AMERICAN COLLEGE of SPORTS MEDICINE®

Progression Models in Resistance Training for Healthy Adults

POSITION STAND

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SUMMARY

In order to stimulate further adaptation toward specific training goals, progressive resistance training (RT) protocols are necessary. The optimal characteristics of strength-specific programs include the use of concentric (CON), eccentric (ECC), and isometric muscle actions and the performance of bilateral and unilateral single- and multiple-joint exercises. In addition, it is recommended that strength programs sequence exercises to optimize the preservation of exercise intensity (large before small muscle group exercises, multiple-joint exercises before single-joint exercises, and higher-intensity before lower-intensity exercises). For novice (untrained individuals with no RT experience or who have not trained for several years) training, it is recommended that loads correspond to a repetition range of an 8–12 repetition maximum (RM). For intermediate (individuals with approximately 6 months of consistent RT experience) to advanced (individuals with years of RT experience) training, it is recommended that individuals use a wider loading range from 1 to 12 RM in a periodized fashion with eventual emphasis on heavy loading (1–6 RM) using 3- to 5-min rest periods between sets performed at a moderate contraction velocity (1–2 s CON; 1–2 s ECC). When training at a specific RM load, it is recommended that 2–10% increase in load be applied when the individual can perform the current workload for one to two repetitions over the desired number. The recommendation for training frequency is 2–3 $d \cdot wk^{-1}$ for novice training, 3–4 $d \cdot wk^{-1}$ for intermediate training, and 4–5 $d \cdot wk^{-1}$ for advanced training. Similar program designs are recommended for *hypertrophy* training with respect to exercise selection and frequency. For loading, it is recommended that loads corresponding to 1–12 RM be used in periodized fashion with emphasis on the 6–12 RM zone using 1- to 2-min rest periods between sets at a moderate velocity. Higher volume, multiple-set programs are recommended for maximizing hypertrophy. Progression in *power* training entails two general loading strategies: 1) strength training and 2) use of light loads (0–60% of 1 RM for lower body exercises; 30–60% of 1 RM for upper body exercises) performed at a fast contraction velocity with 3–5 min of rest between sets for multiple sets per exercise (three to five sets). It is also recommended that emphasis be placed on multiple-joint exercises especially those involving the total body. For *local muscular endurance* training, it is recommended that light to moderate loads (40–60% of 1 RM) be performed for high repetitions (>15) using short rest periods (<90 s). In the interpretation of this position stand as with prior ones, recommendations should be applied in context and should be contingent upon an individual's target goals, physical capacity, and training status. **Key Words:** strength, power, local muscular endurance, fitness, functional abilities, hypertrophy, health, performance

INTRODUCTION

The current document replaces the American College of Sports Medicine (ACSM) 2002 Position Stand entitled "Progression Models in Resistance Training for Healthy Adults" (8). The 2002 ACSM Position Stand extended the resistance training (RT) guidelines initially established by the ACSM in the position stand entitled "The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults" (7), which suggested the minimal standard of one set of 8–12 repetitions for 8–10 exercises, including one exercise for all major muscle groups, and 10–15 repetitions for older and more frail persons. The 2002 Position Stand (8) provided a framework for superior training prescription guidelines relative to the need for progression in healthy (without disease or orthopedic limitations) novice, intermediate, and advanced trainees. Specifically, these guidelines effectively distinguished numerous modifications to the original guidelines to accommodate individuals seeking muscular development beyond that of minimal general health and fitness. Since 2002, numerous studies have been published examining one or more RT variable(s) to support the progressive adaptation in muscular strength and performance. These studies have identified other mechanisms of physiological adaptations and have served to bolster the scientific integrity of the RT knowledge base. As with all position stands, interpretation of these revised recommendations should be applied in context and should be contingent upon an individual's goals, physical capacity, and training status.

Progression in RT may be defined as "the act of moving forward or advancing toward a specific goal over time until the target goal has been achieved," whereas maintenance

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RT refers to programs designed to maintain the current level of muscular fitness (8). Although it is impossible to improve at the same rate over long-term periods (e.g., >6 months), the proper manipulation of program variables (choice of resistance, exercise selection and order, number of sets and repetitions, frequency, and rest period length) can limit training plateaus and increase the ability to achieve a higher level of muscular fitness. Trainable characteristics include muscular strength, power, hypertrophy, and local muscular endurance (LME). Variables such as speed and agility, balance, coordination, jumping ability, flexibility, and other measures of motor performance may be enhanced by RT. RT, when incorporated into a comprehensive fitness program, improves cardiovascular function (72), reduces the risk factors associated with coronary heart disease (89,130) and non–insulin-dependent diabetes (184), prevents osteoporosis (163), may reduce the risk of colon cancer (146), promotes weight loss and maintenance (61), improves dynamic stability and preserves functional capacity (61), and fosters psychological well-being (62).

This position stand presents evidence-based guidelines using The National Heart, Lung, and Blood Institute (194) criteria shown in Table 1. Each recommendation is given a grade of A, B, C, or D based on the quantity and quality of evidence.

PROGRESSION PRINCIPLES

The foremost principles of RT progression are progressive overload, specificity, and variation (157). Countless RT models can be effective if these principles are incorporated and manipulated into the design. The magnitude of improvement depends upon the individual's training status and genetic predisposition (8). *Progressive overload* is the gradual increase of stress placed upon the body during exercise training. Among untrained or novice populations, physiological adaptations to an RT program may occur in a short period. Systematically increasing the demands placed upon the body is necessary for further improvement and may be accomplished through altering one or more of the following variables: 1) exercise intensity (i.e., absolute or relative resistance/load for a given exercise/movement) may be increased; 2) total repetitions performed at the current intensity may be increased; 3) repetition speed/tempo with submaximal loads may be altered according to goals; 4) rest periods may be shortened for endurance improvements or lengthened for strength and power training; and 5) training volume (total work represented as the product of the total number of repetitions performed and the resistance) may be gradually increased (e.g., 2.5–5% [75]) (Table 2).

Specificity. All training adaptations are "specific" to the stimulus applied. The specific physiological adaptations to RT are determined by various factors, including 1) muscle actions involved (56), 2) speed of movement (39,44), 3) range of motion (145), 4) muscle groups trained (156), 5) energy systems involved (259), and 6) intensity and volume of training (225). Although there is some carryover of training effects to other general fitness and performance attributes, the most effective RT programs are those that are designed to target-specific training goals.

Variation. Variation, or *periodization*, entails the systematic process of altering one or more program variable(s) over time to allow for the training stimulus to remain challenging and effective. Because the human body adapts quickly to an RT program, at least some changes are needed in order for continual progression to occur. It has been shown that systematic variation of volume and intensity is most effective for long-term progression (254). Variation may take place in many forms and manifests by manipulation of any one or a combination of the acute program variables. However, the two most commonly studied variables have been volume and intensity. The concept of periodization was developed based on the studies of general adaptation syndrome by Hans Selye (239) to optimize performance and recovery (74,100). In addition to sport-specific training, periodized RT has been shown to be effective for recreational (54) and rehabilitative (67) objectives and is supported through a meta-analytical investigation to be superior to nonperiodized RT (223).

Classical periodization. The classic (linear) model of periodization is characterized by high initial training volume and low intensity, and as training progresses, volume decreases and intensity gradually increases. This traditional model of periodization is carried out to enhance fundamental fitness variables through training in a designated succession to serve as an appropriate arrangement to elicit "peak" performance of a distinct fitness variable (e.g., strength, rate of force development [RFD], and/or peak power) for a precise and often narrow time window (74). Most, but not all (14), studies have shown classic strength/power periodized training to be superior to nonperiodized RT for increasing maximal strength (e.g., 1 repetition

TABLE 1. National Heart, Lung, and Blood Institute (NHLBI; 194) evidence categories.

Category	Source of Evidence	Definition
A	Randomized control trials (RCT; rich body of data)	Evidence is from well-designed RCT that provide a consistent pattern of findings in the population for which the recommendation is made. Requires substantial number of studies involving substantial number of participants.
B	RCT (limited body of data)	Evidence is from intervention studies that include only a limited number of RCT, *post hoc* or subgroup analysis of RCT, or meta-analysis of RCT. Pertains when few randomized trials exist, they are small, and the results are somewhat inconsistent or were from a nonspecific population.
C	Nonrandomized trials, observational studies	Evidence is from outcomes of uncontrolled trials or observations.
D	Panel consensus judgment	Expert judgment is based on panel's synthesis of evidence from experimental research or the consensus of panel members based on clinical experience or knowledge that does not meet the above-listed criteria.

maximum [RM] squat), cycling power, motor performance, and jumping ability (252,254,272). It appears that longer training periods (>6 months) may be necessary to underscore the benefits of periodized training (273) because periodized and nonperiodized training are effective during short-term training. Important to periodization is the use of rest days to allow recovery and to reduce the probability or magnitude of overtraining (79).

