods ranging from 4 wk to 2 yr (3). Although the training programs, durations, and testing procedures of these studies differed, the data clearly show a specific trend toward slower rates of progression with training experience. This has recently been shown via meta-analysis of 140 studies (89). In this study, statistically greater effect sizes (ES) were observed in untrained individuals compared with resistance-trained individuals with respect to training intensity (ES range of 0.65–1.80 for trained vs 1.60–2.80 for untrained), frequency (ES range of 0.70–1.40 for trained vs 1.20–1.90 for untrained), and volume (ES range of 0.47–1.17 for trained vs 1.16–2.28 in untrained) on progression.

The difficulty in continuing gains in strength appears to occur within as little as several months of training. Each subsequent improvement brings the individual closer to his/her genetic limit. It is well documented that changes in muscular strength are most prevalent early in training when the "window of adaptation" is greatest (33). Investigations which have examined the time course of strength gains to various training protocols support this view (44,73). Short-term studies (11–16 wk) have shown that the majority of strength increases take place within the first 4–8 wk (44).
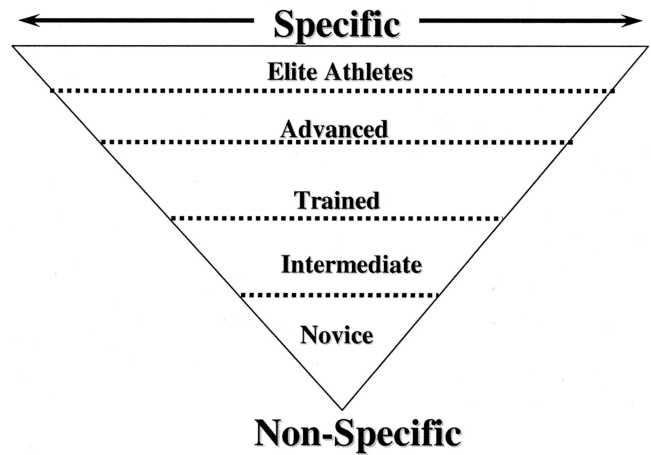
General-to-Specific Model

FIGURE 1—General-to-specific model of resistance training progression.

Similar results have been observed during 1 yr of training (73). These data demonstrate the rapidity of initial strength gains in untrained individuals but also show slower gains with further training. Decisions must be made regarding the exercise prescription as to the cost-benefit ratio of putting additional attention, time, and effort into strength improvement as gains become increasingly more difficult. In certain circumstances small changes in strength require large amounts of training time as the individual approaches his/her genetic ceiling. Furthermore, the increase observed may be far less than the gains observed earlier in a person's training history. Such small gains may be the difference between winning and losing in certain types of elite athletic competitions but may be less important in other situations. The increased time needed to obtain small gains in strength might not be the best use of available training time, unless the small gains are directly related to needed performance abilities. For example, some athletes may need a "*strength cap*" for those exercises that are already strong (i.e., maintaining the present training to focus on other areas) so more attention and time could be given to weaknesses. Thus, clinical judgments often have to be made regarding the exercise prescription. This requires a solid knowledge of an

TABLE 1. Recommendations for progression during strength training.

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exerc. selection	Single and multiple-joint	Single and multiple-joint	Single and multiple-joint with multi-emphasis
Exerc. order	Large < small muscles	Large < small muscles	Large < small muscles
	Multi < single	Multi < single	Multi < single
	High < low intensity	High < low intensity	High < low intensity
Loading	60–70% 1 RM	70–80% 1 RM	70–100% 1 RM
Volume	1–3 × 8–12 reps	Multi sets × 6–12 reps	Multi sets × 1–12 reps
Rest intervals	1–2 min	2–3 min—core	~3 min—core
		1–2 min for others	1–2 min for others
Velocity	Slow to moderate	Moderate	Unint. slow to fast
Frequency	2–3 d·wk^{-1}	2–4 d·wk^{-1}	4–6 d·wk^{-1}

<, indicates the preceding exercise is to be performed before the succeeding exercise.

TABLE 2. Recommendations for progression during hypertrophy training.

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exerc. selection	Single and multiple-joint	Single and multiple-joint	Single and multiple-joint
Exerc. order	Large < small muscles	Large < small muscles	Large < small muscles
	Multi < single	Multi < single	Multi < single
	High < low intensity	High < low intensity	High < low intensity
Loading	60–70% 1 RM	70–80% 1 RM	70–100% 1 RM with emphasis 70–85%
Volume	1–3 × 8–12 reps	Multi sets × 6–12 reps	Multi sets × 1–12 reps with emphasis 6–12
Rest intervals	1–2 min	1–2 min	2–3 min—heavy
			1–2 min or less for others
Velocity	Slow to moderate	Slow to moderate	Slow, moderate, and fast
Frequency	2–3 d·wk^{-1}	2–4 d·wk^{-1}	4–6 d·wk^{-1}

<, indicates the preceding exercise is to be performed before the succeeding exercise.

individual's strength profile for a variety of muscles. Furthermore, one must understand the basic physiological adaptations associated with strength-training programs.

