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A CRITICAL ANALYSIS OF THE ACSM POSITION STAND ON RESISTANCE TRAINING: INSUFFICIENT EVIDENCE TO SUPPORT RECOMMENDED TRAINING PROTOCOLS

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ABSTRACT

A CRITICAL ANALYSIS OF THE ACSM POSITION STAND ON RESISTANCE TRAINING: INSUFFICIENT EVIDENCE TO SUPPORT RECOMMENDED TRAINING PROTOCOLS. **Ralph N. Carpinelli, Robert M. Otto, Richard A. Winett**. **JEP**online 2004;7(3):1-60. In February 2002, the American College of Sports Medicine (ACSM) published a Position Stand entitled Progression Models in Resistance Training for Healthy Adults. The ACSM claims that the programmed manipulation of resistance-training protocols such as the training modality, repetition duration, range of repetitions, number of sets, and frequency of training will differentially affect specific physiological adaptations such as muscular strength, hypertrophy, power, and endurance. The ACSM also asserts that for progression in healthy adults, the programs for intermediate, advanced, and elite trainees must be different from those prescribed for novices. An objective evaluation of the resistance-training studies shows that these claims are primarily unsubstantiated. In fact, the preponderance of resistance-training studies suggest that simple, low-volume, time-efficient, resistance training is just as effective for increasing muscular strength, hypertrophy, power, and endurance—regardless of training experience—as are the complex, high-volume, time-consuming protocols that are recommended in the Position Stand. This document examines the basis for many of the claims in the Position Stand and provides an objective review of the resistance training literature.

Key Words**:** Strength, power, hypertrophy, muscular endurance

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INTRODUCTION

The American College of Sports Medicine (ACSM) published a Position Stand (1) entitled *Progression Models in Resistance Training for Healthy Adults*, which attempts to augment the ACSM's previous Position Stand (2) entitled *The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults*. The most recent Position Stand claims that the ACSM's previous resistance-training recommendation to perform 1 set of 8-12 repetitions 2-3 times/week for all the major muscle groups is effective for only previously untrained (*novice)* individuals, and that it did not include guidelines for those who wish to improve muscular strength, hypertrophy, power, and endurance beyond the beginning programs (p. 365).

The Position Stand states that its purpose is to provide guidelines for progression in *intermediate* trainees, who are defined in the Position Stand as those with approximately six months of consistent resistance training, for *advanced* trainees with years of resistance training, and for *elite* athletes who are highly trained and compete at the highest levels (p. 366).

Given the way that the ACSM has defined and categorized their target populations (intermediate, advanced, and elite trainees), the reader should expect that the Position Stand would first cite evidence to support their assumption that the target populations require training programs different from beginning programs, and then present supporting evidence (peer-reviewed resistance-training studies) for recommendations that are drawn exclusively from those specific demographics. Neither obligation is fulfilled in the Position Stand, thereby rendering the majority of claims in the Position Stand unsubstantiated.

The preponderance of published resistance-training research has used previously untrained subjects. Consequently, most of the studies cited in the Position Stand and in this document involved subjects with little or no resistance training experience (novices). Although the rate of progression tends to be greater in novices than in intermediate and advanced trainees, there is very little evidence to suggest that the resistance-training programs recommended for increasing muscular strength, hypertrophy, power, and endurance in novice trainees need to be different for intermediate and advanced trainees.

Because many resistance-training reviews and books may be inundated with misinterpretations of legitimate resistance training studies, and often contain unsubstantiated opinions, the only acceptable sources of supporting evidence are peer-reviewed resistance-training studies (primary sources). Therefore, secondary sources such as reviews and books are not acceptable as evidence, and consequently they are not discussed in this document.

Contrary to the ACSM's claim that Positions Stands are based on solid research and scientific data (3), we specifically demonstrate how the Position Stand based its claims and recommendations on selective reporting or misinterpretation of studies, and that the Position Stand represents merely the unsubstantiated opinions of its authors and the ACSM.

The entire burden of proof is on the authors of the Position Stand and the ACSM to support their claims and recommendations with resistance-training studies, and that proof must be based entirely on the evidence that was available prior to and throughout the preparation of their document. Because we do not claim that one resistance-training protocol is superior to another, it is not our responsibility to cite studies. However, in order to reveal the selective reporting of studies in the Position Stand, we cite a number of resistance-training studies that do not support the primary claim or recommendation in the Position Stand. All the studies we cite were in print and available to the authors of the Position Stand prior to its publication. Thus, our objective analysis of the Position Stand also relies exclusively on resistance training studies that were available prior to the publication of the Position Stand.

We address all the components of a resistance training program, which include the selection of a training modality (free weights and machines), repetition duration (speed of movement), range of repetitions, number of sets, rest between sets and exercises, types of muscle actions, and frequency of training. Because the ACSM and the authors of the Position Stand apparently believe that muscular endurance, power, and hypertrophy are differentially affected by various training protocols and that specific adaptations are affected by so-called *periodization*, they created separate categories for these topics. Therefore, we also address each of these issues separately.

Our document concludes with remarkably simple recommendations for resistance training, which are based on the preponderance of scientific evidence.

FREE WEIGHTS AND MACHINES

The Position Stand claims that multiple-joint exercises such as the bench press and squat are generally regarded as most effective for increasing overall muscular strength because they enable a greater magnitude of weight to be lifted (p. 368). Only a review by Stone et al. (4) is cited in an attempt to support that claim.

The Position Stand claims that resistance exercise machines are safer to use, easier to learn, allow the performance of some exercises that may be difficult with free weights, help stabilize the body, and focus on the activation of specific muscles (p. 368). The only reference cited is an article by Foran (5), which is a brief opinion about machines that states nothing related to—and therefore does not support—the opinions expressed in the Position Stand.

The Position Stand claims that resistance training with free weights results in a pattern of intra- and inter-muscular coordination that mimics the movement requirements of a specific task and that emphasis should be placed on free-weight exercises for advanced resistance training, with machine exercises used to complement the program (p. 368). There is no reference cited to support either opinion.

Only a few studies (6-8) have compared the effects of free weights and machines on muscular strength. Boyer (6) randomly assigned 60 previously untrained females (19-37 years) to one of three resistance-training programs. All subjects performed 3 x 10 RM (i.e., 3 sets of 10 repetitions where RM denotes a maximal effort on the last repetition of a set) wk 1-3, 3 x 6 RM wk 4-6, and 3 x 8 RM wk 7-12 on two lower-body and five upper-body exercises 3x/wk for 12 weeks. They exercised similar muscle groups using free weights, Nautilus® machines, or Soloflex® machines, which utilize rubber weight straps for resistance. There was a significant pre- to post-training decrease in thigh (16.6, 14.5 and 14.5 %), arm (15.8, 8.9 and 17.1 %) and iliac (4.2, 7.3 and 9.6 %) skin-folds, and percent body fat (9.6, 6.2 and 9.6 %) for the free-weight, Nautilus® and Soloflex® groups, respectively, with no significant difference between the groups for any anthropometric variable. The free-weight group showed significantly greater gains than the Nautilus® group when tested on the equipment used for training: 1 RM bench press (24.5 and 15.3 %), behind-the-neck press (22.3 and 10.9 %), and leg sled (15.5 and 11.2 %), for free-weight and Nautilus® groups, respectively. The Nautilus® group showed significantly greater gains than the free-weight group when tested on the Nautilus® machines: bench press (23.3 and 47.2 %), lateral raise (19.4 and 46.8 %), and leg press (17.1 and 28.2 %), for the free-weight and Nautilus® groups, respectively. Overall, the average strength gain in the free-weight group was 20.4 % (Nautilus and free-weight equipment combined), while the Nautilus® group increased 26.6 % (Nautilus and free-weight equipment combined). Interestingly, the Soloflex® group significantly increased strength by 29.5 % when tested on the Soloflex® machine and 15.1 % when tested on the other modalities. Boyer (6) concluded that although the strength gains were significantly greater when each group was tested on their training modality, the programs produced comparable changes in muscular strength and body composition.

Sanders (7) randomly assigned 22 college students to a free-weight (bench press and behind-the-neck seated press) or Nautilus® (chest press and shoulder press machines) training group. All subjects performed 3 x 6 RM 3x/wk for five weeks. They were tested pre- and post-training for 3-minute bouts of rhythmic isometric exercise (maximal muscle actions every other second) for the elbow extensors at 90° and shoulder flexors at 135°. Initial and final strength levels were measured by using the average of three successive muscle actions at each 15-second time interval. A strength decrement during each test was obtained by subtracting the final strength from the initial strength. Results revealed that elbow extensor strength significantly increased in the free-weight (~22 %) and Nautilus® groups (~24 %). Shoulder flexor strength significantly increased following free weight training (~12 %) and Nautilus® training (~13 %). There was no significant difference between the free weight and Nautilus® groups for initial strength, final strength, or strength decrement. Sanders (7) concluded that free weights and Nautilus® machines were equally effective for developing muscular strength and endurance.

Silvester et al. (8) reported the results of two experiments comparing free weights and machines. In experiment #1, 60 previously untrained college-age males were randomly assigned to one of three groups who performed 1 x 4-16 RM for the lower-body exercises using a Nautilus® machine, Universal® machine (2 x 7-15), or free-weight squats (3 x 6). The intensity for the Universal® and free-weight groups was not specified. The

Nautilus® and free-weight groups completed each repetition in three seconds, while the Universal® group did not exceed two seconds for each repetition. The Universal® and free-weight groups trained 3x/wk for 11 weeks, while the Nautilus® group trained 3x/wk for the first six weeks and 2x/wk for the last five weeks. There was a significant increase in vertical jump height (0.2, 1.0, and 1.3 %, for Nautilus®, Universal®, and free-weight groups, respectively). Silvester et al. (8) noted that it appeared that the Universal® and free-weight groups improved to a greater extent than the Nautilus® group, with no significant difference between the Universal® and free-weight groups. However, later in their Discussion they state that the increases in vertical jump were equal (p. 32). There was a significant increase in lower-body strength (8.6, 9.7, and 12.5 %, for Nautilus®, Universal®, and free-weight groups, respectively), with no significant difference among the groups. Different numbers of sets and repetitions, intensity, repetition duration, frequency of training, and types of equipment did not result in significantly different gains in strength.

In experiment #2, Silvester et al. (8) randomly assigned 48 previously untrained college-age males to one of four groups who performed barbell curls for either one set or three sets of six repetitions with 80 % 1 RM, or one set or three sets of 10-12 RM Nautilus® machine curls 3x/wk for eight weeks. The four groups significantly increased elbow-flexion strength at four angles (70, 90, 135, and 180°) after training with one set of barbell curls (23 %), three sets of barbell curls (30 %), one set of Nautilus® machine curls (25 %) or three sets of machine curls (19 %). There was no significant difference in strength gains among the groups at any angle. Silvester et al. (8) concluded that one set is just as effective as three sets, and that it does not appear to matter which modality of resistance training (free weights or machines) is chosen.

In summary, there is no scientific evidence cited in the Position Stand to support the superiority of free weights or machines for developing muscular strength, hypertrophy, power, or endurance (Table 1). Either training modality or a combination of modalities appears to be effective.

Table 1 provides a summary of the studies in this section and their relative support, or lack of support, for the Position Stand. The order of presentation in Table 1 and the level of support for each study follow the descriptions in the narrative. Summary tables using the same format are provided in subsequent sections.

Table 1. Summary of Research Comparing Free Weights and Machines.

Reference	Rating
Boyer (6)	*
Sanders (7)	*
Silvester et al. (8)	↓

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

REPETITION DURATION

The Position Stand often incorrectly refers to the *duration* of a repetition or muscle action as *velocity* of muscle action (p. 368). For example, a 1 s concentric muscle action coupled with a 1 s eccentric muscle action is actually a description of a shorter duration repetition, while a 10-second concentric muscle action and 4 s eccentric muscle action is a longer duration repetition. Seconds do not describe the velocity of muscle action. Speed of movement may be expressed in °/s or radians/s for rotational motion, and cm/s for linear movement.

The Position Stand claims that muscle actions that are less than 1 to 2 s duration have been shown to be more effective than longer durations for increasing the rate of strength gain (p. 369), and they cite a study by Hay et al. (9). Hay et al. (9) compared the resultant joint torque in three resistance-trained males (~33 years). The subjects used different loads and rates of lifting while performing seated curls with a barbell as well as with a curling device on a machine. Hay et al. (9) noted that when the duration of the lift was less than two seconds, very little torque was required to maintain momentum during the latter half of the lift. That is, faster lifting made the exercise easier (less intense). Antithetically, and without any rationale, Hay et al. (9) expressed their opinion that for a given load, a faster rate of lifting (shorter duration) is likely to yield a slightly better rate of strength development than slower rates of lifting (longer duration). However, because this was not a training study, there is no evidence to support the opinion of Hay et al. (9) or the claim in the Position Stand.

In support of shorter repetition durations, the Position Stand cites a study by Keeler et al. (10) who randomly assigned 14 previously untrained females (~33 years) to either a *traditional* (2 s concentric/4 s eccentric) or *super-slow* (10 s concentric/5 s eccentric) resistance-training protocol. A stopwatch was used to monitor repetition duration. All subjects performed 1 set of 8-12 repetitions to muscular fatigue for each of eight exercises 3x/wk for 10 weeks. The traditional group initiated the program with 80 % 1 RM, while the super-slow group used 50 % 1 RM. Both groups significantly increased 1 RM for all eight exercises, with the traditional group showing significantly greater gains in five out of the eight individual exercises and a significantly greater overall increase in strength (39 %) compared with the super-slow group (15 %). There was no significant change in body mass, percent fat, lean body mass or body-mass index in either group.

The results reported by Keeler et al. (10) suggest that the 2 s/4 s repetition duration produced significantly greater gains in some strength measures compared with a 10 s/5 s protocol. However, the small strength gains for the super-slow group (e.g., ~7 % leg press and ~11 % bench press) in previously untrained females after 10 weeks of resistance training suggest that the protocol selected for the super-slow group (8-12 repetitions with 50 % 1RM) was remarkably ineffective.