Reverse periodization. A reverse linear periodization model has also been studied (227). This model is the inverse of the classical model in which intensity is initially at its highest and volume at its lowest. Subsequently, over an extended time, intensity decreases and volume increases with each phase. This periodization model has been used for individuals targeting local muscular endurance (LME) enhancement (59) and was shown to be superior for enhancing LME to other periodization models when volume and intensity were equated (227). Strength improvements following this model have been shown to be lower compared with linear and undulating models (227).

Undulating periodization. The undulating (nonlinear) model of periodization enables variation in intensity and volume within a cycle by rotating different protocols to train various components of neuromuscular performance (e.g., strength, power, LME). For example, in loading schemes for core exercises (those exercises most specific to target goals), the use of heavy, moderate, and light resistances may be systematically or randomly rotated over a training sequence, for example, 3–5 repetition maximum (RM) loads, 8–10 RM loads, and 12–15 RM loads may used in the rotation. This model has compared favorably with linear periodized and nonperiodized multiple-set models (14) and has been shown to produce superior strength increases over 12 wk of RT compared with the classical model (226). Further, this model has demonstrated advantages in comparison to nonperiodized, low-volume training in women (155,169). Few investigations have evaluated the impact of undulating RT for multiple fitness objectives (199). Most recently, this model has been demonstrated superior over nonundulating RT for generating fitness and performance enhancement outcomes among firefighter trainees (209).

TRAINABLE CHARACTERISTICS

Muscular Strength

The ability to generate force is necessary for all types of movement. Muscle fiber cross-sectional area (CSA) is positively related to maximal force production (71). The arrangement of fibers according to their angle of pennation, muscle length, joint angle, and contraction velocity can alter the expression of muscular strength (95,145). Force generation is further dependent upon motor unit activation, and motor units are recruited according to their recruitment threshold that typically involves the activation of the slower (lower force-producing) motor units before the faster (higher force-producing) units, that is, *size principle* (114). Adaptations to RT enable greater force generation through numerous neuromuscular mechanisms. Muscle strength may increase significantly within the first week of training (39), and long-term strength enhancement manifests itself through enhanced neural function (e.g., greater recruitment, rate of discharge) (234), increased muscle CSA (5,176,250), changes in muscle architecture (138), and possible adaptations to increased metabolites, for example, H^+ (242), for increased strength. The magnitude of strength enhancement is dependent on the type of program used and the careful prescription of muscle actions, intensity, volume, exercise selection and order, rest periods between sets, and frequency (157).

Muscle Action

Most RT programs primarily include dynamic repetitions with both concentric (CON; muscle shortening) and eccentric (ECC; muscle lengthening) muscle actions, whereas isometric (ISOM; no net change in muscle length) actions play a secondary role (e.g., during nonagonist muscle stabilization, core strength, grip strength, pauses between ECC and CON actions, or specific agonist ISOM exercises). Greater force per unit of muscle size is produced during ECC actions (147) than either CON or ISOM actions. Moreover, ECC actions require less motor unit activation per specific load (147), are less metabolically demanding (26), and are conducive to promoting hypertrophic adaptation (112) yet result in more pronounced delayed onset muscle soreness (58) as compared with CON actions. Dynamic CON muscular strength improvement is greatest when ECC actions are included with CON actions (56), and independently, ECC isokinetic training has been shown to produce greater muscle action-specific strength gains than CON training (64). The role of muscle action manipulation during RT is minimal with respect to overall progression because most programs include both CON and ECC actions in a given repetition. However, the inclusion of additional ISOM exercise may be beneficial. In some programs, the use of different forms of ISOM training, for example, functional ISOM (131) and supramaximal ECC actions (143), has been reported to produce additional benefit. Specifically, certain ISOM actions have been recommended for promoting low back health and have been demonstrated effective for the selective recruitment of postural, spinal-stabilization musculature (181).

Evidence statement and recommendation. *Evidence category A*. For progression during RT for novice, intermediate, and advanced individuals, it is recommended that CON, ECC, and ISOM muscle actions be included (56,64,112,131,143).

Loading

Altering the training load affects the acute metabolic (221), hormonal (151–154,158,159,165,219), neural (96,235), and cardiovascular (72) responses to resistance

SPECIAL COMMUNICATIONS

exercise. Depending on an individual's training experience and current level of fitness, proper loading during RT encompasses one or more of the following loading schemes: 1) increasing load based on a percentage of 1 RM, 2) increasing absolute load based on a targeted repetition number, or 3) increasing loading within a prescribed zone (e.g., 8–12 RM). The load required to increase maximal strength in untrained individuals is fairly low. Loads of 45–50% of 1 RM (and less) have been shown to increase dynamic muscular strength in previously untrained individuals (9,33,255,268). Light loads that can be lifted a maximum of 15–25 repetitions have been shown to increase strength in moderately trained individuals (227). It appears greater loading is needed with progression. At least 80% of 1 RM is needed to produce further neural adaptations and strength during RT in experienced lifters (96). Several pioneering studies indicated that training with loads corresponding to 1–6 RM (mostly 5–6 RM) was most conducive to increasing maximal dynamic strength (22,201). Strength increases have been shown to be greater using heavy weights for 3–5 RM compared with 9–11 and 20–28 RM (33). Although significant strength increases have been reported using loads corresponding to 8–12 RM and lighter (33,149,250), this loading range may be inferior for maximizing strength in advanced lifters (96). Research examining periodized RT has demonstrated a need for variable-intensity loading schemes (74,223). Contrary to early suggestions of 6 RM loading, it appears that using a variety of training loads is most conducive to maximizing muscular strength (74). Meta-analytical data have shown that 60% of 1 RM produced the largest effect sizes for strength increases in novice individuals whereas 80% of 1 RM produced the largest effect sizes for strength increases in trained individuals (225) and 85% of 1 RM was most effective in athletes (206). For novice individuals, it has been suggested that moderate loading (50–60% of 1 RM or less) be used initially as learning proper form, and technique is paramount. These dose–response data refer to average training dosages, that is, mean loads used for all exercises. Further, using a variety of loads appears to be most effective for long-term progression in muscular strength (157). Recent studies have shown that self-selected RT intensities are lower than what is recommended, for example, 38–58% of 1 RM (76,87,222). Thus, intensity needs to be prescribed above one's threshold (based on targeted repetition number) for progression in experienced populations.

Evidence statement and recommendation. *Evidence category A.* It is recommended that novice to intermediate individuals train with loads corresponding to 60–70% of 1 RM for 8–12 repetitions and advanced individuals cycle training loads of 80–100% of 1 RM to maximize muscular strength (9,33,96,206,225,227,255,268).

Evidence category B. For progression in those individuals training at a specific RM load, it is recommended that a 2–10% (lower percent for small muscle mass exercises, higher percent increase for large muscle mass exercises) increase in load be applied when the individual can perform the current workload for one to two repetitions over the desired number on two consecutive training sessions (68).

Volume

Training volume is a summation of the total number of repetitions performed during a training session multiplied by the resistance used (kg) and is reflective of the duration of which muscles are being stressed (262). Volume has been shown to affect neural (102), hypertrophic (258), metabolic (221), and hormonal (92,151,152,191,220) responses and subsequent adaptations to RT. 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 per exercise. Low-volume programs, for example, high load, low repetitions, moderate to high number of sets, have been characteristic of RT. Studies using two (55,170), three (149,250), four to five (56,122), and six or more (123,236) sets per exercise have all produced significant increases in muscular strength in both trained and untrained individuals. In direct comparison, studies have reported similar strength increases in novice individuals between two and three sets (35) and two and four sets (202), whereas three sets have been reported superior to one and two (23). Although little is known concerning the optimal number of sets performed per muscle group per session, a meta-analysis of 37 studies has shown that approximately eight sets per muscle group produced the largest effect size in athletes (206,207).

Another aspect that has received considerable attention is the comparison of single- and multiple-set programs. In many of these studies, one set per exercise performed for 8–12 repetitions at a relatively slow 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 controlled from other variables such as intensity, frequency, and repetition velocity. Notwithstanding this concern, most research investigations comparing single- versus multiple-set training for muscular fitness have examined the effects of a standard single-set training program relative to that of any number of possible multiple-set programs of varying intensity. This design has made the process of identifying a clear-cut prescription recommendation very difficult because these studies have yielded conflicting results. Several studies have reported similar strength increases between single- and multiple-set programs (40,132,248), whereas others reported multiple-set programs superior (23,27,237,251,256) in previously untrained individuals. Since 2002, six studies have shown multiple-set superiority for 33–100% of the dynamic strength assessments used, whereas the remaining dynamic strength assessments showed similar increases (81,126, 175,192,203,231). These data have prompted the notion that untrained individuals respond favorably to both single- and multiple-set programs and formed the basis for the popularity of single-set training among general fitness enthusiasts (68). In resistance-trained individuals, multiple-set programs have been shown to be superior for strength enhancement (142, 149,155,160,228,238) in all but one study (110). Among resistance-trained postmenopausal women, multiple-set training led to 3.5–5.5% strength increases, whereas single-set training led to −1% to 2% strength reductions (142). No comparative study has shown single-set training superior to multiple-set training in trained or untrained individuals.