GENERAL-TO-SPECIFIC MODEL OF PROGRESSION

There have been a limited number of studies that examined different models of progression over long-term resistance training. Most resistance training studies have been short-term (i.e., 6–24 wk) and have used mostly previously untrained individuals. All of these studies have shown significant improvements in muscular strength during the short-term. However, little is known about adaptations and improvements in strength in response to longer training periods. Resistance-trained individuals have shown a slower rate of progression (38,41). In addition, advanced lifters have demonstrated a complex cyclical pattern of training variation to optimize performance (38–41). It appears from the available literature that resistance-training progression occurs in an orderly manner from a general program design initially to a more specific design with higher levels of training when the rate of improvement becomes slower (see Fig. 1). For example, most studies using untrained individuals have shown great improvements regardless of the type of training program (37). This has been evident in both the volume and intensity (4,101) chosen. Loads of < 45–50% of 1 RM and less (i.e., performed with very high repetitions) may increase strength in untrained individuals (4,101), whereas trained lifters appear responsive only to heavier loading (35,38). It is difficult to differentiate program design in untrained individuals as these individuals do not appear to be sensitive to either volume, or in some cases intensity, this early in training. Therefore, it is recommended that a general program design be used with these individuals.

Longer-term studies (i.e., 16 wk and longer) have clearly demonstrated the need for training variation (56,64,69,106). Performance plateaus have been observed with nonperiodized programs whereas periodized resistance training has been shown to continually increase performance over 24 wk of training. In a recent study, Marx et al. (69) showed that similar improvements were observed during the first 3 months of training comparing a nonperiodized single-set (8–12 repetitions) with a periodized, multiple-set program. However, only the periodized multiple-set group improved over the subsequent 3 months of training. These findings were similar to those reported by Kraemer et al. (64), who examined periodized multiple-set training versus single-set nonperiodized training in women collegiate tennis players over 9 months. The nonperiodized group improved over the first 3 months only whereas the periodized training group improved over the entire 9-month period. These data demonstrate the importance of varying the progression of resistance training. Therefore, advanced training targeting progression is more complex and requires great variation specific to training goals. Figure 1 is a simplified schematic representing a theoretical continuum of the amount of variation needed in resistance training for progression. The narrow segment of the triangle (e.g., novice) suggests limited variation is needed in this population, as most programs

TABLE 3. Recommendations for progression during power training.

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exerc. selection	Multiple-joint	Multiple-joint	Multiple-joint
Exerc. order	Large < small muscles	Large < small muscles	Large < small muscles
	Most complex < least	Most complex < least	Most complex < least
	High < low intensity	High < low intensity	High < low intensity
Loading	60–70%—strength	70–80%—strength	>80% for strength
	30–60%—velocity/tech.	30–60%—velocity/tech.	30–60% for velocity
Volume	Similar to strength	1–3 × 3–6 reps	3–6 × 1–6 reps
Rest intervals	2–3 min—core	2–3 min—core	>3 min—heavy
	1–2 min for others	1–2 min for others	1–2 min—moderate
Velocity	Moderate	Fast	Fast
Frequency	2–3 d·wk^{-1}	2–4 d·wk^{-1}	4–6 d·wk^{-1}

<, indicates the preceding exercise is to be performed before the succeeding exercise.

TABLE 4. Recommendations for progression during endurance training.

	Novice	Intermediate	Advanced
Muscle action	ECC and CON	ECC and CON	ECC and CON
Exerc. selection	Single and multiple-joint	Single and multiple-joint	Single and multiple-joint
Exerc. order	Variety	Variety	Variety
Loading	50–70% 1 RM	50–70% 1 RM	30–80% 1 RM
Volume	1–3 × 10–15 reps	Multi sets × 10–15 reps or more	Multi sets × 10–25 reps or more
Rest intervals	1–2 min—high reps	1–2 min—high reps	1–2 min—high reps
	<1 min—mod. reps	<1 min—mod. reps	<1 min—mod. reps
Velocity	Slow—moderate reps	Slow—moderate reps	Slow—moderate reps
	Moderate—high reps	Moderate—high reps	Moderate—high reps
Frequency	2–3 d·wk^{-1}	2–4 d·wk^{-1}	4–6 d·wk^{-1}

are effective at this level. It is important to begin gradually (i.e., learn proper technique, allow large recovery time); therefore, a simple program design is recommended. However, as one progresses, the triangle becomes wider. This suggests that more variation (i.e., specific training cycles) is necessary in order to optimally progress.

Recently, the American College of Sports Medicine (3) has published recommendations for progression for strength, power, hypertrophy, and local muscle endurance training. These recommendations expand the previous position stand (2) for novice training. Tables 1–4 summarize these recommendations.

SUMMARY

In summary, specific needs and goals should be addressed before resistance training. The resistance training program design should be simple at first for untrained individuals but should become more specific with greater variation in the acute program variables during progression. Manipulation of the program variables may be performed in numerous ways, many of which are beneficial to progression suffice they adhere to general principles. Progression may be maximized by the incorporation of progressive overload, specificity, and training variation in the program.

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