Westcott et al. (11) reported the results of two studies that were conducted in a recreational training center. Although the 147 previously untrained males and females (25-82 years) were not randomly assigned, they chose a specific time to train based on their schedule without knowing whether the *traditional* (shorter repetition duration) or *super-slow* protocol (longer repetition duration) was assigned to a specific group. The traditional group performed 8-12 repetitions using a 2 s concentric, 1 s isometric, and 4 s eccentric duration, while the super-slow group performed 4-6 repetitions with 10 s concentric and 4 s eccentric muscle actions. Intensity was not described for either group. Strength was assessed using a 5 RM in the super-slow group and 10 RM in the traditional group. Westcott et al. (11) claimed that the time under load (~70 s) was similar for both groups during testing and training. Both groups performed one set for each of 13 exercises 2-3x/wk for 8-10 weeks. In the first study, the super-slow group showed significantly greater strength gains (59.1 %) for the 13 exercises compared with the traditional group (39.0 %). In the second study (only the results of the chest-press exercise were reported), the super-slow group also showed a significantly greater strength gain (43.6 %) compared with the traditional group (26.8 %). Westcott et al. (11) did not use a metronome or any other timing device to measure repetition duration (the independent variable) during either the testing or the training in either study. Therefore, because there was no control for the independent variable, any conclusion from this study (11) relative to repetition duration should, at best, be regarded as questionable.

In summary, neither of these studies by Keeler et al. (10) or Westcott et al. (11) provides sufficient evidence to support the advantage of one repetition duration over another.

The Position Stand claims that compared with longer repetition durations, moderate (1-2 s concentric/1-2 s eccentric) and shorter (<1 s concentric/1 s eccentric) durations have been shown to be more effective for enhanced muscular performance (p. 369). Studies by LaChance and Hortobagyi (12) and Morrissey et al. (13) are cited. LaChance and Hortobagyi (12) reported the acute effects of different repetition durations (*fast self-paced*, 2 s concentric/2 s eccentric, and 2 s concentric/4 s eccentric) for push-up and pull-up exercises in 75 moderately trained college-age males. The exercise was terminated when a subject was unable to complete a full range of motion or maintain prescribed duration. The self-paced duration resulted in a greater number of repetitions performed, and greater concentric work and power than the longer repetition durations for both pull-up and push-up exercises. The number of push-ups (sixty-four) and pull-ups (eleven) in the self-paced trial was significantly greater than the 2 s/2 s protocol (thirty-eight and seven), and the 2 s/4 s protocol (twenty-six and six), push-ups and pull-ups, respectively. All the exercises were performed with the same resistance (an estimated percent of the subject's body mass). Therefore, the results suggest that the longer duration repetitions were harder (greater intensity) than the shorter, self-paced duration. Because this was not a training study (12), the opinion stated in the Position Stand that shorter duration repetitions are more productive than longer durations is relevant only to the acute demonstration of a specific muscular performance, with no evidence that the specific performance will transfer to other demonstrations of muscular performance, and more importantly, no evidence to suggest that shorter repetition durations will stimulate superior adaptations for enhancing muscular performance.

Morrissey et al. (13) randomly assigned 24 previously untrained females (~24 years) to perform six sets of free-weight squats (50 % 8 RM set 1, 75 % 8 RM sets 2-3, 8 RM sets 4-6) 3x/wk for seven weeks. The longer-duration group used a 2 s concentric/2 s eccentric repetition duration (2 s/2 s) and the shorter-duration group used 1 s concentric/1 s eccentric (1 s/1 s). A custom made device was used to cue the subjects to the appropriate repetition duration. There was a significant increase in horizontal long-jump distance in both the 1 s/1 s (44 %) and 2 s/2 s (31 %) groups, but Morrissey et al. (13) did not state whether the difference between groups was significant. Improvement in vertical jump was significant only in the 1 s/1 s group (12 %), although the authors noted that the percent change in the 2 s/2 s group (20 %) exceeded that of the 1 s/1 s group. The pre- to post-training increases in concentric work on an isokinetic dynamometer were significant for all test velocities in the shorter-duration group and were not significant for the longer-duration group. However, Morrissey et al. (13) specifically noted that both groups significantly improved in all the numerous variables that have practical significance, including the 1 RM slow squat (26 and 31 %), 1 RM fast squat (30 and 26 %), vertical jump peak force rate (59 and 62 %), peak power (10 and 9 %), average power (35 and 30 %), long jump peak force rate (77 and 73 %), peak power (17 and 22 %), average power (27 and 37 %), and knee extension isometric peak torque (13 and 16 %), for the 2 s/2 s and 1 s/1 s groups, respectively. There was no significant difference between groups for any of these variables. Morrissey et al. (13) concluded that the squat tests did not support the concept of a specificity of velocity (repetition duration) for resistance training.

The Position Stand claims that studies have shown that using shorter repetition durations with moderately high resistance (not defined) are more effective for advanced training than longer durations (p. 369). However, the references cited (14-15) do not support this opinion. Jones et al. (14) randomly assigned 30 males (~20 years), who were Division I baseball players with approximately three years resistance training experience, to a high-resistance or low-resistance group. The high-resistance group performed 3-10 repetitions with 70-90 % 1 RM and the low-resistance group used 40-60 % 1 RM for 5-15 repetitions. All subjects performed three full range-of-motion sets and one partial range of motion set, with two minutes rest between sets for each of four exercises (parallel squat, dead lifts, lunges, and partial squats) 2x/wk for 10 weeks. All the trainees in both groups attempted to move the resistance as rapidly as possible during the concentric phase of each repetition. Neither repetition duration nor velocity of movement was reported for any of the four exercises. Subjects were tested for maximal performance: peak power, force, and velocity in the set angle jump (140°), countermovement jumps with 30 and 50 % 1 RM, and depth jumps at 27 cm. There was no significant difference between the high-resistance (70-90 % 1 RM) and low-resistance (40-60 % 1 RM) groups for any of the 12 performance outcomes. Jones et al. (14) assessed strength using a 1 RM parallel squat. The gain in the high-resistance group (presumably the longer repetition duration) was significantly greater than the low-resistance (shorter duration) group (16.3 and 11.5 %, respectively). Jones et al. (14) stated two times in their Abstract and eight times in their Discussion and Practical Application sections that the *trends* in their data are supportive of a specificity of training, which obviously conflicts with the results of their own statistical analysis. Thus, the actual results reported by Jones et al. (14) contradict the claim in the Position Stand.

Moss et al. (15) assigned 31 well-trained (not defined) males (~23 years) to one of three groups that performed unilateral elbow flexion exercise 3x/wk for nine weeks (3 sets wk 1, 4 sets wk 2-5, and 5 sets wk 6-9). The groups performed two, seven or 10 repetitions per set using 90, 35 or 15 % 1 RM (groups G90, G35 and G15, respectively). Moss et al. (15) attempted to make the total contractile time similar for the three groups, which was reported as 3.5 s in each set of repetitions. However, they did not report repetition duration or angular velocity. All subjects were encouraged to perform each lift as fast as possible. As measured by computerized tomography, mean cross-sectional area of the elbow flexors showed a small significant increase (2.8 %) in G35. G90 and G35 showed a significant increase in power at all loads (2.5 kg, 15, 25, 35, 50, 70, and 90 % of pre-training 1 RM). There was no significant difference in power between G90 and G35 at any load. Angular velocity significantly increased at all loads, with no significant difference between G90 and G35. There was a significant increase in 1 RM in G90 (15.2 %), G35 (10.1 %), and G15 (6.6 %), with no significant difference between G90 (presumably the longer repetition duration) and G35 (presumably a shorter repetition duration). The results reported by Moss et al. (15) do not support the claim in the Position Stand.

In summary, the studies by Jones et al. (14) and Moss et al. (15) render the claim in the Position Stand unsubstantiated.

Three studies, involving previously untrained participants that compared repetition durations using free weights (16-17) and free weights and machines (18), were not cited in the Position Stand. Berger and Harris (16) arbitrarily divided 69 male college students into three resistance training groups who performed one set of the free-weight bench-press exercise 3x/wk for eight weeks. The shortest-duration group executed an 18-20 RM at a duration of ~1.3 s/rep, the intermediate-duration group used an 8-10 RM at ~2.8 s/rep, and the longest-duration group performed four repetitions with an 18-20 RM load for a duration of ~6.3 s/rep. Total time for the set was similar for the three groups (25 s). All the subjects performed the sets with a maximal effort for their specific repetition duration. There was a significant increase in 1 RM bench press in the shortest (15.2 %), intermediate (17.7 %), and longest duration (17.7 %) groups, with no significant difference among the groups. Absolute muscular endurance (with 50 % initial 1 RM) significantly increased in the three groups (30.3, 27.5, and 38.2 %, respectively), with no significant difference among the groups. Berger and Harris (16) concluded that the three repetition durations were equally effective for increasing muscular strength and endurance.

Young and Bilby (17) reported the results of resistance training with the free weight barbell squat. Eighteen males (19-23 years) were randomly assigned to one of two experimental groups: one group exploded on the concentric phase of the repetition (shorter-duration group), while the other group performed the concentric portion in what the authors described as a slow and controlled manner to minimize acceleration (longer-duration group). All subjects followed a similar training protocol of four sets of 8-12 RM 3x/wk for 7½ weeks. Both groups showed a significant improvement on maximal rate of force development (68.7 and 23.5%), vertical jump (4.7 and 9.3 %), absolute (21.0 and 22.5 %) and relative (19.5 and 20.4 %) 1 RM, absolute (21.0 and 22.5 %) and relative (19.5 and 20.4 %) isometric peak force, middle (2.1 and 2.2 %) and distal (5.0 and 4.4 %) thigh circumference, vastus intermedialis (24.4 and 21.0 %) and rectus femoris (1.4 and 1.5 %) thickness, and body mass (1.2 and 1.9 %), for shorter-duration and longer-duration groups, respectively. There was no significant difference between groups for any of the measured variables.

Palmieri (18) randomly assigned 54 previously untrained subjects (18-23 years) to one of three training groups: longer-duration, shorter duration, or a combination of longer and shorter repetition durations. All the groups trained the lower body 3x/wk using barbell squats and three machine exercises. For the free-weight squats, all subjects followed a multiple-set program that varied the number of sets, repetitions, and percent 1 RM (2-3 sets of 1-10 repetitions at 53-97 % 1 RM) throughout the 10-week study. Subjects in the shorter-duration group performed the concentric phase of the free-weight squat in three-quarters of a second or less, while those in the longer-duration group executed the concentric portion in two seconds or more. The combination group followed the longer-duration protocol for six weeks and then switched to the shorter-duration protocol for the remaining four weeks. All subjects used a 4 s duration for the eccentric phase of each repetition. Palmieri (18) attempted to estimate lower-body *power* (functional performance) by using the subject's vertical jump height and body mass. The three groups showed a significant increase in lower-body functional performance (3.7, 3.8 and 3.2 %) and 1 RM squat (25, 20, and 20 %, longer-duration, shorter-duration, and combination groups, respectively), with no significant difference among the groups for either measure. When the combination group switched from the longer-duration protocol to the shorter-duration protocol, there was no increase in either 1 RM squat or lower-body functional performance for the remaining four weeks. Palmieri (18) concluded that training with longer, shorter or combination of longer and shorter repetition durations will produce similar gains in lower-body strength and functional performance.

The Position Stand recommends that advanced trainees use *unintentionally slow* to *fast training velocities* in order to maximize strength (p. 369). There is no evidence cited to support this recommendation.

In summary, there is very little evidence to support the superiority of any specific repetition duration for developing muscular strength, hypertrophy, power, or endurance (Table 2).

Table 2. Summary of Research Comparing Repetition Duration.

Reference	Rating
Berger & Harris (16)	*
Hay et al. (9)	↓
Jones et al. (14)	↓
Keeler et al. (10)	↑
LaChance & Hortobagyi (12)	↓
Morrissey et al. (13)	↓
Moss et al. (15)	↓
Palmieri (18)	*
Westcott et al. (11)	?
Young & Bilby (17)	*

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.
? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.
↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.
* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

RANGE OF REPETITIONS

The Position Stand claims that several pioneering studies reported that training with 1-6 RM, and more specifically with 5-6 RM, is most effective for increasing maximal dynamic strength (p. 367). Three studies (19-21) are cited.

Berger (19) trained 199 male college students who performed one maximal set of the free-weight bench press 3x/wk for 12 weeks. Training for each of the six groups differed in the number of repetitions performed: 2 RM, 4 RM, 6 RM, 8 RM, 10 RM, or 12 RM. Although Berger (19) only reported the post-training means, his analysis of covariance revealed a significantly greater gain in strength (1 RM) for the 4 RM, 6 RM, and 8 RM groups compared with the 2 RM group, with no significant difference between the 4 RM, 6 RM, and 8 RM groups. The 4 RM and 8 RM groups showed a greater increase than the 2 RM and 10 RM groups. The strength gain for the 8 RM group was significantly greater than the 2 RM, 10 RM, and 12 RM groups, with no significant difference between the 2 RM, 10 RM, and 12 RM groups. Contrary to the claim in the Position Stand, Berger (19) reported that the 6 RM group produced strength gains that were not significantly different from the 4 RM and 8 RM groups (Table 2, p. 337).

O'Shea (20) randomly assigned 30 young, previously untrained, male college students to perform three sets of free-weight barbell squats 3x/wk for six weeks using one of three repetition ranges: 2-3 RM, 5-6 RM, or 9-10 RM. There was a significant increase in dynamic 1 RM squat (21.8, 26.7, and 20.4 %, 2-3 RM, 5-6 RM and 9-10 RM groups, respectively), static strength on a lower-body dynamometer (23.2, 15.5, and 21.1 %, 2-3 RM, 5-6 RM and 9-10 RM groups, respectively), and thigh girth (3-6 %). There was no significant difference among the groups for any of the changes. O'Shea (20) concluded that the three training protocols resulted in similar improvements in thigh girth, static strength and dynamic strength.

Weiss and colleagues reported the effects of resistance training with different ranges of repetitions on muscular strength in one publication (21) and hypertrophy in another (22). They randomly assigned 44 males (18-30 years), who were not previously engaged in any systematic physical training, to one of three training groups or a control group. Subjects performed four sets of free-weight barbell squats to muscular fatigue 3x/wk for seven weeks using a 3-5 RM, 13-15 RM, or 23-25 RM protocol. The three training groups significantly increased isokinetic knee-extensor strength (percent change not reported), with no significant difference among the groups. They also significantly increased 1 RM squat, with the 3-5 RM group showing a significantly greater increase than the 23-25 RM group, but not significantly greater than the 13-15 RM group (21). Weiss et al. (22) reported quadriceps muscle thickness using ultrasound. The three training groups significantly increased quadriceps muscle thickness, with no significant difference among the three protocols. Weiss et al. (21-22) concluded that performance of four sets of barbell squats within the range of 3 RM to 15 RM three days a week for seven weeks elicits similar increases in quadriceps thickness and strength.