The results of meta-analytical studies have shown multiple-set RT superior to single sets for strength enhancement in untrained (224,225) and trained populations (224, 225,278) and superior for strength increases for programs lasting 17–40 wk (278). These studies have shown that performing three to four sets per exercise produced the most substantial effect sizes (224,225). Thus, it appears that both program types are effective for increasing strength in untrained to moderately trained individuals during relatively short-term training periods. Long-term studies support the contention that a moderate increase in training volume is needed for further improvement (27,224,225,278). However, there is a point where further increase in volume may be counterproductive. In weightlifters, a moderate volume was shown to be more effective for increasing strength than low or high volumes of training with similar intensity (90). The key factor may be variation of training volume (and its interaction with intensity) rather than absolute number of sets.

Evidence statement and recommendation. *Evidence category A*. It is recommended that one to three sets per exercise be used by novice individuals initially (23,35,40, 55,132,170,202,206,207).

Evidence category B. For progression into intermediate to advanced status, data from long-term studies indicate that multiple sets be used with systematic variation of volume and intensity over time (142,149,155,160,228,238). To reduce the risk of overtraining, a dramatic increase in volume is not recommended. 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 volume is related to the program priorities of the individual as well as the muscle(s) trained in an exercise movement.

Exercise Selection

Both single- and multiple-joint exercises have been shown to be effective for increasing muscular strength in the targeted muscle groups using multiple modalities, for example, free weights, machines, cords, etc. (47,157). Multiple-joint exercises, such as bench press and squat, require complex neural responses (37) and have generally been regarded more effective for increasing overall muscular strength because they enable a greater magnitude of weight to be lifted (253). Single-joint exercises, such as knee extensions and knee curls, have been used to target-specific muscle groups and pose a reduced level of skill and technical involvement. It is important to note that alterations in body posture, grip, and hand width/foot stance and position change muscle activation and alter the exercise. Thus, many variations or progressions of single- and multiple-joint exercises can be performed. Another way to vary exercise selection is to include unilateral as well as bilateral exercises. The level of muscle activation differs when an exercise is performed bilaterally versus unilaterally. Unilateral training may increase bilateral strength (in addition to unilateral strength), and bilateral training may increase unilateral strength (179). Unilateral training has been shown to improve some aspects of sports performance, such as single-leg jumping ability to a greater extent than bilateral training (179). Of interest has been the performance of single- and multiple-joint exercises in unstable environments, for example, with stability balls, wobble boards, and BOSU balls (144). These exercises have been shown to increase the activity of lower torso musculature and other stabilizer muscles (compared with stable environments); however, the magnitude of agonist force production is considerably lower resulting in lighter weights lifted (10,21). There are a multitude of exercises that can be performed in a variety of conditions that leaves many options for RT variation.

Evidence statement and recommendation. *Evidence category A*. Unilateral and bilateral single- and multiple-joint exercises should be included in RT with emphasis on multiple-joint exercises for maximizing overall muscle strength in novice, intermediate, and advanced individuals (33,96–107,113,118,120,149–157,169,172,176).

Free Weights and Machines

Weight machines have been regarded as safer to use, easy to learn, and allow performance of some exercises that may be difficult with free weights, for example, knee extension. Machines help stabilize the body and limit movement about specific joints involved in synergistic force production, and machine exercises have demonstrated less neural activation when matched for intensity for most comparisons to free-weight exercises (178). Unlike machines, free weights may result in a pattern of intra- and intermuscular coordination that mimics the movement requirements of a specific task. Both free weights and machines are effective for increasing strength. Research shows that free-weight training leads to greater improvements in free-weight tests and machine training results in greater performance on machine tests (30). When a neutral testing device is used, strength improvement from free weights and machines appears similar (274). The choice to incorporate free weights or machines should be based on level of training status and familiarity with specific exercise movements as well as the primary training objective.

Evidence statement and recommendation. *Evidence category A*. For novice to intermediate training, it is recommended that free-weight and machine exercises are included (30,169,172,178,248–250,274).

Evidence category C. For advanced RT, it is recommended that emphasis be placed on free-weight exercises with machine exercises used to compliment program needs (100–103,251).

Exercise Order

The sequencing of exercises significantly affects the acute expression of muscular strength (240). This also applies when exercises are sequenced based on agonist/antagonist muscle group relationships. Muscle force and power may be potentiated when opposing exercises (antagonist movements) are performed (16); however, force and power may be reduced if the exercises are performed consecutively (171). Studies show that multiple-joint exercise (bench press, squat, leg press, and shoulder press) performance declines significantly when these exercises are performed later (after several exercises stressing similar muscle groups) rather than early in a workout (244,245). Considering that these multiple-joint exercises have been shown to be effective for increasing strength, maximizing performance of these exercises by performing them early in a workout may be necessary for optimal strength gains (247).

Evidence statement and recommendation. *Evidence category C*. Recommendations for sequencing exercises for novice, intermediate, and advanced strength training for total body (all muscle groups trained in the workout), upper/lower body split (upper-body musculature trained 1 d and lower-body musculature trained another day), and muscle group split (individual muscle groups trained during a workout) workouts include large muscle group exercises before small muscle group exercises, multiple-joint exercises before single-joint exercises, higher-intensity exercises before lower-intensity exercises, or rotation of upper and lower body or agonist–antagonist exercises, that is, exercise performed for a muscle group followed by an exercise for the opposing muscle group (244,245).

Rest Periods

The amount of rest between sets and exercises significantly affects metabolic (150,221), hormonal (158), and cardiovascular (72) responses to an acute bout during resistance exercise as well as performance of subsequent sets (149,279) and training adaptations (212,230). Acute resistance exercise performance may be compromised with one versus 3-min rest periods (149), and strength recovery may not be complete within 3 min (20). Several studies have shown that the number of repetitions performed may be compromised with short rest intervals, and 3- to 5-min rest intervals produce less performance decrements than 30 s to 2 min (221,229,269–271). In untrained individuals, circuit RT programs (using minimal rest in between exercises) have been shown to produce modest increases in strength (108). However, most longitudinal training studies have shown greater strength increases with long versus short rest periods (e.g., 2–5 min vs 30–40 s [3,213,230]), and one study has shown a lack of strength increase with 40-s rest periods (213). It is important to note that rest period length will vary based on the complexity of a given exercise (e.g., Olympic lifts and variations require longer rest periods) and the primary objective for incorporating the exercise into the training program (i.e., not every exercise will use the same rest interval).

Evidence statement and recommendation. *Evidence category B*. For novice, intermediate, and advanced training, it is recommended that rest periods of at least 2–3 min be used for core exercises using heavier loads (those exercises included specifically to improve maximal strength such as the squat and bench press) (3,149,213,214,221,229,230,269–271).

Evidence category C. For assistance exercises (those exercises complimentary to core exercises), a shorter rest period length of 1–2 min may suffice (149,213,229, 230,269).

Velocity of Muscle Action

The velocity of muscular contraction used to perform dynamic muscle actions affects the neural (97), the hypertrophic (123,241), and the metabolic (17,173) responses to resistance exercise and is inversely related to the relative load during maximal muscle contractions (48,234). Isokinetic training has been shown to increase strength specific to the training velocity with some carryover in performance at other velocities in the proximity to the training velocity (39,44,63, 123,137,145). However, it appears that training at moderate velocity (180–240°$\cdot$s^{-1}) produces the greatest strength increases across all testing velocities (137).

Dynamic constant external resistance (also called *isotonic*) or isoinertial training poses a different stress. Significant reductions in force production are observed when the intent is to perform the repetition slowly with submaximal loading. In interpreting the effects of intent to perform slow repetitions, it is important to note that two types of slow-velocity contractions exist during dynamic RT, unintentional and intentional. *Unintentional slow velocities* are used during high-intensity repetitions in which either the loading or the fatigue is responsible for the repetition tempo and duration (velocity of movement) (187). Conversely, *intentional slow-velocity* contractions are used with submaximal loads and occur when an individual has greater control of the velocity and influences the time the muscles are under tension.

It has been shown that CON force was significantly lower for an intentionally slow velocity (5:5; e.g., 5-s CON, 5-s ECC) compared with a traditional (moderate) velocity with a corresponding lower level of neural activation, for example, determined via electromyography (143). The rate of energy expenditure is lower using an intentionally slow velocity (173). Substantially, less peak force, power, and number of repetitions performed were observed with "super slow" repetition velocity (10:10) compared with a self-selected fast velocity when matched for intensity (111). A 30% reduction in training load is necessary when using a "very slow" velocity (10:5) compared with a slow velocity (2:4) (141).

Another study comparing "very slow" (10:5) to traditional velocity (1:1) showed that 37–40% reductions in training loads were needed to attain the same number of repetitions (129). These data suggest that motor unit activity may be limited when intentionally slow velocities at lighter loads are incorporated and ultimately may not provide an optimal stimulus for strength enhancement in resistance-trained individuals.

Compared with slow velocities, moderate (1–2:1–2) and fast (<1:1) velocities have been shown to be more effective for enhanced muscular performance capacities (e.g., number of repetitions performed, work and power output, and volume) (161,189) and for increasing the rate of strength gains (113). The number of repetitions performed is based upon a continuum depending on the lifting velocity where the largest numbers of repetitions are performed with a fast velocity and decreases proportionately as velocity becomes slower (234). The effect of lifting velocity on repetition performance appears largest with light to moderately heavy loading (234). Most advanced RT studies examining fast velocities with moderately high intensities have shown these velocities to be more effective than traditionally slower velocities for strength increases (133,190). It appears that the intent to maximally accelerate the weight during training is critical in maximizing strength gains (19). Although loading may be moderate to heavy, the intent to lift the weight as fast as possible has been shown to be critical for maximizing strength increases (19). Keeler et al. (141) showed that traditional velocity (2:4) RT produced significantly greater strength increases over 10 wk than "super slow" training in five of eight exercises trained (overall increase of 39% vs 15% in traditional and "super slow," respectively). Over 6 wk of RT in untrained individuals, it was shown that training at a faster velocity (1:1) led to ~11% greater strength increases than training at a slower velocity (3:3) (192). However, a study by Neils et al. (195) showed statistically similar increases in strength between "super slow" and slow-velocity (2:4) training.

Evidence statement and recommendation. *Evidence category A*. For untrained individuals, it is recommended that slow and moderate velocities be used (113,141,161,189,192,195).

Evidence category B. For intermediate training, it is recommended that moderate velocity be used for RT (113,141,161,189,192,195).

Evidence category C. For advanced training, the inclusion of a continuum of velocities from unintentionally slow to fast velocities is recommended. The velocity selected should correspond to the intensity and the intent should be to maximize the velocity of the CON muscle action (19,133).

Frequency

Optimal RT frequency (the number of workouts per week) depends upon several factors such as volume, intensity, exercise selection, level of conditioning, recovery ability, and number of muscle groups trained per workout session. Numerous studies have used frequencies of two to three alternating days per week in previously untrained individuals (34,44,56,116). This frequency has been shown to be an effective initial frequency, whereas 1–2 $d{\cdot}wk^{-1}$ appears to be an effective maintenance frequency for those individuals already engaged in RT (93). In several studies comparing strength gains, 1) 3 d of training per week was superior to 1 (183) and 2 d (94), 2) 3 d produced similar strength increases to 2 $d{\cdot}wk^{-1}$ when volume was equated (34), 3) 4 $d{\cdot}wk^{-1}$ was superior to three (127), 4) 2 $d{\cdot}wk^{-1}$ was superior to 1 (217), and 5) 3–5 $d{\cdot}wk^{-1}$ was superior to 1 and 2 d (85). Meta-analytical data have shown that strength gains in untrained individuals were highest with a frequency of 3 $d{\cdot}wk^{-1}$ (225).

Evidence statement and recommendation. *Evidence category A*. It is recommended that novice individuals train the entire body 2–3 $d{\cdot}wk^{-1}$ (34,44,56,94,116,183,225).

It appears that progression from untrained to intermediate training does not necessitate a change in frequency for training each muscle group but may be more dependent upon alterations in other acute variables such as exercise selection, volume, and intensity. Increasing frequency enables greater specialization (e.g., greater exercise selection and volume per muscle group in accordance with more specific goals). Upper/lower body split or muscle group split routines are common at this level in addition to total-body workouts (157). Similar increases in strength have been observed between upper/lower- and total-body workouts (32).

Evidence category B. It is recommended that for progression to intermediate training, a frequency of 3–4 $d{\cdot}wk^{-1}$ be used (3 d if using a total-body workout, 4 d if using a split routine thereby training each major muscle group twice) (34,85,94,183,225).

Optimal progression of frequency during advanced training varies considerably. It has been shown that football players training 4–5 $d{\cdot}wk^{-1}$ achieved better results than those who trained either 3 or 6 $d{\cdot}wk^{-1}$ (118). Advanced and elite weightlifters and bodybuilders use high-frequency training, for example, four to six sessions per week or more. Double-split routines (two training sessions per day with emphasis on different muscle groups) are common during training (102), which may result in 8–12 training sessions per week. Frequencies as high as 18 sessions per week have been reported in elite Olympic weightlifters (280). The rationale for high-frequency training is that frequent short sessions followed by periods of recovery, nutrition supplementation, and food intake allow for high-intensity training and performance (reduced fatigue). Häkkinen and Kallinen (103) reported greater increases in muscle cross-sectional area (CSA) and strength when training volume was divided into two sessions per day as opposed to one. Elite power lifters train 4–6 $d{\cdot}wk^{-1}$ (75). It is important to note that not all muscle groups are trained per workout during a high-frequency model of training. Meta-analytical data have shown that training a muscle group two times per week in advanced individuals yielded the highest effect size (225) and two to three times per week yielded similar effect sizes in athletes (206).

Evidence category C. It is recommended that advanced lifters train 4–6 $d \cdot wk^{-1}$. Elite weightlifters and bodybuilders may benefit from using very high frequency, for example, two workouts in 1 d for 4–5 $d \cdot wk^{-1}$ (102,118,206,225).

Muscular Hypertrophy

It is well known that RT induces muscular hypertrophy (156,176,249,250) through mechanical, metabolic, and hormonal processes. The process of hypertrophy involves a proportionate increase in the net accretion of the contractile proteins actin and myosin as well as other structural proteins. Mechanical loading leads to a series of intracellular events that ultimately regulates gene expression and protein synthesis. RT may alter the activity of nearly 70 genes (232), up-regulate factors involved with myogenesis (e.g., myogenin, MyoD), and down-regulate inhibitory growth factors (e.g., myostatin) (148,233). Protein synthesis in human skeletal muscle increases after only one bout of vigorous RT (210) and peaks approximately 24 h postexercise. This anabolic environment remains elevated from 2 to 3 h postexercise up through 36–48 h postexercise (83,166). Other factors such as fiber type (176), muscle action (84), metabolite formation (242), amino acid intake (80), and endocrine responses (testosterone, growth hormone [GH], cortisol, insulin, and insulin-like growth factor I) contribute to the magnitude of hypertrophy (158). Optimal hypertrophy may comprise maximizing the combination of mechanical (use of heavy weights, ECC actions, and low to moderate volume) and metabolic (accumulation of metabolic waste products) stimuli.

The time course of hypertrophy has been examined in previously untrained individuals. Neural adaptations predominate during the early stages of training (188). Muscle hypertrophy becomes evident within the first 6 wk (211), although changes in the quality of proteins (250) and protein synthesis rates (211) take place much earlier. From this point onward, there appears to be interplay between neural adaptations and hypertrophy in the expression of strength. Less muscle mass is recruited during training with a given workload once adaptation has taken place (215). These findings indicate that progressive overloading is necessary for maximal muscle fiber recruitment and, consequently, muscle fiber hypertrophy. This also indicates that alterations in program design targeting both neural and hypertrophic factors may be most beneficial for maximizing strength and hypertrophy.

PROGRAM DESIGN RECOMMENDATIONS FOR INCREASING MUSCLE HYPERTROPHY

Muscle Action

Evidence statement and recommendation. *Evidence category A*. Similar to strength training (55,112,131), it is recommended that CON, ECC, and ISOM muscle actions be included for novice, intermediate, and advanced RT.