In summary, the aforementioned studies (19-21) fail to support the claim in the Position Stand.

While some individuals may prefer a lower or higher range of repetitions for different muscle groups or for simple variation in their training, there is very little evidence to support the specificity of any particular range of repetitions. Although most resistance-training research involves previously untrained subjects, several other studies (23-26) in this population also suggest that particular outcomes are not related to a specific range of repetitions.

Bemben et al. (23) trained 25 females (41-60 years) 3x/wk for six months with either eight repetitions at 80 % 1 RM or 16 repetitions at 40 % 1 RM. Three sets for each of three lower-body and five upper-body exercises were executed on resistance machines, but only one set for each of four additional lower-body exercises: hip flexion, extension, abduction, and adduction. Three sets of exercise produced an average increase in strength of approximately 25 %, while one set produced almost twice the increase of about 49 %. Strength gains were similar as a result of performing different numbers of repetitions using either heavier or lighter resistance. That is, ~27 and ~22 %, 8-repetition and 16-repetition groups, respectively, for 3-set exercises, and ~44 and ~52 %, 8-repetition and 16-repetition groups, respectively, for 1 set exercises. As measured with ultrasound, both training groups showed significant improvements in rectus femoris cross-sectional area (~20 %) and biceps brachii cross-sectional area (~30 %), with no significant difference between groups.

Chesnut and Docherty (24) randomly assigned 24 previously untrained males (~24 years) to either a 4 RM or 10 RM group. Subjects exercised 3x/wk for 10 weeks performing seven upper-body exercises for 1-6 sets each. Both the 4 RM and 10 RM groups, respectively, significantly increased 1 RM elbow flexor strength (~13 and ~11 %) and elbow extensor strength (~22 and ~28 %), as well as the dynamic training load for the elbow flexors (~20 and ~25 %) and extensors (~22 and ~28 %), with no significant difference between the 4 RM and 10 RM groups for any of the strength gains. Both the 4 RM and 10 RM groups showed a significant increase in arm circumference (~2 and ~2.5 %, respectively) and cross-sectional area measured by MRI (~6 and ~7 %, respectively), with no significant difference between groups. Chesnut and Docherty (24) concluded that the 4 RM and 10 RM training protocols elicited similar increases in strength, muscle cross-sectional area and arm circumference.

Graves et al. (25) instructed 10 pairs of previously untrained identical twins (~19 years) to exercise the quadriceps muscles 2x/wk for 10 weeks. One of each twin performed one set of 7-10 RM and the matched twin executed one set of 15-20 RM variable resistance bilateral knee-extension exercise. Both groups had a significant increase in strength (13.2 and 12.8 %, 7-10 RM and 15-20 RM groups, respectively). There was no significant difference in the magnitude of strength gains between the identical twins, which were quintessentially matched groups.

Pruitt et al. (26) randomly assigned 26 females (65-82 years) to a control group or one of two progressive resistance-training groups (7 repetitions at 80 % 1 RM, or 14 repetitions at 40 % 1 RM), who performed three sets for each of 10 exercises 3x/wk for 52 weeks. Arm strength showed a significantly greater increase in the higher-repetition group (65.5 %) compared with the lower-repetition group (27.4 %). However, both groups (lower-repetition and higher-repetition, respectively) had significant gains in 1 RM for chest (10.1 and 15.4 %), shoulders (18.5 and 27.4 %), upper back (41.4 and 21.0 %), lower back (35.8 and 35.4 %), hips (50.9 and 66.4 %), and legs (47.6 and 42.4 %). There was no significant difference between groups in six out of seven outcomes.

All these studies (19-26) strongly suggest that within a reasonable range of repetitions, approximately 3 to 20, there does not appear to be a specific number of repetitions (e.g., 4-6, 7-10, 12-15, etc.) that will elicit more favorable gains in muscular strength, power, or hypertrophy. Therefore, the claim in the Position Stand that specific ranges of repetitions produce specific outcomes has very little scientific foundation.

Bone Mineral Density

The effect of the range of repetitions, and consequently, the amount of resistance, on bone mineral density is not discussed in the Position Stand, but may be relevant to establishing resistance-training protocols. For example, Kerr et al. (27) randomly assigned 56 previously untrained females (~57 years) to one of two resistance-training programs using free weights and machines 3x/wk for 52 weeks. All subjects performed three sets for each of five upper-body and five lower-body exercises, with 2-3 minutes rest between sets. One group used an 8-10 RM protocol and the other performed 20-25 RM. The exercising limb was allocated by randomization to either the left or right side with the contralateral limb acting as the non-exercising control. By using each subject as her own control, genetic and environmental aspects of bone density were controlled. Muscle strength (1 RM) significantly increased for all 10 exercises with no significant difference between the 8-10 RM group (~75 %) and the 20-25 RM group (~69 %). However, only the 8-10 RM group significantly increased bone density (measured by dual-energy x-ray absorptiometry) in both the upper and lower limbs compared with their non-exercised contra-lateral limbs.

Taaffe et al. (28) randomly assigned 36 previously untrained females (65-79 years) to a control group or one of two progressive resistance training protocols: 7 repetitions with 80 % 1 RM, or 14 repetitions with 40 % 1 RM. The two training groups performed three sets of leg-press, thigh-curl and knee-extension exercises 3x/wk for 52 weeks. Both the low-repetition and high-repetition groups, respectively, showed a significant increase in 1 RM leg press (~49 and 30 %), thigh curl (~62 and 81 %), and knee extension (~82 and 60 %), with no significant difference between the two training groups. However, the low-repetition group retained bone mineral density, while the high-repetition and control groups lost a significant amount (~2 %) of bone mineral density.

Table 3. Summary of Research Comparing Repetition Range.

Reference	Rating	
Bemben et al. (23)		*
Berger (19)	↓	
Chestnut & Docherty (24)		*
Graves et al. (25)		*
Kerr et al. (27)		*
O'Shea (20)	↓	
Pruitt et al. (26)		*
Taaffe et al. (28)		*
Weiss et al. (21)	↓	
Weiss et al. (22)		*

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.
? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.
↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.
* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

These two studies (27-28), in addition to the previously discussed studies (19-26) suggest that different ranges of repetitions produce similar strength gains. However, fewer repetitions with a heavier load may be required to increase bone density. In addition, based on the site-specific response of bone to exercise reported by Kerr et al. (27), a wide variety of exercises with a heavier rather than lighter resistance should probably be employed in order to stimulate maximal increases in bone density throughout the body.

The Position Stand recommends a specific range of repetitions for different outcomes such as muscular strength, hypertrophy, power, and endurance (p. 374). There are no references cited to support that recommendation.

In summary, the claim in the Position Stand that different ranges of repetitions specifically affect muscular strength, hypertrophy, power, and endurance is unsubstantiated (Table 3).

MULTIPLE SETS

The Position Stand claims that several studies reported multiple-set programs superior to single-set programs (p. 367) in previously untrained subjects (29-32), untrained subjects in long-term (~6 months) studies (33-34), and resistance-trained individuals (35-38). However, a close examination reveals that most of the studies cited do not support the claims in the Position Stand.

Previously Untrained Subjects

Berger (29) instructed nine groups of college-age males (N = 177) to perform the free-weight bench press as part of their beginning weight-training program using one of nine combinations of sets and repetitions (1 x 2 RM, 1 x 6 RM, 1 x 10 RM, 2 x 2 RM, 2 x 6 RM, 2 x 10 RM, 3 x 2 RM, 3 x 6 RM, or 3 x 10 RM) 3x/wk for 12 weeks. There was no control for the number of sets or repetitions performed for any of the other exercises in the program, and the participants were not equated or randomized before training. When Berger (29) combined his nine resistance-training groups according to the number of sets performed (1, 2 or 3 sets), he reported a significantly greater increase in 1 RM bench press as a result of performing three sets (25.5 %) compared with one set (22.3 %) or two sets (22.0 %). There was no significant difference between the 1-set and 2-set groups. Using an analysis of covariance to test for any significant interaction between sets and repetitions, Berger (29) noted that training with one, two, or three sets in discrete combination with two, six, or 10 repetitions (interaction) was not systematically more effective in improving strength than other combinations. Berger (29) reported no significant interaction, but then concluded that the combination of three sets and six repetitions was more effective than any other combination of sets and repetitions. In fact, Berger (29) reported no significant difference in the magnitude of strength gains in seven out of nine of his comparisons between groups who performed the same number of repetitions (two, six, or ten repetitions) for one, two, or three sets (Table 4, p. 176). Thus, this seminal study by Berger (29), which is frequently cited in support of multiple sets, shows that the majority of outcomes do not favor multiple sets.

Sanborn et al. (30) randomly assigned 17 previously untrained females (18-20 years) to either a single-set (8-12 reps) or multiple-set group (3-5 sets of 2-10 repetitions). All participants trained 3x/wk, involving the completion of five of the exercises 1x/wk and the other five exercises (including the squat) 2x/wk for eight weeks. Both groups showed a significant increase in 1 RM squat, with no significant difference between the single-set (24.2 %) and multiple-set groups (34.7 %). The increase in vertical jump was significantly greater in the multiple-set group (11.2 %) compared with the single-set group (0.3 %). However, the multiple-set group was encouraged to drive up on the balls of their feet when executing the squat, thereby involving additional muscle groups (gastrocnemius and soleus), which contribute to vertical jump performance. There was no explanation why these instructions were given to the multiple-set group and not to the single-set group. There was no significant change in body mass in either group. This study by Sanborn et al. (30) fails to substantiate the superiority of multiple-set protocols for increasing muscular size or strength.

Stone et al. (31) trained 34 previously untrained males 3x/wk for five weeks. There were different training modalities (8 machines and 9 free-weight exercises), different number of sets (1 set for all machines and 3-7 sets of free-weight exercises), and different number of repetitions (2, 12, or 15 for the machines, and 3, 6, 10, or 12 for free-weight exercises), executed at different *velocities* (maximum velocity for the free-weight exercises). Stone et al. (31) claimed that the free-weight group (3-7 sets) had a significantly greater increase in squat strength and vertical jump compared with the machine group (1 set). However, the authors also reported no significant difference in machine leg press strength, no significant increase in what they described as *power* (vertical jump and the Lewis formula) and no significant increase in body mass in either group. Stone et al. (31) did not report any pre- or post-training data or the percent change for any of the variables, which leaves this study open to different interpretations.

Stowers et al. (32) compared the effects of resistance training in subjects who performed four exercises 1x/wk, and four exercises (including the squat and bench press) 2x/wk for seven weeks. The 84 previously untrained college-age males were randomly assigned to either 1 x 10 RM, 3 x 10 RM, or a varied multiple-set protocol (5 x 10 wk 1-2, 3 x 5 wk 3-5, and 3 x 3 wk 6-7). Intensity was not described for the varied multiple-set group. All groups significantly increased 1 RM squat, with the varied multiple-set group (~25 %) showing a significantly greater increase than the 1-set (~16 %) and 3-set (~18.5 %) groups. Only the varied multiple-set group significantly increased vertical jump height (~10 %). The three groups showed a significant increase in 1RM bench press (~8.5 %), with no significant difference among groups. There was no significant difference between the 1-set and 3-set groups at the end of the 7-week study, and no significant increase in body mass in any group.

In summary, only one study (29) out of the four studies (29-32) cited in the Position Stand in support of multiple sets, which involved previously untrained participants, reported a small but statistically significant benefit for a multiple-set protocol.

Previously Untrained Subjects in Long-Term Studies

Borst et al. (33) recruited 31 healthy, sedentary males and females (~38 years) who were stratified by sex and quadriceps strength into one of three groups: single-set resistance training, multiple-set, or non-exercising control. The 1-set and 3-set groups performed seven exercises on a circuit of machines using an 8-12 range of repetitions to muscular fatigue 3x/wk for 25 weeks. The 3-set group (3 circuits) had a significantly greater increase in strength (~48 %) compared with the 1-set group (~32 %). There was no reported change in body mass or body composition in either group.

Marx et al. (34) randomly assigned 34 previously untrained females (~23 years) to a single-set, multiple-set, or control group for six months of resistance training. The single-set group trained 3x/wk performing one set of 8-12 RM for each exercise on two alternating circuits of 10 machines. The multiple-set group trained 4x/wk and performed 2-4 sets of 8-10 RM on Tuesday and Friday, and 3-5 RM, 8-10 RM, or 12-15 RM on Monday and Thursday on 7-12 free-weight and machine exercises. The multiple-set group showed a significantly greater strength gain in 1 RM bench press (46.8 %) and leg press (31.9 %) compared with the single-set group (12.2 and 11.2 %, bench press and leg press, respectively). There was no significant increase in lean body mass or decrease in percent body fat in the single-set group, while the multiple-set group showed a significant 3.3 kg increase in lean body mass and a significant decrease in percent body fat from 26.5 to 19.8 %.

In summary, both of these long-term (~6 months) studies (33-34) support the superiority of multiple sets in previously untrained subjects.

There are a plethora of studies (8, 23-24, 39-61) that show no significant difference in the magnitude of strength gains or muscle hypertrophy (whenever hypertrophy was measured) as a result of performing a greater number of sets. For example, Hass et al. (46) randomly assigned 42 males and females (20-50 years) to either a 1-set or

3-set protocol of 8-12 RM for each of nine exercises, which were completed in a circuit 3x/wk for 13 weeks. Subjects had been regularly performing resistance exercise 2.7x/wk for an average 6.2 years (minimum 1 year), which qualified them as *advanced* trainees according to the Position Stand. Each session was conducted and monitored by the investigators, with both groups progressing similarly and exerting equivalent efforts based of a rating of perceived exertion. The average increase in isometric knee extension torque (6.3 and 6.6 %, 1-set and 3-set groups, respectively), and isometric knee flexion torque (7.7 and 15.6 %) were not significantly different between groups. The significant increase in absolute muscular endurance for the chest press (49.5 and 66.7 %) and knee extension exercises (48.2 and 58.4 %), 1-set and 3-set groups, respectively, was not significantly different between groups. The 1-set group significantly decreased anterior thigh skin-fold and increased lean body mass (data not reported), while the 3-set group increased chest and biceps circumference and lean body mass, and decreased the sum of seven skin-folds and percent body fat (data not reported). There was no significant difference between groups for any of these variables.