Loading and Volume

A variety of styles of training have been shown to increase hypertrophy in men and women (3,49,157,249). In untrained individuals, similar increases in lean body mass have been shown between single- and multiple-set training (175,228), although there is evidence supporting greater hypertrophy enhancement with multiple-set training (231). Many of these studies in previously untrained individuals have demonstrated that general, nonspecific program design is effective for increasing hypertrophy in novice to intermediate individuals. Manipulation of acute program variables to optimize both the mechanical and the metabolic factors (using several loading/volume schemes) appears to be the most effective way to optimize hypertrophy during advanced stages of training. RT programs targeting muscle hypertrophy have used moderate to very high loading, relatively high volume, and short rest intervals (75,157). These programs have been shown to induce a greater acute elevation in testosterone and GH than high-load, low-volume programs with long (3 min) rest periods (91,151,152). Total work, in combination with mechanical loading, has been implicated for both gains in strength and hypertrophy (190). This finding 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 (149,155,169). Traditional RT (high load, low repetition, and long rest periods) has produced significant hypertrophy (96,258); however, it has been suggested that the total work involved with traditional RT alone may not maximize hypertrophy. Goto et al. (91) showed that the addition of one set per exercise (to a conventional RT workout) consisting of light loading for 25–35 repetitions led to increased muscle CSA whereas conventional strength training alone (e.g., multiple sets of 3–5 RM) did not increase muscle CSA. The addition of the high-volume sets led to greater acute elevations in GH (91). However, light loading alone may not be sufficient as Campos et al. (33) have reported that 8 wk of training with two sets of 25–28 RM did not result in Type I or Type II muscle fiber hypertrophy. Thus, it appears that the combination of strength training (emphasizing mechanical loading) and hypertrophy training, that is, moderate loading, high repetitions, short rest intervals, which emphasizes total work (and reliance upon glycolysis and metabolic factors), is most effective for advanced hypertrophy training.

Evidence statement and recommendation. *Evidence category A*. For novice and intermediate individuals, it is recommended that moderate loading be used (70–85% of 1 RM) for 8–12 repetitions per set for one to three sets per exercise (3,49,157,175,228,249).

Evidence category C. For advanced training, it is recommended that a loading range of 70–100% of 1 RM be used for 1–12 repetitions per set for three to six sets per exercise in periodized manner such that the majority of training is devoted to 6–12 RM and less training devoted to 1–6 RM loading (149,155,169).

Exercise Selection and Order

Both single- and multiple-joint exercises increase hypertrophy, and the complexity of the exercises chosen has been shown to affect the time course of hypertrophy such that multiple-joint exercises require a longer neural adaptive phase than single-joint exercises (37). Less is understood concerning the effect of exercise order on muscle hypertrophy. Although exceptions exist (e.g., using an opposite sequencing strategy to induce higher levels of fatigue), it appears that the recommended exercise sequencing guidelines for strength training apply for increasing muscle hypertrophy.

Evidence statement and recommendation. *Evidence category A.* It is recommended that single- and multiple-joint free-weight and machine exercises be included in an RT program in novice, intermediate, and advanced individuals (30,157,169,172,178,248–250,274).

Evidence category C. For exercise sequencing, an order similar to strength training is recommended (244,245,256).

Rest Periods

The amount of rest between sets and exercises significantly affects the metabolic (221) and the hormonal (158) responses to an acute bout of resistance exercise. Rest period length significantly affects muscular strength, but less is known concerning hypertrophy. One study reported no significant difference between 30-, 90-, and 180-s rest intervals in muscle girth, skinfolds, or body mass in recreationally trained men over 5 wk (230). Ahtiainen et al. (3) showed that 3 months of training with 5-min rest intervals produced similar increase in muscle CSA to training with 2-min rest intervals. Short rest periods (1–2 min) coupled with moderate to high intensity and volume have elicited the greatest acute anabolic hormonal response in comparison to programs utilizing very heavy loads with long rest periods (151,152). The acute hormonal responses have been regarded potentially more important for hypertrophy than chronic changes (177). It appears a range of rest intervals may be used effectively to target hypertrophy depending on training intensity. In that regard, training for muscular hypertrophy alone may differ from training for strength or power *per se* because the explicit objective is to produce an anabolic environment.

Evidence statement and recommendation. *Evidence category C.* It is recommended that 1- to 2-min rest periods be used in novice and intermediate training programs. For advanced training, rest period length should correspond to the goals of each exercise or training phase such that 2- to 3-min rest periods may be used with heavy loading for core exercises and 1–2 min may be used for other exercises of moderate to moderately high intensity (3,151,152).

Repetition Velocity

Less is known concerning the effect of repetition velocity on hypertrophy. In untrained individuals, fast (1:1) and moderate to slow (3:3) velocities of training produced similar changes in elbow flexor girth after 6 wk of training (192). However, 8 wk of fast ($210°\cdot s^{-1}$) ECC isokinetic training produced larger increases in Type II muscle fiber CSA than slow ($20°\cdot s^{-1}$) training (241), and 8 wk of fast ECC ($180°\cdot s^{-1}$) isokinetic training produced greater hypertrophy than slow ECC ($30°\cdot s^{-1}$), fast and slow CON training (64). For dynamic constant external RT, it has been suggested that higher velocities of movement pose less of a stimulus for hypertrophy than slow and moderate velocities. However, intentional slow velocities require significant reductions in loading and result in less of a blood lactate response and less metabolic response when total training time is equated (129). It does appear that the use of different velocities is warranted for long-term improvements in hypertrophy for advanced training.

Evidence statement and recommendation. *Evidence category C.* It is recommended that slow to moderate velocities be used by novice- and intermediate-trained individuals. For advanced training, it is recommended that slow, moderate, and fast repetition velocities be used depending on the load, the repetition number, and the goals of the particular exercise (64,192).

Frequency

The frequency of training depends upon the number of muscle groups trained per workout as well as the volume and intensity. Frequencies of 2–3 $d\cdot wk^{-1}$ have been effective in novice and intermediate men and women (34,49,116). Higher frequency of RT has been suggested for advanced hypertrophy training. However, only certain muscle groups are trained per workout with a high frequency.

Evidence statement and recommendation. *Evidence category A.* It is recommended that a frequency of 2–3 $d\cdot wk^{-1}$ be used for novice training (when training the total body each workout) (34,49,116).

Evidence category B. For intermediate training, the recommendation is similar for total-body workouts or 4 $d\cdot wk^{-1}$ when using an upper/lower body split routine (each major muscle group trained twice per week).

Evidence category C. For advanced training, a frequency of 4–6 $d\cdot wk^{-1}$ is recommended. Muscle group split routines (one to three muscle groups trained per workout) are common enabling higher volume per muscle group.

PROGRAM DESIGN RECOMMENDATIONS FOR INCREASING MUSCULAR POWER

Maximal power production is required in the movements of sport, work, and daily living. By definition, more power is produced when the same amount of work is completed in a shorter period or when a greater amount of work is performed during the same period. Muscular power is the scalar product of force generation and movement velocity, is demonstrated as the highest power output attainable during a given movement/repetition, and has been viewed as an exceedingly important testing variable and training objective.

Neuromuscular contributions to maximal muscle power include 1) maximal rate of force development (RFD), 2) force production at slow and fast contraction velocities, 3) stretch-shortening cycle performance, and 4) coordination of movement pattern and skill. Several studies have shown improved power performance following traditional RT (1,88,156,277), demonstrating the reliance of power production on muscular force development. However, programs consisting of movements with high power output using relatively light loads have been shown to be superior for improving vertical jump ability than traditional strength training (98,99). Considering that power is the product of force and velocity, it appears that heavy RT with slow velocities improves maximal force production whereas power training (utilizing light to moderate loads at high velocities) increases force output at higher velocities and RFD (98,99).

Heavy RT could decrease power output over time unless accompanied by explosive movements (25). The inherent problem with traditional weight training is that the load is decelerated for a considerable proportion (24–40%) of the CON movement (60,197). This percentage increases to 52% when performing the lift with a lower percentage (81%) of 1 RM lifted (60) or when attempting to move the bar rapidly in an effort to train more specifically near the movement speed of the target activity (197). Ballistic resistance exercise (explosive movements which enable acceleration throughout the full range of motion resulting in greater peak and average lifting velocities) has been shown to limit this problem (48,121,198,276). Loaded jump squats with 30% of 1 RM have been shown to increase vertical jump performance more than traditional back squats and plyometrics (276).

Exercise Selection and Order

Although single-joint exercises have been studied, multiple-joint exercises have been used extensively for power training (139). The inclusion of total-body exercises (e.g., power clean and push press) is recommended as these exercises have been shown to require rapid force production (82) and be very effective for enhancing power (263). It is recommended that these exercises be performed early in a workout and sequenced based on complexity (e.g., snatch before power cleans and variations such as high pulls). Additionally, performing high-velocity power exercises before a multiple-joint exercise such as the squat has been shown to improve squat performance (247), for example, via postactivation potentiation.

Evidence statement and recommendation. *Evidence category B.* The use of predominately multiple-joint exercises performed with sequencing guidelines similar to strength training is recommended for novice, intermediate, and advanced power training (82,139,247,263).