Hass et al. (46) reported that the 1-set and 3-set groups showed a significant increase in 1 RM knee extension (~15 and 15 %), knee flexion (~10 and 13 %), chest press (~11 and 13 %), overhead press (~10 and 12 %), and biceps curl (~9 and 8%), for 1-set and 3-set groups, respectively. There was no significant difference in strength gains between the 1-set and 3-set protocols at any time point.

Out of the original 49 subjects, Hass et al. (46) removed five because of poor compliance, and two withdrew because of injuries. The seven subjects who did not complete the study were all from the 3-set group. Hass et al. (46) concluded that because there was no significant difference in outcomes between protocols, the single-set protocol represented a time-efficient method for developing muscular strength, endurance, and body composition, regardless of the individual's fitness level.

There are at least 18 additional resistance-training studies (62-79) whose primary purpose was to determine specific health-related benefits of resistance training in males and females of various ages performing total-body resistance training. All these studies used a 2-set protocol for each of three lower-body exercises and a 1-set protocol for each of eight upper-body exercises. The same resistance-training protocol was employed for all the studies (62-79). Hence, they provide fertile ground, with incredible replication, for examining the effect of one set or two sets on strength. Each study was well controlled and supervised, longer than most resistance-training studies (4-6 months compared with 6-12 weeks), and published in prestigious journals. The participants in each specific study served as their own controls; that is, these strength data were reported for upper- and lower-body exercises in the whole study group, rather than a comparison of two separate groups. Although the researchers did not report statistical comparisons between 1-set and 2-set exercises, the average reported increases in strength were similar for 1-set (~40 %) and 2-set (~36 %) exercises. The serendipitous, robust and unequivocal finding of similar strength gains in all of these studies (62-79) minimizes researcher bias, which may be inherent in studies specifically designed to investigate the effects of single versus multiple sets. Only one (64) of the aforementioned 18 studies (62-79) is cited in the Position Stand, and is cited relative only to the effect of resistance training on gastrointestinal transit time.

In summary, most of the research (8, 23-24, 39-61) shows that performing a greater number of sets does not significantly affect the magnitude of strength gain or muscular hypertrophy.

Resistance Trained Subjects

As Editor-in-Chief of the Journal of Strength and Conditioning Research, Kraemer (35) published a series of *Experiments* in that journal. The data for these *Experiments* were resurrected from a database that he accumulated as a coach, which we estimate was at least 15 years before their publication. *Experiments* 2, 3, and 4 are resistance-training studies, which collectively involved 118 male American football players (~20 years) with an average 2.9 years of resistance-training experience. The players performed either single-set or multiple-set (2-5 sets) resistance training using free weights and machines 3-4x/wk for 10-24 weeks. Compared with single-set groups, the multiple-set groups produced a three times greater increase in 1 RM bench press, five times greater increase in 1 RM leg press, seven times greater increase in hang clean, three times greater increase in body mass and decrease in percent body fat, four times greater increase in vertical jump, and 14 times greater increase in Wingate power test (collectively *Experiments* 2, 3, & 4).

In *Experiment* 5 of the series, Kraemer (35) gave 115 football players a survey questionnaire regarding their adherence to a single-set protocol. In fact, 89 % of the players reported using multiple-set protocols at home or during off hours at health clubs. It is not clear if these athletes are the same participants Kraemer (35) used for his database. However, if 89 % of his participants from a similar population of collegiate American football players were performing multiple sets in addition to their single-set program, the difference in outcomes reported by Kraemer (35) for *Experiments* 2, 3, and 4 are even more remarkable because both groups may have been following similar multiple-set protocols.

Kraemer (35) cites a study by Ostrowski et al. (53), which coincidentally appears immediately after Kraemer's study (35) in the same issue of that journal. Kraemer (35) claims that the results of Ostrowski et al. (53) contradict his data regarding the magnitude of strength gains as a result of multiple-set and so-called *periodization* resistance training. The study by Ostrowski et al. (53) is especially noteworthy because the subjects were advanced trainees and the resistance training was a *periodization* program, which is recommended throughout the Position Stand. The subjects were 35 males (~23 years) who were currently weight training for an average of 2.9 years, and had the ability to bench press at least 100 % of their body mass and squat with 130 % of their body mass. They were randomly assigned to perform one, two, or four sets of each exercise (3, 6, or 12 sets per muscle group per week) on 24 free-weight and machine exercises (6 exercises at each session), and they followed a split routine (2 days upper body and 2 days lower body each week) for 10 weeks. A 12 RM was used during weeks 1-4, 7 RM weeks 5-7, and 9 RM weeks 8-10. All sets were performed to muscular fatigue (same relative intensity of effort), with three minutes rest between sets. Ostrowski et al. (53) carefully manipulated only one variable, so that the only difference in training variables among the three programs was the number of sets. All other training variables were identical among the three groups. Ostrowski et al. (53) reported a significant increase in each of the three groups for 1 RM squat (7.5, 5.5, and 11.6 %), 1 RM bench press (4.0, 4.7, and 1.9 %), bench press power (2.3, 2.3, and 3.1 %), and bench press throw height (4.8, 7.7, and 4.9 %), 1-set, 2-set, and 4-set groups, respectively. There was no significant difference among the groups. Vertical jump did not significantly increase in any group. There was a significant increase in triceps brachia thickness (2.3, 4.7, and 4.8 %), rectus femoris hypertrophy (6.8, 5.0, and 13.1 %), rectus femoris circumference (3.0, 1.5, and 6.3 %), and body mass (2.0, 2.6, and 2.2 %), 1-set, 2-set, and 4-set groups, respectively. There was no significant difference among the three groups for any of the outcomes.

The average strength gains (7.5 %) reported by Ostrowski et al. (53) are within the predicted range established by Kraemer as Chairman of the Writing Group for the Position Stand. That is, the Position Stand predicts that *advanced* trainees who have years of experience and have attained significant improvements in muscular fitness can increase muscular strength approximately 10% over a period of four weeks to two years (p. 366). The Position Stand defines *elite* individuals as those athletes who are highly trained and have achieved a high level of competition. However, the average combined strength gain (19.6 %) for Kraemer's (35) *Experiments* 3 (15.4 %) and 4 (23.8 %), which involved Division III collegiate American football players, was two times greater than what is predicted in the Position Stand for advanced trainees, and almost 10 times greater than the ACSM's predicted increase for elite athletes. The strength gain (15.8 %) for *Experiment* 2 in the study by Kraemer (35), which involved highly-trained Division I collegiate American football players, is more than seven times greater than what is predicted for elite athletes (2 %) in the Position Stand.

Ostrowski et al. (53) reported no significant pre- to post-training changes in resting concentrations of testosterone (+17, +38, and –37 %), cortisol (-13, +97, and +26 %), or testosterone/cortisol ratio (+75, +73, and –57 %) in the 1-set, 2-set, and 4-set groups, respectively. Based on their results, Ostrowski et al. (53)

speculated that once a minimum threshold volume is attained (one set of each exercise), there is no advantage to an increased volume of training, and that higher volumes (four sets per exercise) may result in a decreased testosterone/cortisol ratio in some individuals.

These two contrasting studies by Kraemer (35) and Ostrowski et al. (53) deserve particular attention because the Writing Group for the Position Stand and the ACSM gave much greater precedence to the results reported by Kraemer (35) compared with Ostrowski et al. (53). The Kraemer study (35) is cited at least 14 times in the Position Stand and the study by Ostrowski et al. (53) is cited only once, and cited incorrectly. That is, the Position Stand claims that some studies have reported similar strength gains in *novice* individuals who performed either two sets or four sets of each exercise, and the study by Ostrowski et al. (53) is cited (p. 367). However, the subjects in the study by Ostrowski et al. (53) were at least in the *advanced* category, as defined in the Position Stand, and the comparison was among 1-set, 2-set, and 4-set groups.

Ostrowski et al. (53) concluded that their results demonstrated that low (1-set), moderate (2-set), and high-volume (4-set) protocols showed no significant difference in their effect on muscular strength, hypertrophy and power, and that the 1-set group represented a time-efficient method of resistance training, even in resistance-trained males (*advanced* trainees). Kraemer (35) concluded that if simple low-volume single-set protocols were really effective, as they were in the study by Ostrowski et al. (53), there would be little need for highly paid strength and conditioning specialists.

Kramer et al. (36) randomly assigned 53 moderately trained (not defined) males (~20 years) to a 1-set (8-12 RM), 3-set (10 RM), or varied multiple-set group (1-3 sets of 2-10 repetitions). All the groups trained 3x/wk for 14 weeks. The 1-set group performed the squat exercise with RM loads 2x/wk, while the two multiple-set groups executed the squat exercise with RM loads 1x/wk, and used a 10 % lighter resistance 1x/wk. Three so-called *assistance* exercises were also performed at each session using a similar training protocol of three sets of 5-10 repetitions in the multiple-set groups, and one set of 8-12 RM in the 1-set group. All the subjects significantly increased 1 RM squat (12, 26, and 24 %, 1-set, 3-set, and varied multiple-set groups, respectively), with the two multiple-set groups improving significantly more than the 1-set group. Neither body mass nor body composition changed significantly.

Kraemer et al. (37) randomly assigned 24 female collegiate tennis players (~19 years) to one of three groups: single-set, multiple-set or control. The single-set group performed one set of 8-10 repetitions and the multiple-set group rotated each session using 4-6, 8-10, or 12-15 repetitions for 2-4 sets of each of 17 exercises, with 1-3 minutes rest between sets. The single-set group performed each repetition in what the authors describe as a slow, controlled manner, and the multiple-set group was instructed to execute repetitions with moderate-to-explosive muscle actions. Both groups trained 2-3x/wk for nine months. There were 17 exercises executed with at least five exercises performed unilaterally. Assuming at least one minute to set up and perform each of the 22 exercises (22 + 5), with an average of three sets per exercise (3 x 22 = 66 sets x 1 min = 66 min), and an average of two minutes rest between sets (66 x 2 = 132 min), each session for the multiple-set group would require approximately 198 minutes. However, Kraemer et al. (37) reported that all workouts were completed within 90 min.

With the exception of pre-training age, height and body mass, Kraemer et al. (37) did not report any data for absolute or percent changes pre- to post-training. The following estimates of the changes are taken from Figure 3 (p. 630) presented in the study (37). The significant increase in 1 RM free-weight bench press was more than three times greater in the multiple-set group (~27 %) compared with the single-set group (~8 %). The single-set group showed a significant increase of ~8 % in leg press strength and the multiple-set group increased ~24 %, which was three times greater than the single-set group. In the free-weight military press, the single-set group increased strength by ~12 % and the multiple-set group increased ~33 %. After nine months of strength training there was no significant improvement in the single-set group for Wingate cycle power, tennis-serve velocity or vertical jump. The multiple-set group had a significant increase in cycle power (~17 %), tennis-serve velocity (~25 %), and vertical jump (~53 %).

Although body mass did not change significantly in either group, the multiple-set group reduced body fat from ~23 to ~18 % (37). Calculating this 3.1 kg loss of body fat and the reported average 60.4 kg body mass, which did not change from pre- to post-training, the female athletes in the multiple-set group purportedly gained 3.1 kg of lean body mass in nine months. Kraemer et al. (37) concluded that the high volume multiple-set program elicited superior increases in muscular strength, power, lean body mass, and tennis serve velocity, as well as a significant decrease in percent body fat.

Kraemer et al. (37) noted that the goal of the resistance-training program was to increase tennis-specific fitness components beyond the gains produced by typical tennis practice. They also noted that in an attempt to minimize the learning effect on

Table 4. Summary of Research Comparing Single and Multiple Sets.

Reference	Rating
Bemben et al. (23)	*
Berger (29)	?
Berger (39)	*
Berger (40)	*
Borst et al. (33)	↑
Capen (41)	↓
Chestnut & Docherty (24)	*
Ciriello et al. (42)	*
Coleman et al. (43)	↓
Dudley et al. (44)	↓
Girouard & Hurley (62)	*
Graves et al. (45)	*
Hass et al. (46)	↓
Hisaeda et al. (47)	*
Hurley et al. (63)	*
Jacobson (48)	↓
Koffler et al. (64)	*
Kosmahl et al. (49)	*
Kraemer (35)	?
Kraemer et al. (37)	↓
Kramer et al. (36)	↑
Larshus et al. (50)	*
Leighton et al. (51)	*
Lemmer et al. (65)	*
Lott et al. (66)	*
Martel et al. (67)	*
Marx et al. (34)	↑
Menkes et al. (68)	*
Messier & Dill (52)	↓
Miller et al. (69)	*
Nicklas et al. (70)	*
Ostrowski et al. (53)	↓
Parker et al. (71)	*
Pollock et al. (54)	↓
Reid et al. (55)	↓
Rhea et al. (72)	*
Roth et al. (73)	*
Rubin et al. (74)	*
Ryan et al. (75)	*
Ryan et al. (76)	*
Ryan et al. (77)	*
Ryan et al. (78)	*
Sanborn et al. (30)	↓
Schlumberger et al. (38)	↑
Schmidtbleicher & Buehrle (56)	*
Silvester et al. (8)	↓
Starkey et al. (57)	↓
Stone et al. (31)	?
Stowers et al. (32)	↓
Treuth et al. (79)	*
Wenzel & Perfetto (58)	*
Westcott (59)	*
Westcott (60)	*
Withers (61)	*

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

the potential strength gains, the subjects were familiarized (at least three training sessions) with all resistance-training protocols before initiating the study. There is no mention of previous resistance training in this study. Therefore, the inference is that the female tennis players were not resistance-trained individuals, which is contrary to what is claimed in the Position Stand (p. 367). Perhaps the most questionable aspect of this study (37) was the inability of this single-set group of previously untrained females to elicit any significant change in performance variables, and produce only a very small strength gain (~10 %) after nine months of resistance training.

Schlumberger et al. (38) randomly assigned 27 females (~26 years) to a 1-set, 3-set, or control group. The 1-set and 3-set groups performed 6-9 RM for each of seven exercises 2x/wk for six weeks. Both groups had a significant increase in 1 RM bilateral knee extension, with the gains for the 3-set group (15.8 %) significantly greater than the 1-set group (6.7 %). Only the 3-set group showed a significant increase in 1RM bench press (10 %). Schlumberger et al. (38) first noted that the participants had a minimum of six months resistance training, but then noted two times that the basic resistance-training experience ranged from 3-6 months. Consequently, it is not possible for readers to determine if the participants were *novices* or *intermediate* trainees, as defined in the Position Stand.

In summary, only two of the studies cited in the Position Stand support the superiority of multiple sets over a single set in moderately trained (36) and in novice or intermediate trainees (38). Although there is a lack of evidence to suggest that single-set protocols are superior to multiple sets (except for time efficiency), most of the resistance-training research fails to support the superiority of multiple-set training, while strongly supporting the efficacy of single-sets (Table 4).

REST PERIODS

The Position Stand claims that the amount of rest between sets and exercises significantly affects training adaptations. Two references (80-81) are cited in an attempt to support their assertion that there are greater strength gains as a result of longer rather than shorter rest periods (p. 368).

Pincivero et al. (80) compared 40 seconds rest (group 1) and 160 seconds rest (group 2) between sets of ten maximal unilateral concentric-only isokinetic knee-extension and knee-flexion exercise, which were performed at 90°/s. The 15 volunteers (~22 years), who did not perform resistance training for at least six months prior to this investigation, trained 3x/wk for four weeks. They executed four sets during each of the first three sessions, with an additional set at each of the nine remaining sessions (wk 2-4). Isokinetic dynamometry was used to evaluate the effects of training on the quadriceps and hamstrings, and the distance for a single-leg hop was designated as the functional performance assessment.

Quadriceps average power (trained and untrained limbs combined) at 60°/s (-0.96 and 5.2 %, groups 1 and 2, respectively) and quadriceps peak torque at 180 °/s (2.3 and 8.4 %, groups 1 and 2, respectively) were the only variables that were significantly affected by rest interval manipulation (Table 4, p. 232), with the change in group 2 significantly greater than group 1. An objective evaluation of the results reveals that 12 out of the 14 variables measured on the dynamometer, and the functional performance measure, were not significantly affected by rest interval manipulation (80).

Robinson et al. (81) assigned 33 moderately trained males (~20 years) to one of three groups with different rest time between sets of exercise: group 1 (180 seconds), group 2 (90 seconds), or group 3 (30 seconds). Subjects executed five sets of 10 RM for the squat, push-press, clean-pull and power-snatch exercises, and three sets of 10 RM for the bench press, dead lift, shrug, row, and crunch exercises. Training was scheduled 4x/wk and each exercise was performed 2x/wk for five weeks. Robinson et al. (81) stated that the increase in 1 RM squat was significantly greater for group 1 (7 %) compared with group 3 (2 %). However, they did not state whether or not the difference between group 1 (7 %) and group 2 (6 %), or between group 2 and group 3, was significantly different. Therefore, the claim by Robinson et al. (81) that their data suggest a rest-period continuum, with longer rest periods producing greater strength gains, is not supported by their data. Furthermore, there was no significant difference among the groups for any of the other 10 measured variables: body mass, skin folds, girth circumference, vertical jump, vertical jump power index, cycle peak power, average peak power, average power, total work, and average total work.

Neither of these cited studies (80-81) supports the opinion in the Position Stand that at least 2-3 min of rest are required between sets and exercises, and neither study involved advanced trainees.

In summary, the claims in the Position Stand that the rest time between sets and exercises is dependent on the specific goals of a particular exercise, that shorter rest periods decrease the rate of strength gains, and that multiple-joint exercises require longer rest periods than single-joint exercises on machines, are bereft of any scientific support (Table 5).

Table 5. Summary of Research Comparing Rest Periods.

Reference	Rating
Pincivero et al. (80)	↓
Robinson et al. (81)	↓

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

∗ Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

MUSCLE ACTIONS

The Position Stand claims that some advanced programs incorporate supra-maximal eccentric muscle actions to maximize gains in muscular strength and hypertrophy (p. 366). One study (82) is cited to support the efficacy of this training technique.

Keogh et al. (82) reported a cross-sectional comparison of force, power, EMG, time under tension, and lactate response to eight different bench press techniques performed on a plyometric power system. Keogh et al. (82) suggested that supra-maximal eccentric muscle actions (~six 4-second eccentric-only repetitions with 110 % concentric 1 RM) impose a greater overload than heavy weight training (6 RM) on the musculature. However, this was not a longitudinal resistance-training study. Consequently, Keogh et al. (82) and the authors of the Position Stand are merely expressing their opinion about the benefits of supra-maximal eccentric muscle actions. There is no evidence cited to support that opinion.

Because the Position Stand cites Koegh et al. (82) when referring to "supra-maximal" eccentric muscles actions, the inference is that the Position Stand is referring to eccentric-only muscle actions with a resistance greater than the concentric 1 RM. Several resistance-training studies (83-87) have compared the effects of training with "supra-maximal" eccentric muscle actions with concentric-only muscle actions.

Concentric-Only versus Eccentric-Only ("supra-maximal") Muscle Actions

Hakkinen and Komi (83) reported the results of resistance training with different muscle actions in a group of competitive junior Olympic weightlifters, as well as in a group of non-competitive resistance trainees. Thirteen competitive weightlifters (17-23 years) performed exercises described as the snatch, clean and jerk, squat, snatch and clean pull, and arm press 4x/wk for 12 weeks. Group A progressively performed all the exercises concentrically using 70-100 % of concentric maximum. Group B performed a similar routine except they executed eccentric-only muscle actions for 25 % of the snatch and clean pulls, squat, seated press, and lower-back exercises with a progression of 100-130 % of the concentric maximum (sets and repetitions not reported for either group). There were five different dynamometer tests for the knee-extensor muscles involving isometric, concentric, and eccentric muscle actions, and each group significantly improved in two of those tests. Group B showed a significantly greater increase in the clean and jerk (13.5 %) compared with group A (5.7 %).

However, both groups significantly increased the snatch (7.1 and 9.9 %, groups A and B, respectively), with no significant difference between groups.

The 27 non-competitive males (20-30 years) who comprised groups C, D, and E trained 3x/wk with the bench press and squat, performing 1-6 repetitions per set for concentric muscle actions (80-100 %) and 1-3 repetitions per set for eccentric muscle actions (100-130 %), totaling 16-22 repetitions per exercise (83). Group C performed all the exercises concentrically. Group D performed approximately half the squats and bench presses eccentrically. Group E executed about three-quarters of the exercises eccentrically. In the five tests on the dynamometer for the knee extensors, group C did not significantly improve on any test, group D significantly increased four variables, and group E on two variables. The three groups significantly increased 1 RM squat, with the gains in groups D (29.2 %) and E (28.6 %) significantly greater than group C (20.3 %). Group C (15.2 %), D (19.5 %), and E (12.3 %) significantly increased 1 RM bench press. The gains in bench-press strength were not significantly different among the groups. Thigh girth significantly increased for group C (1.4 %), D (2.4 %), and E (1.4 %), with no significant difference among the groups (83).

Johnson et al. (84) trained eight college students 3x/wk for six weeks. The four exercises were described as the arm curl, arm press, knee flexion and knee extension. Exercises were performed concentric-only with 80 % 1 RM unilaterally, and eccentric-only ("supra-maximal") with 120 % 1 RM on the contra-lateral side. Two sets of 10 repetitions were employed for concentric-only muscle actions, and two sets of six repetitions for eccentric-only muscle actions. Both types of training produced significant gains in isometric strength in all subjects, except for elbow flexion in the eccentric-only limb, and elbow flexion and knee flexion in the concentric-only limb. Dynamic strength increased for the arm-curl (~32 and 29 %), arm-press (~55 and 60 %), knee-flexion (~25 and 25 %), and knee-extension (~30 and 30 %) exercises, concentric-only and eccentric-only muscle actions, respectively. There was no significant difference between concentric (80 % 1 RM) and eccentric (120 % 1 RM) training for any of the dynamic strength measures.

Jones and Rutherford (85) assigned five previously untrained males and one female (~28 years) to perform concentric-only knee-extension exercise with one limb using 80 % 1 RM, and eccentric-only knee-extensions with the contra-lateral limb using a resistance 145 % greater than what was used for the concentric-only training. Subjects performed four sets of six repetitions (~2-3 s/muscle action) for each limb with one-minute rest between sets 3x/wk for 12 weeks. Assistants either lifted or lowered the resistance for the two different protocols. Strength increased 15 % in the concentric-only limb and 11 % in the eccentric-only limb, with no significant difference in the strength gains. Computerized tomography revealed a significant increase in quadriceps cross-sectional area in the concentric-only (5.7 %) and eccentric-only limbs (3.5 %), with no significant difference between limbs.

Komi and Buskirk (86) randomly assigned 31 males (~20 years) to a concentric, eccentric, or control group. The exercising groups performed either maximal concentric or maximal eccentric right elbow flexor muscle actions six times a day 4x/wk for seven weeks. The exercising tension was approximately 40 % greater in the eccentric group. The increase in maximal eccentric tension was significantly greater in the eccentric group (15.6 %) compared with the concentric group (6.7 %). Maximal isometric tension (8.6 %) and right arm girth (1.8 %) showed a significant increase only in the eccentric group. There was a significant increase in maximal concentric tension (the more practical functional ability to lift a resistance) and there was no significant difference between the concentric (12.1 %) and eccentric (15.8 %) groups.

Seliger et al. (87) assigned 15 highly trained rugby players (~26 years) to perform several upper-body and lower-body free-weight resistance exercises 2x/wk for 13 weeks. One group performed concentric-only muscle actions with 90-95 % of maximal resistance, and another group performed eccentric-only muscle actions with 145-150 % of maximal resistance (specific exercises, repetitions and sets not reported). Both groups showed a significant increase in bench press (~13 and 9 %) and squat strength (~49 and 49 %) in the concentric-only and eccentric-only groups, respectively. There was no significant difference in strength gains between groups.

Most of the results from these five studies (83-87) do not support the superiority of "supra-maximal" eccentric exercise. In the two studies (83, 86) that showed some advantage to "supra-maximal" eccentric muscle actions, there was no comparison group that performed conventional concentric and eccentric muscle actions, which is a combination of lifting and lowering the same resistance. It is important to note that "supra-maximal" eccentric-only exercise is not typically performed because it requires either specially designed exercise machines to lift the resistance, or highly motivated, knowledgeable, trustworthy training partners. With the exception of the study by Jones and Rutherford (85), which is cited in the Position Stand merely to show that four sets of resistance exercise will significantly increase muscular strength (p. 367), these studies (83-84, 86-87) are not cited in the Position Stand.

Concentric and Eccentric versus Concentric and Accentuated-Eccentric Muscle Actions

Another form of training with an eccentric resistance greater than the concentric resistance is accentuated eccentric exercise. It is accomplished with the help of a spotter, special exercise machines, or by using two limbs to perform the concentric muscle action and one limb for the eccentric muscle action. However, there were only two published studies (88-89) that compared this type of training with traditional concentric-eccentric training (lifting and lowering the same resistance).

Ben-Sira et al. (88) randomly assigned 60 previously untrained females (~21 years) to one of four experimental groups or a control group. The subjects performed bilateral concentric-only (65 % 1 RM), eccentric-only (65 % 1 RM), conventional concentric/eccentric (65 %/65 % 1 RM), or concentric/accentuated eccentric (65 %/130 % 1 RM) knee-extensor muscle actions for three sets of 10 repetitions 2x/wk for eight weeks. The 65/130 % group lifted the resistance (65 % 1 RM) with both limbs, and alternated lowering the resistance (130 % 1 RM) with one limb. Dynamic knee-extensor strength gains in the conventional group (19 %) and the eccentric-accentuated group (23 %) were significantly greater than the control group (~3 %), but not significantly different from each other. Post-hoc comparisons of the groups revealed no significant difference.

Godard et al. (89) randomly assigned 28 previously untrained males and females (~22 years) to a concentric/eccentric (con/ecc), concentric/accentuated eccentric (con/ecc+), or a control group. Resistance was initially set at 80 % 1 RM for both concentric and eccentric muscle actions in the con/ecc group. In the con/ecc+ group, resistance for the eccentric component was 40 % greater than the concentric resistance. Both groups performed one unilateral set of 8-12 RM knee extensions 2x/wk for 10 weeks. There was a significant increase in 1 RM (~95 and 94 %) and thigh girth (~6 and 5 %) in the con/ecc and con/ecc+ groups, respectively, with no significant difference between groups. Godard et al. (89) concluded that using the same amount of resistance for concentric and eccentric muscle actions was just as effective as the addition of accentuated eccentric muscle actions for producing increases in strength and thigh girth.

Several studies suggest that resistance training with exercises that provide resistance for a combination of concentric and eccentric

Table 6. Summary of Research Comparing Muscle Actions.

Reference	Rating
Ben-Sira et al. (88)	∗
Godard et al. (89)	∗
Hakkinen & Komi (83)	∗
Johnson et al. (84)	∗
Jones & Rutherford (85)	↓
Keogh et al. (82)	↓
Komi & Buskirk (86)	∗
Seliger et al (87)	∗

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

∗ Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

muscles actions (i.e., conventional resistance training), as compared with concentric-only resistance training, produce significantly greater strength gains (44, 90-93), retention of strength gains (91), and muscle hypertrophy (94).

In summary, there is very little evidence cited to support the superiority of supra-maximal eccentric training, as claimed in the Position Stand (Table 6). Two studies (83, 86) reported an advantage in some but not all measures of strength with supra-maximal eccentric training. However, the protocols were not compared to resistance training that typically includes both concentric and eccentric muscle actions. The research (88-89) suggests that there is no additional benefit to performing accentuated eccentric muscle actions compared with traditional concentric/eccentric muscle actions (lifting and lowering a similar resistance).

FREQUENCY OF TRAINING

The Position Stand cites several resistance-training studies (54, 95-97) and then recommends that novices (those with no resistance training experience or who have not trained for several years) train the entire body two to three times per week (p. 369). Although this is a reasonable recommendation, the references prior to that statement may not be relevant to the recommended training frequency.