Loading/Volume/Repetition Velocity

The intensity of which peak power is attained has been variable and shown to be dependent on the type of exercise, whether it is ballistic or traditional, and the strength level of the individual (139). Peak power during ballistic exercises has been shown to range between 15% and 50% (upper body exercises), from 0% (body weight) to 60% (lower body exercises, primarily the jump squat), and peak power for traditional exercises ranges between 30% and 70% of 1 RM (41–43,139,260). Peak power for the Olympic lifts typically occurs approximately 70–80% of 1 RM (42,140). Although any intensity can enhance muscle power and shift the force-velocity curve to the right, specificity is needed such that training encompasses a range of intensities but emphasis placed upon the intensities that match the demands of the sport or activities performed (139). Fast lifting velocities are needed to optimize power development with submaximal loading, and the intent to maximally lift the weight fast is critical when a higher intensity is used (19).

Evidence statement and recommendation. *Evidence category A.* It is recommended that concurrent to a typical strength training program, a power component is incorporated consisting of one to three sets per exercise using light to moderate loading (30–60% of 1 RM for upper body exercises, 0–60% of 1 RM for lower body exercises) for three to six repetitions (19,41–43,139,260).

Evidence category B. Progression for power enhancement uses various loading strategies in a periodized manner. Heavy loading (85–100% of 1 RM) is necessary for increasing the force component of the power equation, and light to moderate loading (30–60% of 1 RM for upper body exercises, 0–60% of 1 RM for lower body exercises) performed at an explosive velocity is necessary for increasing fast force production. A multiple-set (three to six sets) power program be integrated into a strength training program consisting of one to six repetitions in periodized manner is recommended (74,199,206).

Rest Periods

Rest period length for power training is similar to strength training. Taking the needed rest is vital to ensure the quality of each repetition being performed in a set (achieving a high percent of peak velocity and achieving a high percentage of maximal power output). In addition to the technical quality of each repetition performed in a power training program, accentuated rest periods are also needed for preservation of the appropriate training intensity to occur, which will elicit the desired neurological response.

Evidence statement and recommendation. *Evidence category D.* Rest periods of at least 2–3 min between sets for core exercises are recommended. A shorter rest interval (1–2 min) is recommended for assistance exercises.

Frequency

Power training is typically integrated into a periodized strength training program due to the important inherent relationships between the two variables (97,198,199).

Evidence statement and recommendation. *Evidence category A.* The recommended frequency for novice power training is similar to strength training (2–3 $d \cdot wk^{-1}$ stressing the total body).

Evidence category B. For intermediate power training, it is recommended that either a total-body or an upper/lower-body split workout be used for a frequency of 3–4 $d \cdot wk^{-1}$.

Evidence category C. For advanced power training, a frequency of 4–5 $d \cdot wk^{-1}$ is recommended using predominantly total-body or upper/lower body split workouts.

PROGRAM DESIGN RECOMMENDATIONS FOR INCREASING MUSCULAR ENDURANCE

Local muscular endurance, submaximal local muscular and high-intensity (or strength) endurance, has been shown to improve during RT (9,59,125,169,255). RT has been shown to increase absolute LME (i.e., the maximal number of repetitions performed with a specific pretraining load) (9,33,125,149), but limited effects are observed in relative LME (i.e., endurance assessed at a specific relative intensity or %1 RM) (172). Moderate to low RT with high repetitions has been shown to be most effective for improving absolute LME in most studies (9,33,91,125,227), although one study found high-intensity, low-repetition training to be more effective in highly trained endurance athletes (59). A relationship exists between increases in strength and LME such that strength training alone may improve endurance to a certain extent. However, specificity of training produces the greatest improvements (9,255). Training to increase LME implies that the individual 1) performs high repetitions (long-duration sets with high muscle time under tension) and/or 2) minimizes recovery between sets.

Exercise Selection and Order

Exercises stressing multiple or large muscle groups have elicited the greatest acute metabolic responses during resistance exercise (17). Metabolic demand is an important stimulus for adaptations within skeletal muscle necessary to improve LME (increased mitochondrial and capillary number, fiber type transitions, and buffering capacity). The sequencing of exercises may not be as important in comparison to strength training as fatigue (i.e., substrate depletion and accumulation of metabolic waste products) is a necessary component of endurance training.

Evidence statement and recommendation. *Evidence category A.* It is recommended that unilateral and bilateral multiple- and single-joint exercises be included in a program targeting improved LME using various sequencing combinations for novice, intermediate, and advanced LME training (9,59,125,169,255).

Loading and Volume

Loading is multidimensional. Light loads coupled with higher repetitions (15–25 repetitions or more) have been shown to be most effective for increasing LME (9,33,227,255). However, moderate to heavy loading (coupled with short rest periods) is also effective for increasing high-intensity and absolute LME (9,33). High-volume (including multiple sets) programs have been shown to be superior for LME enhancement (33,149,169,255).

Evidence statement and recommendation. *Evidence category A.* For novice and intermediate training, it is recommended that relatively light loads be used (10–15 repetitions) (9,33,227,255).

Evidence category C. For advanced training, it is recommended that various loading strategies be used for multiple sets per exercise (10–25 repetitions or more) in periodized manner leading to higher overall volume using lighter intensities (227).

Rest Periods

The duration of rest intervals during resistance exercise appears to affect LME. It has been shown that bodybuilders (who typically train with high-volume and short rest periods) demonstrate a significantly lower fatigue rate in comparison to power lifters (who typically train with low to moderate volume and longer rest periods) (150). These data demonstrate the benefits of high-volume, short rest period workouts for improving LME. It is important to note that another popular method of endurance training is circuit RT. Circuit RT has been shown to increase LME (167,275) and is effective due to its high continuity. Thus, minimal rest is taken between exercises.

Evidence statement and recommendation. *Evidence category C.* It is recommended that short rest periods be used for LME training, for example, 1–2 min for high-repetition sets (15–20 repetitions or more), <1 min for moderate (10–15 repetitions) sets. For circuit weight training, it is recommended that rest periods correspond to the time needed to get from one exercise station to another (167,275).

Frequency

The frequency for LME training appears similar to hypertrophy training.

Evidence statement and recommendation. *Evidence category A.* Low frequency (2–3 $d \cdot wk^{-1}$) is effective in novice individuals when training the entire body (9,59,125,169,255).

Evidence category B. For intermediate training, 3 $d \cdot wk^{-1}$ is recommended for total-body workouts and 4 $d \cdot wk^{-1}$ is recommended for upper/lower body split routine workouts.

Evidence category C. For advanced training, a higher frequency may be used (4–6 $d \cdot wk^{-1}$) if muscle group split routines are used.

Repetition Velocity

Studies examining isokinetic exercise have shown that a fast training velocity, that is, $180°·s^{-1}$, was more effective than a slow training velocity, that is, $30°·s^{-1}$, for improving LME (2,186). Thus, fast contraction velocities are recommended for isokinetic training. However, it appears that both fast and slow velocities are effective for improving LME during dynamic constant external RT. 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. Ballor et al. (17) has shown that intentionally slow-velocity training with light loads (5:5 and slower) was more metabolically demanding than moderate and fast velocities. However, Mazzetti et al. (173) showed that explosive CON repetition velocity resulted in greater rates of energy expenditure than a slower velocity (2:2). When matched for intensity and volume, slower velocity may result in greater blood lactates (173).

Increasing the time under tension with sufficient loading can increase muscular fatigue (262), and fatigue is important to eliciting LME enhancement. This result was shown by Tran et al. (262) who compared three sets of 10 repetitions (5:5), 10 repetitions (2:2), or 5 repetitions (10:4) and reported that the highest volume load and time under tension, for example, protocol 1, resulted in the largest magnitude of peripheral fatigue. Peak ISOM force (19%) and rate of force development (RFD) (46%) were reduced significantly more than with the other protocols (13–15% and 9–13%, respectively). Thus, traditional velocities may result in less fatigue than slower velocities provided loading is sufficient. However, it is difficult to perform a large number of repetitions using intentionally slow velocities.

Evidence statement and recommendation. *Evidence category B.* It is recommended that intentionally slow velocities be used when a moderate number of repetitions (10–15) are used. Moderate to fast velocities are more effective for increasing repetition number than slow-velocity training (161). If performing a large number of repetitions (15–25 or more), then moderate to faster velocities are recommended.

RELEVANCE TO SPORTS APPLICATIONS

Motor Performance

Improved motor performance results from RT. The principle of "specificity" is important for improving motor performance as the greatest improvements are observed when RT programs are prescribed that are specific to the task or the activity. The recommendations for improving motor performance are similar to that of strength and power training.