The Position Stand cites a study by Gillam (95) to show that 3x-5x/wk is superior to 1x and 2x/wk resistance training (p. 369). Gillam (95) randomly assigned previously untrained male high school students to one of five groups who performed the free-weight bench-press exercise 1x, 2x, 3x, 4x, or 5x/wk for nine weeks. The 3x (32.3 %), 4x (29.0 %), and 5x/wk (40.7 %) groups showed a significantly greater increase in 1 RM bench press than the 1x/wk group (19.5 %), and the gains in the 3x and 5x/wk groups were significantly greater than the 2x/wk group (24.2 %). There was no significant difference between the 1x and 2x/wk groups, or between the 3x and 4x/wk groups. The protocol used by Gillam (95) was highly unusual and although 90 % of the participants completed the study, it is highly doubtful that most healthy adults would readily comply with a training protocol of 18 sets 1 RM 3-5x/week for each of the targeted muscle groups.

The Position Stand notes that a 4x/wk training frequency has been shown (96) to be superior to 3x/wk training (p. 369). Hunter (96) compared the effects of two frequencies of training with a slightly different distribution of the same amount of exercise for the two groups. Forty-six previously untrained males and females (~23 years) performed 7-10 RM for each of seven exercises (bench press, squat, power clean, behind-the-neck press, biceps curl, behind-the-neck pull-down, and thigh curls) for seven weeks. The 3x/wk group performed three sets of each exercise on alternate days. The 4x/wk group executed two sets of each exercise 3x/wk on three consecutive days and three sets of each exercise on the fourth consecutive day. Hunter (96) noted that the number of weekly sets (nine) for each of the seven exercises was identical for both groups. Bench press strength (14.1 and 21.9 %), bench press endurance (41.4 and 59.9 %), and chest circumference (0.2 and 3.2 %) significantly increased in both the 3x and 4x/wk groups, respectively, with a significantly greater increase in the 4x/wk group. Both groups had significant improvements in biceps circumference (2.6 and 4.3 %), standing long jump (4.6 and 4.5 %), lean body mass (0.7 and 1.0 %), and percent body fat (from 16.6 to 15.8 % and 15.1 to 14.4 %), 3x and 4x/wk groups, respectively, with no significant difference between groups for any of these variables. Although this study does report a more favorable response for the 4x/wk group in three out of the seven measured variables, each exercise was performed on four consecutive days. Therefore, Hunter's (96) results do not support the recommendation of two to three days a week in the Position Stand.

The study by McLester et al. (97) involved advanced trainees (those with years of resistance training experience) and is discussed shortly.

The Position Stand cites a study (54) in an attempt to show that a frequency of three times per week (3x/wk) is superior to 1x/wk resistance training (p. 369). Pollock et al. (54) compared the effects of one set of 8-12 RM (dynamic) or two sets (dynamic + isometric) resistance exercise on the cervical extensors in four groups (N = 78) of previously untrained males and females (~28 years) either 1x or 2x/wk for 12 weeks. Isometric strength was evaluated at eight angles throughout 126^{o} range of cervical flexion. Pollock et al. (54) reported that the increase in isometric strength was significantly greater for the 2x/wk groups only at 126^{o} of cervical flexion. Dynamic training loads significantly increased in both 1x/wk groups (35.0 and 42.0 %, dynamic and dynamic + isometric groups, respectively) and both 2x/wk groups (40.9 and 43.5 %, dynamic and dynamic + isometric groups, respectively), with no significant difference between the groups. There was no 3x/wk group in this study (54), as claimed in the Position Stand. The authors of the Position Stand apparently selected the one isometric strength measure that supported their opinion about frequency of training and incorrectly claimed that it was a result of training 3x/wk. They failed to report that the strength gains in seven out of eight isometric measures and the increase in dynamic resistance showed no significant difference between the 1x/wk and 2x/wk groups.

Several studies (described below) have reported similar responses in previously untrained participants as a result of training 1x, 2x or 3x/wk (98-100), 1x or 3x/wk (101), and 3x or 5x/wk (102). One study reported that 3x/wk was better than 2x/wk (103); while another showed 2x/wk was superior to 3x/wk (104). In addition, one study (105) found no difference between 2x and 3x/wk, and that both frequencies were better than 1x/wk.

Carpenter et al. (98) reported the results of lumbar-extension exercise in 23 males and 18 females (~35 years). The participants were rank ordered by peak isometric torque and randomly assigned to perform one set of 8-12 RM 1x, 2x, 3x, 1x/2wk (every other week), or no training. All the training groups significantly increased peak isometric torque at the seven angles tested (from 17.2 % at 72^{o} flexion to 123.1 % at 0^{o} flexion), with no significant difference in isometric strength gains among the groups. The four training groups significantly increased the training resistance (8-12 RM) after 20 weeks, with no significant difference among the 1x (46.3 %), 2x (51.5 %), and 3x/wk (48.1 %) groups. The only significant difference was a greater increase in strength for the 2x/wk group compared with 1x/2wk (33.4 %).

Graves et al. (99) placed 72 males (~31 years) and 42 females (~28 years) in rank order by peak isometric strength and randomly stratified them to one of five training groups: 1x/2wk, 1x, 2x, 3x/wk dynamic training, or 1x/wk isometric training. All the participants in the dynamic training groups performed one set (8-12 RM) of lumbar-extension exercise for 12 weeks. The isometric group performed maximal isometric strength tests at each of seven angles once a week. The five groups significantly increased maximal isometric torque at all seven angles, with no significant difference in the magnitude of responses among the groups. The resistance used for dynamic training (8-12 RM) significantly increased in the 1x/2wk (26.6 %), 1x (38.9 %), 2x (41.4 %), and 3x/wk (37.2 %) groups. The increase was significantly greater for the 1x, 2x, and 3x/wk groups compared with the 1x/2wk group but there was no significant difference in strength gains among the 1x, 2x, and 3x/wk groups.

Taaffe et al. (100) randomly assigned 34 previously untrained males and 19 females (~69 years) to a 1x, 2x, or 3x/wk training group, or a control group. The exercise groups performed three sets of eight repetitions with 80 % 1 RM for each of five upper-body and three lower-body exercises for 24 weeks. Dual energy X-ray absorptiometry (DEXA) revealed a significant increase in lean body mass for the 1x (4.9 %), 2x (2.8 %) and 3x/wk (1.7 %) groups, which were all significantly greater than the control group (-5.9 %). The average increase in strength for the eight exercises was significant for group 1x (37.0 %), 2x (41.9 %) and 3x/wk (39.7 %). There was no significant difference in upper body, lower body, or whole body strength gains among the three training groups at any time point.

After initially training (1 x 6 RM) 79 males (18-23 years) in the free-weight squat for three weeks, Berger (101) randomly assigned his seven weight training classes to seven groups for an additional six weeks of training. All the participants performed only one repetition at each session with 66, 80, and 90 % 1 RM 2x/wk in groups 1, 2 and 3, respectively. Groups 1, 2 and 3 also performed the 1 RM 1x/wk. Group 4 executed the 1 RM 3x/wk, group 5 used 66 % 1 RM 3x/wk, and group 6 performed the 1 RM 1x/wk. Group 7 was the control. Group 5 (66 % 1 RM 3x/wk) and 7 (control group) did not significantly increase strength. There was a significant increase in 1 RM squat for group 1 (17.8 kg), 2 (15.7 kg), 3 (12.5 kg), 4 (15.0 kg), and 6 (10.6 kg). There was no significant difference in the magnitude of strength gains among these groups. Berger (101) concluded that training 1x/wk with the 1 RM was just as effective as training 3x/wk.

Rozier and Schafer (102) trained the right knee extensors in 40 females (18-23 years) either 3x or 5x/wk for six weeks. All subjects performed three sets of eight repetitions on an isokinetic dynamometer and were encouraged to apply maximal force throughout each knee extension. Both groups significantly increased peak isometric torque (17 and 12 %, 3x and 5x/wk groups, respectively) and peak isokinetic torque (15 and 12 %, 3x and 5x/wk groups, respectively). There was no significant difference in the magnitude of strength gains as a result of training 3x or 5x/wk.

Gregory (103) trained 152 previously untrained males (~21 years) either 2x or 3x/wk for 14 weeks. Both groups performed three sets of 6-10 RM for seven exercises, and were tested pre- and post-training on four of those exercises (bench press, seated press, leg press, and biceps curl). Compared with the 2x/wk group, the 3x/wk group had a significantly greater increase in the seated press (17.5 and 13.1 %, 3x and 2x/wk groups, respectively) and the leg press exercises (12.6 and 9.6 %, 3x and 2x/week groups, respectively). Both groups (2x and 3x/wk, respectively) showed a significant increase in 1 RM bench press (16.7 and 17.9 %) and biceps curl (12.9 % and 15.1 %), with no significant difference between groups. The overall mean difference in strength gains between the groups was 2.7 %. Gregory (103) noted that the 3x/wk group demonstrated a more rapid increase in strength during the first seven weeks and found diminishing returns from weeks 8-14, while the 2x/week group showed a more uniform increase in strength throughout the 14 weeks.

Carroll et al. (104) randomly assigned 17 previously untrained males and females (~19 years) to a 2x, 3x/wk, or control group. The 2x/wk group trained for nine weeks (18 sessions), while the 3x/wk group trained for six weeks (18 sessions). Both training groups performed three sets of repetitions that ranged from 4-6 RM to 15-20 RM, depending on the exercise (4 upper-body and 3 lower-body). After completing 18 sessions, 1 RM squat significantly increased in the 2x (22.6 %) and 3x/wk (32.2 %) groups, with no significant difference between groups. The 2x/wk group demonstrated a significant increase (31.2 %) in peak isometric knee-extension and isokinetic strength (28.8, 38.1, 57.7, and 61.7 % at 1.05, 3.14, 5.24, and 8.73 rad/s, respectively). There was no significant increase in the 3x/wk group.

DeMichele et al. (105) randomly assigned 98 males and females (~30 years) to one of three training groups (1x, 2x or 3x/wk) or a control group. Subjects performed one 8-12 RM set (one set left-to-right and one set right-to-left) of dynamic torso-rotation exercise for 12 weeks. The average increase in peak isometric torque at the seven angles tested was 4.9, 16.3, and 11.9 %, group 1x, 2x, and 3x/wk, respectively. There was no significant difference between the 2x and 3x/wk groups at any of the seven angles tested. The increase in resistance used for training (8-12 RM) was significantly greater for the 2x (37.0 %) and 3x/wk (34.3 %) groups compared with the 1x/wk group (no significant change pre- to post-training), with no significant difference between the 2x and 3x/wk groups. DeMichele et al. (105) noted that the dropout rate was inversely related to training frequency (4, 7, and 15 dropouts in groups 1x, 2x, and 3x/wk, respectively). Because the 2x/wk frequency resulted in better adherence and equal strength gains compared with the 3x/wk group, DeMichele et al. (105) recommended a training frequency of 2x/wk.

For intermediate trainees (those with approximately six months of consistent resistance training experience), the Position Stand recommends a similar frequency of 2x-3x/wk total-body workouts, or split routines (upper-body/lower-body) to provide a greater volume of exercise. There is no resistance-training study cited to support the efficacy of a greater volume of exercise or split routines in intermediate trainees. The only reference cited is a book by Fleck and Kraemer (106).

There are only two studies (97, 107) cited in the Position Stand that employed previously trained participants and compared different training frequencies (p. 369). The study by McLester et al. (97) is cited in the Position Stand in the section relating to novice trainees. However, this study involved advanced trainees as defined in the Position Stand. McLester et al. (97) randomly assigned 25 males and females (~26 years), who had been exercising each muscle group at least twice a week and had approximately 5.7 years of recreational resistance-training experience (advanced trainees according to the Position Stand), to a 1x or 3x/wk resistance-training program for 12 weeks. The 1x/wk group performed three sets of 5-8 RM for each of five upper-body and four lower-body exercises, while the 3x/wk group performed one set of 3-10 RM for each exercise. There was no significant change in six out of the seven health-related variables (resting diastolic blood pressure, sum of nine circumferences, sum of three skin folds, percent body fat, body mass, and lean body mass) from pre- to post-training in either group. Resting systolic blood pressure significantly decreased 5 % in the 1x/wk group and 3 % in the 3x/wk group. Both groups significantly increased upper-body strength (20.2 and 32.4 %, 1x and 3x/wk groups, respectively), with no significant difference in strength between groups for any of the upper body exercises. There was a significant increase in the four lower-body exercises (23.5 and 37.4 %, 1x and 3x/wk groups, respectively). There was no significant difference between groups except for the leg press, with the 3x/wk group (46.1 %) significantly greater than the 1x/wk group (22.3 %). However, there was no significant difference between the 1x and 3x/wk groups in eight out of the nine strength measures. McLester et al. (97) concluded that 1x/wk training produced comparable strength gains to 3x/wk training.

The study by Hoffman et al. (107) deserves particular attention because Hoffman et al. (107) noted in their introduction that previous studies (prior to 1990) involved relatively untrained participants. In addition, the Hoffman study is one of only two studies (97, 107) cited in the Position Stand on frequency of training that involved the target population specified as advanced trainees. Hoffman et al. (107) trained 61 male Division I American football players (~20 years) with approximately three years resistance-training experience. Players were not randomly assigned to different programs, nor were the different programs randomly assigned. Each player was given the option to select a training frequency of 3, 4, 5, or 6 days/week. Although it does not guarantee that the groups would have been equated on all variables, rank order and randomization should have been performed, as this would have attempted to create equivalent groups that were essentially similar on all or most of the relevant variables. If these strategies were followed, then similar results would be expected in the experimental groups if the independent variable (frequency of training) made no difference. If the results were different among the groups, the difference could be attributed to the independent variable. It is also not clear if the independent variable should have been the self-selection of frequency rather than the frequency of training per se. Based on these research design limitations, this study should be considered descriptive or observational, which precludes the determination of a causal relationship.

Subjects performed 4-5 sets of 2-10 repetitions in the free-weight bench press and squat, which were the resistance-training exercises tested and reported. In the Methods section (p. 77), Hoffman et al. (107) claimed that the so-called "core" exercises were operationally defined as the bench press and squat; however, in their Table 3 (p. 78) there are six exercises designated as core exercises. Therefore, the exact number of so-called "core" exercises is not clear. Hoffman et al. (107) also failed to describe exactly what they meant by the term "core" exercises. Hoffman et al. (107) claimed that the subjects trained the core exercises 2x/wk in the 4day/wk and 6day/wk groups, and 3x/wk in the 3day/wk and 5day/wk groups. There were different distributions of the 40-44 so-called *assistance* exercises and all the subjects performed three sets of 10 RM for each exercise. The 3 day/week group exercised the eight listed body parts on M, W, F, the 4day/wk group trained the chest, shoulders, triceps, neck on M, Th, and legs, back, biceps, forearms on Tu, F. The 5day/wk group exercised the chest, triceps, legs, neck on M, W, F, and back, shoulders, biceps, forearms on Tu, Th, and the 6day/wk group trained the chest, triceps on M, Th, legs, shoulders, neck on Tu, F, and back, biceps, forearms on W, Sa. In addition to the resistance-training program, all the athletes participated in a football-conditioning program, which consisted of speed training, plyometics, flexibility, agility, and endurance exercises 2x/wk. Body mass, 1 RM bench press, 1 RM squat, 40-yard (~37 m) sprint, vertical jump, 2-mile (~3.2 km) run, sum of skin folds, thigh circumference, and chest circumference were the nine variables measured and reported pre- and post-training (10 weeks).

Hoffman et al. (107) claimed that the weekly number of sets for the 6day/wk group was similar to the 4day/wk and 5day/wk group. However, their claim contradicts the data reported in their Table 4 (p. 79) that shows 158 weekly sets for the 6 days/wk group compared with 122 sets for the 4 day/wk group. The 6 days/wk group actually executed a 30 % greater number of sets than the 4 day/wk group.

The increase in 1 RM bench press (1.8, 3.5, 3.2, and 4.0 %, 3, 4, 5, and 6 day/wk groups, respectively) was significant for only the 5 days/wk group. The gains in 1 RM squat (5.2, 7.3, 7.5, and 6.5 %, 3, 4, 5, and 6 day/wk groups, respectively) were significant for all groups except the 3 day/wk group. Hoffman et al. (107) claimed that resistance training in the 5day/wk group, who performed the bench-press exercise 3x/wk, had the greatest impact on strength development because it was the only group to significantly improve 1 RM bench press (3.2 %). However, the 3day/wk group also performed the bench press and squat exercises 3x/wk, but showed no significant increase in either bench-press or squat strength. The 6 day/wk group, who performed the bench press exercise 2x/wk, had a significantly greater pre-training 1 RM bench press (9.8 %), a 4.0 % increase in 1 RM, a similar standard deviation post-training, with less than half the number of participants (n = 11) compared with the 5 day/wk group (n = 23). Perhaps a post-training, between-group statistical comparison would have shown no significant difference between groups; or if there were a similar number of participants in both groups, the gains in bench-press strength would have been similar.

There was no significant difference in pre-training age, height, lifting experience, and time for a 2-mile run among the groups. However, there were significant differences pre-training among the groups for body mass, 1 RM squat, 1 RM bench press, sum of skin folds, thigh circumference, and chest circumference (107). With pre- and post-training data available and the statistical analysis reported for within-group pre- to post-training differences, post-training statistical comparisons among the groups would have been helpful to readers in the interpretation of the data (107).

Hoffman et al. (107) claimed that training 4 and 5 days/wk were superior to 3 and 6days/wk because a greater number of variables improved in those groups. However, the 4 days and 6 days/wk groups, who performed the so-called “core” exercises 2x/wk, significantly improved nine variables, and the 3 and 5days/wk groups, who performed the core exercises 3x/wk, also improved nine variables. That is, the groups that performed the “core” exercises 2x/wk improved in the same number of variables (nine) as the groups performing the “core” exercises 3x/wk. The only obvious difference is that the 3x/wk groups performed 155 sets each week compared with 140 in the 2x/wk groups, and more importantly, they had to perform a greater weekly volume of exercise per muscle group as a result of the greater frequency of training the “core” exercises. A similar comparison can be made between the 6 day/wk (n = 11) and 3 day/wk (n = 12) groups who trained the core exercises either 2x/wk (6 day/wk group) or 3x/wk (3x/wk group). Both groups significantly improved in three variables.

Based on the claim by Hoffman et al. (107) that there are problems with athletes regarding time constraints and compliance to training programs, perhaps their conclusion should have been that the groups improved in the same number of variables training the “core” exercises 2x or 3x/wk, but the groups that trained 2x/wk accomplished this with fewer weekly sets. Therefore, the conclusions by Hoffman et al. (107), and the statement in the Position Stand that football players training 4-5 days/week achieved better results than those who trained three or six days/week are unsubstantiated.

Regarding the study by Hoffman et al. (107), the Position Stand claims that the 5 day/wk and 6 day/wk programs elicited a greater increase in vertical jump performance compared with 3 day/wk and 4 day/wk programs (p. 372). In fact, there was no post-training between-group comparative analysis reported by Hoffman, and more importantly, there was no significant increase in vertical jump for any group. The data reported by Hoffman et al. (107) render the claim in the Position Stand unfounded.

Because it is not explained in the Position Stand, it should be noted that the study by Hoffman et al. (107) is the only frequency study cited where the participants may have performed specific exercises (e.g., the so-called "core" exercises) at a frequency (x/wk) that differed from the number of weekly exercise sessions (days/wk). In all the other studies (54, 95-105) the frequency of training (x/wk) was the number of times per week that an exercise was performed and that frequency coincided with the number of sessions/week. That is, the subjects performed the designated exercises at each session.

The Position Stand claims that advanced (those individuals with years of resistance training experience who have attained significant improvements in muscular fitness) weightlifters, powerlifters, and bodybuilders train 4-6 days a week, and that the frequency of training for elite (those athletes who are highly trained and achieved a high level of competition) weightlifters, power lifters, and bodybuilders may total 18 sessions a week (p. 369). Because the references cited are books by Fleck and Kraemer (106) and Zatsiorsky (108), the authors of the Position Stand are apparently basing these claims on their observations of this specific population. However, reports of the pervasive use of anabolic-androgenic steroids among competitive bodybuilders, weightlifters, and power lifters (109-112) render the athletes who use these drugs a highly questionable source of reference for what is purported to be a scientific document for healthy adults (The Position Stand).

Split Routines

The Position Stand states that advanced lifters train 4-6 days a week, and that elite weightlifters and bodybuilders may benefit from using very high frequency training; for example, two sessions a day, 4-5 days a week (p. 369). A study by Hakkinen and Kallinen (113) is cited to support a greater increase in strength and muscle cross-sectional area when training volume was divided into two sessions a day compared with one session a day. However, Hakkinen and Kallinen (113) employed a split routine that is not typically used by the experienced weightlifters and bodybuilders noted in the Position Stand. Ten females (~29 years) with at least 2-3 years of resistance training experience performed approximately 10 sets of squats with 70-100 % 1 RM (1-3 repetitions/set, 18-22 total repetitions) and four sets of leg press or knee extension exercises with 60-70 % 1 RM (5-10 repetitions/set, 20-40 total repetitions) either in one session a day, 3x/wk for three weeks or two sessions a day 3x/wk for three weeks. Half the group used the two sessions/day protocol for the first three weeks followed by the one session/day protocol for the next three weeks; the other half of the group followed the same procedure in reverse order. Percent body fat, which was estimated by skin fold measurement, did not change significantly at any time. With the exercises divided into two sessions a day, there was a significant increase in strength (5.1 %), body mass (1.3 %), and quadriceps femoris cross-sectional area (3.9 %). When the subjects performed the exercises in one session a day, Hakkinen and Kallinen (113) reported no significant increase in strength (0.1 %) or body mass (-0.3 %) in their Results section (p. 120). However, the one session/day pre- and post-training values in their Table 2 (p. 120) show an increase in strength from 2,258 to 2,555 N (13.2 %) with the same number of subjects and a similar standard deviation as shown for the two daily sessions.

Putting aside the questionable data, the practical application of the Hakkinen and Kallinen (113) resistance-training protocol for exercising the major muscle groups in healthy adults is questionable—regardless of how the exercises are distributed. That is, the subjects in the Hakkinen and Kallinen (113) study executed 14 sets (10 sets of squats and four sets of knee extension or leg press exercises) 3x/wk to stimulate the quadriceps. Therefore, advanced trainees who wish to stimulate the major muscle groups of the hips, thighs, legs, lower back, upper back, midsection, chest, shoulders, neck, arms using the Hakkinen and Kallinen (113) protocol of 14 sets of each exercise for each muscle group, would require approximately 140 sets 3x/week. With the rest time recommended in the Position Stand of at least 2-3 minutes between sets and exercises, the weekly time required for resistance training (140 sets x 3x/week x 3 minutes = 1260 minutes) is 21 hours—an overwhelming commitment for many healthy adults.

In summary, most of the frequency studies report no significant difference in response to performing an exercise 2x or 3x/wk, and some studies report similar results training 1x, 2x or 3x/wk. The Position Stand claims that progression may not necessitate a change in frequency for training each muscle group, but that a greater frequency of training may enable a greater volume of exercise for each muscle group. The implication that a greater overall volume of exercise (as a result of a greater frequency of training or split routines) is more effective for enhancing muscular strength, hypertrophy, power, and endurance in any specific population is unsubstantiated (Table 7). There is no evidence cited in the Position Stand to suggest that split routines, as advanced trainees commonly perform them (different muscle groups on different days), are superior to whole-body sessions. The only evidence for split routines is the very unusual protocol of Hakkinen and Kallinen (113), which could require several hours of training each day.

Table 7. Summary of Research Comparing Training Frequency.

Reference	Rating
Gillam (95)	↑
Hakkinen & Kallinen (113)	?
Hoffman et al. (107)	↓
Hunter (96)	↓
McLester et al. (97)	↓
Pollock et al. (54)	↓

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.
? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.
↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.
∗ Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

PERIODIZATION (VARIED MULTIPLE-SET PROTOCOLS)

The Position Stand makes several provocative claims that form the basis for the ACSM's complex and time-consuming recommendations. The first claim is that progression in long-term resistance training requires the manipulation of program variables such as the amount of resistance, exercise selection, order of exercises, number of sets and repetitions, as well as rest time between sets and exercises, and that manipulation of these variables differentially affects specific goals such as muscular strength, hypertrophy, power, and endurance (p. 364). The only reference cited in an attempt to support this opinion is a review by Stone et al. (114).

The second claim in the Position Stand is that each training phase is designed to emphasize a particular physiological adaptation; for example, that hypertrophy is stimulated during the initial *high-volume phase*, whereas strength is maximally developed during the later *high-intensity phase* (p. 365). The only references cited are a review by Fleck (115) and a theoretical model of resistance training by Stone et al. (116).

The Position Stand also claims that the magnitude of strength gains are dependent on the types of muscle actions, intensity, selection and order of exercises, volume of exercise, rest between sets, and frequency of training (p. 366). The only reference cited is a review by Tan (117).

No resistance-training studies are cited to support any of the aforementioned claims in the Position Stand.

The previous sections in this document demonstrate that different training modalities, repetition duration, range of repetitions, number of sets, rest time between sets and exercises, and frequency of training produce very little, if any, difference in outcomes. Therefore, there is no reason to believe the planned manipulation of these variables (so-called "periodization") would significantly affect specific outcomes.

Only three of the studies (118-120) cited in the Position Stand attempted to control volume and intensity (using the authors' definitions of volume and intensity), and compared so-called "periodization" to "traditional" (non-periodized models) resistance training.

Baker et al. (118) matched 33 males (~20 years) with at least six months resistance-training experience, and then randomly assigned them to one of three programs, which included the bench press and squat. Subjects in the "linear periodization"group performed 5 x 10 RM wk 1-4, 5 x 5 RM wk 5-8, 3 x 3 RM and 1 x 10 RM wk 9-11, and 3 x 3 RM wk12. The "undulating periodization" group followed a protocol of 5 x 10 RM wk 1-2, 5 x 6 RM wk 3-4, 5 x 8 RM wk 5-6, 5 x 4 RM wk 7-8, 5 x 6 RM wk 9-10, and 4 x 3 RM wk 11-12. The "traditional" group used 5 x 6 RM throughout the study. After training 3x/wk for 12 weeks, all three groups (linear periodization, undulating periodization, and traditional groups, respectively) showed a significant increase in 1 RM bench press (11.6, 16.4 and 12.5 %), 1 RM squat (27.7, 28.4 and 26.1 %), vertical jump (3.8, 10.1, and 9.3 %), and lean body mass (2.8, 3.3 and 3.2 %). There was no significant difference among the groups for any of the measured variables. Baker et al. (118) concluded that performance outcomes and changes in body composition were similar for periodization and traditional resistance training.

Herrick and Stone (119) randomly assigned 22 previously untrained females (~22 years) to either a progressive resistance program of 3 x 6 RM (traditional) or a varied training protocol of 3 x 10 RM wk 1-8, 3 x 4 RM wk 10-11, and 3 x 2 RM wk 13-14 (periodization), with one-week active rest (low-intensity stationary cycling) between each period. All subjects performed three upper-body and three lower-body exercises 2x/wk for 15 weeks. Both groups, traditional and periodization, respectively, significantly increased 1 RM bench press (25.2 and 31.9 %) and squat (46.3 and 53.5 %). There was no significant difference in strength gains between the traditional and periodization groups. Herrick and Stone (119) concluded that their results did not support the benefits of periodization over traditional progressive resistance training, and they recommended either training protocol for female athletes who wish to maximize strength.

Schiotz et al. (120) matched 22 male Army volunteers (~22 years) based on their years of military training, and then randomly assigned them to a periodization or traditional resistance-training program. Both groups performed the bench press, squat and seven other exercises 2x/wk. The traditional group executed four sets of six repetitions beginning with 80 % 1 RM. The periodization group performed the bench press and squat using 50-105 % 1 RM with different combinations of sets and repetitions throughout the study (5 x 10 wk 1-2, 3 x 10, 1 x 8 and 1 x 6 wk 3, 2 x 8 and 3 x 5 wk 4, 1 x 8, 1 x 6 and 3 x 5 wk 5, 1 x 8 and 4 x 5 wk 6, 1 x 8, 2 x 5, 1 x 3 and 1 x 1 wk 7, 2 x 5, 1 x 3, 1 x 2, and 1 x 1 wk 8, and 2 x 3 and 4 x 1 wk 9-10). The periodization group showed a significant decrease in body fat from 11.6 to 9.9 %. However, there was no significant increase in lean body mass in either group. The increase in 1 RM bench press (10 and 6 %) and 1 RM squat (13 and 14 %) was significant for periodization and traditional resistance training, respectively, but not significantly different between groups. Nor, was there any significant difference between groups in the four Army Ranger Challenge physical performance tests. Schiotz et al. (120) concluded that trainees could follow either a periodization or a traditional resistance-training program and develop similar improvements in muscular strength and performance.