Vertical Jump

Force production during isokinetic and dynamic resistance exercise measures correlates to vertical jump height (28,208,216), and RT may improve vertical jump (1,252). High correlations between closed-chain exercises (exercises where the distal segments are fixed, i.e., squat) and vertical (r = 0.72) and standing long jump (r = 0.65) performance have been reported (24), and training with closed-chain exercises is more effective for improving vertical jump than open-chain exercises (12). Total-body multiple-joint exercises such as the Olympic lifts (snatch, clean and jerk, and variations) have been shown to improve jumping ability (82,120,263) to a greater extent than strength training (120). The high velocity and joint involvement of these exercises and their ability to integrate strength, power, and neuromuscular coordination demonstrates a direct carryover to improving jump performance. The effect of intensity on vertical jump improvements appears related to contraction velocity. Several studies (98,99,276) have shown improvements in jump height using light loads (<60% of 1 RM). Other reports show vertical jump enhancement can be achieved while using higher intensities (>80% of 1 RM) (1). Multiple-set RT has been shown to be superior for improving vertical jump performance in comparison to single-set RT programs (149), and 5–6 $d·wk^{-1}$ of training elicited greater vertical jump improvements than 3–4 $d·wk^{-1}$ in football players (118).

Evidence statement and recommendation. *Evidence category B.* It is recommended that multiple-joint exercises be performed using a combination of heavy and light to moderate loading (using fast repetition velocity), with moderate to high volume in periodized fashion 4–6 $d·wk^{-1}$ for maximal progression in vertical jumping ability (1,82,98,99,120,149,263). The inclusion of plyometric training (explosive form of exercise involving various jumps) in combination with RT is recommended.

Sprint Speed

Force production is related to sprint performance (4,11) and is a good indicator of speed when testing is performed at isokinetic velocities greater than $180°·s^{-1}$ (205). Relative (to body mass) strength correlates highly with sprint velocity and acceleration (r = 0.88) (208) as well as jump squat height and power (46). However, increasing maximal strength does not appear to be highly related to reducing sprint time (15). Traditional strength and ballistic training has only produced small reductions in sprint times (118,120,174). However, specific hip flexor strength training was shown to reduce sprint time (50). The combination of strength and sprint training results in the greatest improvements in sprinting speed (52).

Evidence statement and recommendation. *Evidence category B.* It is recommended that the combination of resistance and ballistic resistance exercise (along with sprint and plyometric training) be included for progression in sprinting ability (51,118,120,174).

Agility

Muscular strength is an important factor in an individual's ability to stop and change direction rapidly (11,119,208).

Lower-body multiple-joint exercise strength and power have been shown to correlate to various agility tests (168). A significant relationship has been reported between peak ECC hamstring force at $90°·s^{-1}$ and agility run time and may be an important indicator of success (11). No change (48,119,120), a reduction (45), or an increase in time (78) in agility (*t*-test) has been observed following RT. It appears that agility-specific training is most beneficial for enhancing agility performance.

Sport-Specific Activities

The importance of RT for other sport-specific activities has been shown. Strength in the kicking limb for soccer players highly correlates to ball velocity (218). Significant correlations have been shown between wrist and elbow extensor and flexors, shoulder abduction/adduction, and shoulder internal rotation strength and throwing speed (73,204). Several studies have shown increases (2.0–4.1%) in throwing velocities in both baseball (162,180,196) and European handball (117) players following traditional (162,196) and ballistic (180) RT. Improvements in shot put performance (38), golf (261), distance running (134), swimming performance (86), and tennis service velocity (155) have been reported following RT.

PROGRESSION MODELS FOR RESISTANCE EXERCISE IN HEALTHY, OLDER ADULTS

Progression and maintenance (maintenance of physical function in this population may be viewed as progression) in healthy, older adults is brought about by systematic manipulation of the acute program variables. However, caution must be taken with the elderly population as to the rate of progression, particularly those with hypertension, arthritis, cardiovascular disease, or any other debilitating condition that limits physical function. There are other modes of resistance exercise, such as aquatic resistance exercise, that have been shown to be especially beneficial in the older population and to reduce some of the risks of resistance exercise. These studies have shown increased muscular strength, power, and bone mineral density as well as improvements in cardiovascular and psychological function (13,257,264,266,267). Further, each individual will respond differently based on their current training status and past experience, joint health, and individual response to the training stress. A quality training program should improve the quality of life by enhancing several components of muscular fitness, that is, strength, balance, etc. (61). Programs that include variation, gradual progressive overload, careful attention to recovery and stress, and specificity are warranted. This finding was recently shown in elderly women where peak torque and average power plateaued as a result of a significant increase in volume (at the same intensity) (243).

Muscular strength and hypertrophy training may improve the quality of life and limit *sarcopenia*. Optimizing strength to meet/exceed performance goals is important to a growing number of older adults. Numerous studies have shown increased muscle strength and size in older adults following RT as long as basic requirements of intensity and volume are met (31,36,61,69,77,105,106). The basic RT program recommended by the ACSM for the healthy adult (6,7) has been an effective starting point in the elderly population.

When the older adult's long-term goal is progression toward higher levels of strength and hypertrophy, evidence supports the use of variation in program design (105, 106,154). Studies have shown significant improvements in strength in this population (61,69,77). It is important that progression be introduced gradually. A training frequency of 1–3 $d·wk^{-1}$ produced similar increases in strength; however, 3 $d·wk^{-1}$ was superior to 1–2 d for improving LME, coordination, balance, and cardiorespiratory fitness in older women (193). Some studies have shown similar strength increases between moderate (50–60% of 1 RM) and high (80–85% of 1 RM) training intensities or 6–15 RM (109, 265) over 18–24 wk of training. Training 3 $d·wk^{-1}$ with 50%, 65%, and 80% of 1 RM each day produced similar strength increases to training 3 $d·wk^{-1}$ with 80% of 1 RM (128). However, several studies have shown greater strength increases with high-intensity (80–83% of 1 RM) versus moderate-intensity (50–63% of 1 RM) and low-intensity (20–48% of 1 RM) training (53,65,66,135,136). Thus, a variety of intensities may be effective in this population especially early in training.

Evidence statement and recommendation. *Evidence category A*. For improvements in strength and hypertrophy in older adults, the use of free-weight and machine multiple- and single-joint exercises with slow to moderate lifting velocity for one to three sets per exercise with 60–80% of 1 RM for 8–12 repetitions with 1–3 min of rest in between sets for 2–3 $d·wk^{-1}$ is recommended (31,53,61,65,66,69,77,105,106, 109,128,135,136,265).

The ability to develop high muscular power diminishes with age (107). An increase in strength and power enables the older adult to improve performance in tasks that require a rapid RFD, including a reduced risk of falls (212). There is support for the inclusion of power training for the healthy older adult (107,154). Muscle atrophy results from fiber denervation with loss of some fibers and atrophy of others, that is, especially fast twitch, with aging and inactivity (164). Age-related muscle atrophy is associated with reductions in strength and power (77,104), and reductions in power exceed decreases in maximal strength (246). Although most studies in the elderly examined heavy RT programs, power training may optimize functional abilities as well as have secondary effects on other physiological systems, for example, connective tissue (18).

Since 2001, several studies have examined power training, for example, free-weight and machine exercises with the CON phase performed rapidly with a controlled

TABLE 2. Summary of progressive resistance training recommendations.

Evidence Statement	Grade
Strength training	
CON, ECC, and ISOM actions be included for novice, intermediate, and advanced training.	A
Training with loads ~60–70% of 1 RM for 8–12 repetitions for novice to intermediate individuals and cycling loads of 80–100% of 1 RM for advanced individuals.	A
When training at a specific RM load, it is recommended that a 2–10% increase in load be applied when the individual can perform the current workload for 1–2 repetitions over the desired number on two consecutive training sessions.	B
It is recommended that 1–3 sets per exercise be used by novice individuals.	A
Multiple-set programs (with systematic variation of volume and intensity) are recommended for progression to intermediate and advanced training.	A
Unilateral and bilateral single- and multiple-joint exercises should be included with emphasis on multiple-joint exercises for maximizing strength in novice, intermediate, and advanced individuals.	A
Free-weight and machine exercises should be included for novice to intermediate training.	A
For advanced strength training, it is recommended that emphasis be placed on free-weight exercises with machine exercises used to compliment program needs.	C
Recommendations for sequencing exercises for novice, intermediate, and advanced strength training include large muscle group exercises before small muscle group exercises, multiple-joint exercises before single-joint exercises, higher-intensity exercises before lower-intensity exercises, or rotation of upper and lower body or opposing exercises.	C
It is recommended that rest periods of at least 2–3 min be used for core exercises using heavier loads for novice, intermediate, and advanced training. For assistance exercises, a shorter rest period length of 1–2 min may suffice.	B C
For untrained individuals, it is recommended that slow and moderate CON velocities be used.	A
For intermediate training, it is recommended that moderate CON velocity be used.	A
For advanced training, the inclusion of a continuum of velocities from unintentionally slow to fast CON velocities is recommended and should correspond to the intensity.	C
It is recommended that novice individuals train the entire body 2–3 $d\cdot wk^{-1}$.	A
It is recommended that for progression to intermediate training, a frequency of 3–4 $d\cdot wk^{-1}$ be used (based on how many muscle groups are trained per workout).	B
It is recommended that advanced lifters train 4–6 $d\cdot wk^{-1}$.	C
Muscle hypertrophy	
It is recommended that CON, ECC, and ISOM muscle actions be included.	A
For novice and intermediate training, it is recommended that moderate loading be used (70–85% of 1 RM) for 8–12 repetitions per set for 1–3 sets per exercise.	A
For advanced training, it is recommended that a loading range of 70–100% of 1 RM be used for 1–12 repetitions per set for 3–6 sets per exercise in a periodized manner such that the majority of training is devoted to 6–12 RM and less training devoted to 1–6 RM loading.	A
It is recommended that single- and multiple-joint free-weight and machine exercises be included in novice, intermediate, and advanced individuals.	A
For exercise sequencing, an order similar to strength training is recommended.	C
It is recommended that 1- to 2-min rest periods be used in novice and intermediate training; for advanced training, length of rest period should correspond to the goals of each exercise such that 2- to 3-min rest periods may be used with heavy loading for core exercises and 1–2 min may be used for other exercises of moderate to moderately high intensity.	C
It is recommended that slow to moderate velocities be used by novice- and intermediate-trained individuals; for advanced training, it is recommended that slow, moderate, and fast repetition velocities be used depending on the load, repetition number, and goals of the particular exercise.	C
It is recommended that a frequency of 2–3 $d\cdot wk^{-1}$ be used for novice training.	A
For intermediate training, the recommendation is similar for total-body workouts or 4 $d\cdot wk^{-1}$ when using an upper/lower body split routine.	B
For advanced training, a frequency of 4–6 $d\cdot wk^{-1}$ is recommended.	C
Muscle power	
The use of predominately multiple-joint exercises performed with sequencing guidelines similar to strength training is recommended for novice, intermediate, and advanced power training.	B
It is recommended that concurrent to a typical strength training program, a power component is incorporated consisting of 1–3 sets per exercise using light to moderate loading (30–60% of 1 RM for upper body exercises, 0–60% of 1 RM for lower body exercises) for 3–6 repetitions not to failure.	A
Various loading strategies are recommended for advanced training. Heavy loading (85–100% of 1 RM) is necessary for increasing force and light to moderate loading	B
(30–60% of 1 RM for upper body exercises, 0–60% of 1 RM for lower body exercises) performed at an explosive velocity is necessary for increasing fast force production.	A
A multiple-set (3–6 sets) power program be integrated into a strength training program consisting of 1–6 repetitions in a periodized manner is recommended.	
Rest periods of at least 2–3 min between sets for core exercises are recommended when intensity is high. For assistance exercises and those of less intensity,	D
a shorter rest interval (1–2 min) is recommended.	A
The recommended frequency for novice power training is similar to strength training (2–3 $d\cdot wk^{-1}$).	C
For intermediate power training, it is recommended that either a total-body or upper/lower–body split workout be used for a frequency of 3–4 $d\cdot wk^{-1}$.	C
For advanced power training, a frequency of 4–5 $d\cdot wk^{-1}$ is recommended using predominantly total-body or upper/lower–body split workouts.	
Local muscular endurance	
It is recommended that unilateral and bilateral multiple- and single-joint exercises be included using various sequencing combinations for novice, intermediate, and advanced local muscular endurance training.	A
For novice and intermediate training, it is recommended that relatively light loads be used (10–15 repetitions) with moderate to high volume.	A
For advanced training, it is recommended that various loading strategies be used for multiple sets per exercise (10–25 repetitions or more) in a periodized manner leading to a higher overall volume using lighter intensities.	C
It is recommended that short rest periods be used for muscular endurance training, e.g., 1–2 min for high-repetition sets (15–20 repetitions or more), less than 1 minute for moderate (10–15 repetitions) sets. For circuit weight training, it is recommended that rest periods correspond to the time needed to get from one exercise station to another.	C
Low frequency (2–3 $d\cdot wk^{-1}$) is effective in novice individuals when training the entire body.	A
For intermediate training, 3 $d\cdot wk^{-1}$ is recommended for total-body workouts and 4 $d\cdot wk^{-1}$ is recommended for upper/lower body split routine workouts.	C
For advanced training, a higher frequency may be used (4–6 $d\cdot wk^{-1}$) if muscle group split routines are used.	C
It is recommended that intentionally slow velocities be used when a moderate number of repetitions (10–15) are used.	B
If performing a large number of repetitions (15–25 or more), then moderate to faster velocities are recommended.	B
Motor performance	
It is recommended that multiple-joint exercises be performed using a combination of heavy and light to moderate loading (using fast repetition velocity) with moderate to high volume in periodized fashion 4–6 $d\cdot wk^{-1}$ for maximal progression in vertical jumping ability. The inclusion of plyometric training (explosive form of exercise involving various jumps) in combination with resistance training is recommended.	B
It is recommended that the combination of heavy resistance and ballistic resistance exercise (along with sprint and plyometric training) be included for progression in sprinting ability.	B
Older adults	
For further improvements in strength and hypertrophy in older adults, the use of both multiple- and single-joint exercises (free weights and machines) with slow-to-moderate lifting velocity, for 1–3 sets per exercise with 60–80% of 1 RM for 8–12 repetitions with 1–3 min of rest in between sets for 2–3 $d\cdot wk^{-1}$ is recommended.	A
Increasing power in healthy older adults include: 1) training to improve muscular strength, and 2) the performance of both single- and multiple-joint exercises for 1–3 sets per exercise using light to moderate loading (30–60% of 1 RM) for 6–10 repetitions with high repetition velocity.	B
Similar recommendations may apply to older adults as young adults, e.g., low to moderate loads performed for moderate to high repetitions (10–15 or more) for enhancing muscular endurance.	B

(2–3 s) ECC phase, in the elderly. Low-to-moderate intensity (20–80% of 1 RM), high-velocity training has been tolerable in this population and consistently shown to enhance power production, strength, and performance of activities of daily living, for example, chair rise, and balance (29,53,57,107,115,124,199,200,243). In comparison to traditional RT, power training has been shown to produce similar (29,70) and inferior increases (185) in maximal strength, greater improvements in power (29,70), and greater functional performance enhancement (29,185). de Vos et al. (53) reported that power training with 50% of subjects' 1 RM led to the highest gains in muscle power, whereas RT with loads corresponding to 80% of subjects' 1 RM led to the highest gains in muscular strength and endurance. On the basis of these data, it appears prudent to include high-velocity, low-intensity movements in progression models for older adults.

Evidence category B. Increasing power in healthy older adults include 1) training to improve muscular strength and 2) the performance of both single- and multiple-joint exercises for one tot three sets per exercise using light to moderate loading (30–60% of 1 RM) for 6–10 repetitions with high repetition velocity (29,53,57,70,107,115,124,185,199,200,243).

Improvements in LME in the older adult may lead to an enhanced ability to perform submaximal work and recreational activities. Although studies examining LME training in the older adult are limited, LME may be enhanced by circuit RT (275), strength training (125), and high repetition, moderate-load programs (9) in younger populations. Multiple-set training led to 44.3–60.5% increases in LME, whereas single-set training led approxiamtely10% increases in individuals 65–78 yr of age (81).

Similar recommendations may apply to older adults as young adults, for example, low to moderate loads (40–70% of 1 RM) performed for moderate to high repetitions (10–15 or more) (81).

CONCLUSION

Progression in RT is dependent upon the development of appropriate and specific training goals and should be an "individualized" process using appropriate equipment, program design, and exercise techniques needed for the safe and effective implementation of a program. Trained and competent strength and conditioning specialists should be involved with this process to optimize the safety and design of a training program. Although examples and guidelines can be presented, ultimately the good judgment, experience, and educational training of the exercise professional involved with this process will dictate the amount of training success. Nevertheless, many exercise prescription options are available in the progression of RT to attain goals related to health, fitness, and physical performance.

This pronouncement was reviewed by the American College of Sports Medicine Pronouncements Committee and by Ira Jacobs, PhD, FACSM; Brian Schilling, PhD; Ann Swank, PhD, FACSM; Anthony Vandervoort, PhD, FACSM; and Joseph Weir, PhD, FACSM.

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