The Position Stand cites five studies (121-125) in an attempt to show that periodization is superior to traditional resistance training (p. 365).

O'Bryant et al. (121) randomly assigned 90 previously untrained males (~19 years) to one of two resistance training programs. Group 1 performed 5 x 10 wk 1-4, 3 x 5 wk 5-8, and 3 x 2 wk 9-11 (intensity not described), while group 2 used 3 x 6 RM for 11 weeks. Subjects performed four exercises (including the free-weight squat) 2x/wk, and five exercises 1x/wk. O'Bryant et al. (121) claimed that the increase in 1 RM squat (estimated from Figure 1, p. 28) was significantly greater for group 1 (~37 %) compared with group 2 (~32 %), as was the increase in cycle ergometer power (~17 and 7 %, groups 1 and 2, respectively). There was no significant increase in body mass in either group of these previously untrained males. O'Bryant et al. (121) concluded that the continuous use of the same number of sets and repetitions resulted in a monotonous training program for group 2, and the lack of variation may have been responsible for the difference between groups in 1 RM squat and cycle power.

O'Bryant et al. (121) also claimed that longitudinal studies suggested that the 3 x 6 RM protocol, which they used to compare with the program in group 1, had previously produced the greatest gains in strength. However, the only resistance-training study cited by O'Bryant et al. (121) was by Berger (39). In fact, Berger (39) compared 3 x 6 RM, 3 x 10 RM, and 6 x 2 RM bench press protocols 3x/wk for nine weeks. The 48 college-age males significantly increased their 1 RM bench press (21, 20, and 17 %, respectively), with no significant difference between the groups. Therefore, Berger's study (39) does not support the claim by O'Bryant et al. (121).

O'Bryant et al. (121) also concluded that their results agreed with three studies by Stone and colleagues (126-128). However, in the first reference Stone et al. (126) did not compare different training models. They trained nine previously sedentary college-aged males 6x/wk for eight weeks. All the subjects followed the same resistance-training protocol. There was no report of any strength measure. The second reference was a review by Stone et al. (127), and the third reference is a book written by Stone and O'Bryant (128). None of these references (126-128) cited by O'Bryant et al. (121) is a resistance-training study that supports the opinion of O'Bryant et al. (121), thereby rendering their claim unfounded and misleading.

Stone et al. (122) reported on one experiment (*Experiment* #1) and two observations (*Observation #1 and #2*). In *Experiment* #1, Stone et al. (122) randomly assigned 20 previously untrained college-age males to what the authors describe as either an experimental (group 1) or control group (group 2). The protocol for group 1 was 5 x 10 (wk 1-3), 5 x 5 (wk 4), 3 x 3 (wk 5), and 3 x 2 (wk 6), while group 2 performed 3 x 6 for weeks 1-6. The level of intensity or percent 1 RM is not described for either group. Both groups performed squats, thigh curls and bench presses 2x/wk, and mid-thigh pulls, floor pulls, and the seated behind-the-neck press 1x/wk for six weeks. The only strength measure reported was the 1 RM squat, with the gain for group 1 (~32 kg) significantly greater than group 2 (~23 kg). There was no report of pre- or post-training data, or percent change for any strength measure.

Stone et al. (122) used the Lewis formula to estimate anaerobic power. They reported a significantly greater gain for group 1 (+4.5 kg/m/s) compared with group 2 (-2.0 kg/m/s). However, Harman et al. (129) reported that the Lewis formula underestimated peak power by 70.1 % and average power by 12.4 % compared with force-platform determination. Harman et al. (129) concluded that the validity of the Lewis formula has never been supported in a scientific peer-reviewed journal, and consequently is not a valid method for estimating average or peak power generated by a subject performing a jump and recommended that its use be discontinued.

Stone et al. (122) noted that group 1 showed an approximate 3.5 % decrease in percent body fat at three weeks and an increase of ~1.1 % during the next three weeks, for a net decrease of ~2.4 %. The changes in percent body fat for group 2 were ~0.1 % at three weeks and ~0.5 % at six weeks. The percent body fat was significantly lower for group 1. Group 1 increased lean body mass by a remarkable ~2.4 kg in the first three weeks, but lost ~2 kg in the next three weeks, with a net gain of 0.4 kg. Group 2 increased by 1.1 kg at three weeks and lost ~2.4 kg during the next three weeks, for a net loss of 1.3 kg of lean body mass. At the end of the 6-week study there was no significant difference in vertical jump height between group 1 (~2.4 cm) and group 2 (~2.2 cm).

Stone et al. (122) claimed that previous studies by Berger (29) and O'Shea (20) have shown that strength gains are most efficiently accomplished with three sets of six repetitions. However, their assumption is weakly supported by one of those studies (29), which is discussed in the Multiple Sets section of this document, and not supported at all by the other study (20), which is discussed in the Range of Repetitions section of this document.

Observations #1 *and* #2 by Stone et al. (122) were not controlled research experiments, and are bereft of any statistical analysis. Therefore, they lend no support for so-called periodization training.

Stone et al. (123) randomly assigned 21 college-age males to either a traditional program or one of two varied multiple-set resistance-training programs. Previous resistance-training experience was not reported. The squat was executed 2x/wk for 5 x 6 RM in group 1, and 2x/wk for 5 x 10 RM, 5 x 5 RM, 3 x 3 RM (wk 1-4, 5-8, 9-12, respectively) in group 2. Group 3 performed 3-5 sets of 3-5 repetitions (RM on Monday, 15 % below RM on Friday) that varied eight times during the 12-week study. There was a significant increase in 1 RM squat for group 2 (15 %) and group 3 (15.4 %), but the change (10 %) for group 1 (n = 1) was not significant. Stone et al. (123) claimed that periodization resistance-training programs produce superior results compared with constant-repetition programs. However, no between-group statistical comparisons were reported. Stone et al. (123) noted that four out of the five subjects in group 1 were removed from the study because they complained of monotony or lack of variation, leaving only one subject in group 1 for evaluation; a dropout rate (80 %) unlike any other resistance-training study cited in this document. The evaluation of only one subject seriously limits any practical application of this study (123).

Willoughby (124) trained 48 males (~20 years) 2x/wk for 12 weeks in four physical education classes. Treatments were randomly assigned to each group. Group 1 performed 3 x 10 RM and group 2 used 3 x 6-8 RM for 12 weeks, while group 3 followed a protocol of 5 x 8-10 RM wk 1-4, 4 x 5-7 RM wk 5-8, and 3 x 3-5 RM wk 9-12. Group 4 refrained from resistance training. The 1 RMs for each exercise were divided by the subject's body mass to estimate the strength to body mass ratio. Neither absolute strength nor percent change in strength was reported, only the ratio of strength to body mass at baseline and post-training. Willoughby (124) did not report post-training values for body mass. Consequently, because it is not known if body mass changed as a result of the resistance training, readers cannot calculate the absolute or percent strength gains from the published data.

For the bench press and squat exercises, Willoughby (124) reported that groups 1, 2, and 3 increased strength significantly more than group 4 (control). It was also reported that strength gains were significantly greater in group 3 compared with groups 1 and 2, and group 2 was significantly greater than group 1. Based on the data reported by Willoughby (124) in Table 1 (p. 137), the correct calculation of the pre- to post-training increase in squat strength for group 2 yields a value of 0.560 rather than 0.385 shown in Table 1 (p. 137). This discrepancy questions whether the 0.676 increase in strength for group 3 was significantly greater than the actual reported 0.560 increase for group 2 (124).

In a different study, Willoughby (125) randomly assigned 92 males (~20 years) to one of three training groups who performed the free-weight bench press and squat exercises 3x/wk for 16 weeks. The subjects were previously trained and considered eligible for the study if they could bench press 120 % of their body mass and squat with 150 % body mass. Although at least three years of resistance training were required for participation, the subjects abstained from resistance training for six months prior to the study. Willoughby (125) stated that it was important to note that the 6-month abstinence constituted a state of detraining in which subjects could have responded differently.

Group 1 performed five sets of 10 repetitions with 78.9 % 1 RM and group 2 performed six sets of eight repetitions with 83.3 % 1 RM for the duration of the study. Group 3 followed a varied program that comprised five sets of ten repetitions with 78.9 % 1 RM wk 1-4, either four or six sets of eight repetitions with 83.3 % 1 RM wk 5-8, three sets of six repetitions with 87.6 % 1 RM wk 9-12, and three sets of four repetitions with 92.4 % 1 RM wk 13-16. Willoughby (125) stated in his Abstract (p. 2) that the protocol for group 3 was six sets of eight repetitions for weeks 5-8. However, in his Methodology section (p. 4) he stated that the protocol for group 3 during the same time interval was four sets of eight repetitions. Consequently, readers cannot determine the exact number of sets. If there was a misprint in either the Abstract or the Methodology sections, that misprint appeared in two publications (125, 130).

This study by Willoughby (125) was apparently published in the *Journal of Human Movement Studies* (130) two years prior to its publication in the *Journal of Strength and Conditioning Research* (125). That is, the same database was apparently used for both publications (125, 130) and the only difference was the way that the main dependent variable (strength to body mass ratio) was presented. That is, Willoughby reported the absolute changes in the strength to body mass ratio from pre-training to weeks 4, 8, 12, and 16 in one publication (125), and reported changes in the strength to body mass ratio from interval to interval (0-4, 4-8, 8-12, 12-16, and 0-16 weeks) in his other publication (130).

Willoughby (125, 130) reported that he monitored and calculated the training volume (total mass lifted per week) for the bench press and squat exercises during each of the four training intervals for weeks 0-4, 4-8, 8-12, and 12-16. The weekly training volume was the product of the amount of resistance times the number of repetitions per set times the number of sets per session times the number of sessions per week for 92 participants (125, 130). The total training volume for each interval is identical in both publications (125, 130) as evidenced by the identical graphs in Figure 1 on page five (125) and Figure 1 on page 242 (130). Willoughby reported that his results revealed a significant multivariate volume difference among the four groups [$F(4,128) = 15.65$; $p<0.0001$], and significantly different training volume for the bench press and squat exercises [$F(2,66) = 8.26$; $p<0.0001$]. These values are identical in both publications (125, 130).

Willoughby (125) reported significant gains in bench press strength to body mass ratio for groups 1, 2 and 3 after four weeks of training, with no significant difference among the groups. At eight, 12 and 16 weeks, the increase for group 3 was significantly greater than groups 1 and 2, with no significant difference between groups 1 and 2. In his Discussion section (p. 6) Willoughby (125) claimed that the decreased volume and increased intensity for group 3 at 8, 12 and 16 weeks resulted in significantly greater gains than groups 1 and 2. However, Figure 1 (p. 5) and the Results section (p. 5) show that the training volume was not significantly different among groups 1, 2 and 3 at eight weeks (125).

In his Results section (p. 6) Willoughby (125) reported that groups 2 and 3 showed a significantly greater gain in the squat strength to body mass ratio compared with group 1 at four, eight and 12 weeks. However, Figure 3 (p. 6) shows no significant difference between groups 1, 2 and 3 at four weeks. At 16 weeks, group 3 showed a significantly greater increase compared with groups 1 and 2, with group 2 significantly greater than group 1. Willoughby (125) claimed that the decreased volume and increased intensity for group 3 did not produce significantly greater gains over group 2 at four, eight and 12 weeks. However, Willoughby's Figure 1 (p. 5) shows that the volume was not significantly different among groups 1, 2 and 3 at four and eight weeks (125).

Willoughby (125) reported that the resistance was changed only after each 1 RM session (every 4 weeks), and that the resistance for each specific 10 RM, 8 RM, 6 RM, and 4 RM was derived from testing the 1 RM. That is, 78.9, 83.3, 87.6, and 92.4 % 1 RM was used for the 10 RM, 8 RM, 6 RM, and 4 RM, respectively. Willoughby cited a study by Berger (131) in both his publications (125, 130) as his rationale for establishing the specific resistance for each RM. However, Berger (131) tested the 1 RM, 5 RM and 10 RM and interpolated the percentage scores for the 2 RM, 3 RM, 4 RM, 6 RM, 7 RM, 8 RM, and 9 RM. He reported data for only one exercise (bench press) and indicated that his table contained approximate values, which were starting points to determine an RM by trial and error. Berger's (131) standard deviations for the percentage of the 5 RM and 10 RM were 3.36 and 3.66, respectively. Therefore, if an individual has a 1 RM bench press of 100 kg and uses the 89.8 kg (89.8 % 1 RM) for the 5 RM, the standard deviation of percentage (89.8 - 3.66 = 86.44 % x 100 kg 1 RM = 86.44 kg, and 89.8 + 3.66 = 93.2 % x 100 kg 1 RM = 93.2 kg) establishes a range of resistance that exceeds the values in Berger's (131) Table 1 (p. 110) for the 4 RM (92.4 kg) and 6 RM (87.6 kg). With a range of values for the 5 RM that exceeds the estimated values used by Willoughby (125, 130) for the 4 RM and 6 RM, predicting a maximal effort of a specific repetition of every set in 92 subjects is highly unlikely.

The only way to determine if the last repetition in a set is a maximal effort (e.g., 4, 6, 8, 10 RM, etc.) is to attempt another repetition. Willoughby (125) claimed that spotters were available to assist a subject in the event that fatigue may have prohibited completion of the designated number of repetitions. However, he reported that all the subjects in each training group were able to complete the designated number of repetitions with the assigned resistance without assistance from spotters (125). This reported scenario questions whether the last repetition was a true RM for the free-weight bench press and squat exercises. In addition, with a given percent of the 1 RM (e.g., 80 %), subjects will differ from one another by one to several repetitions at the point of muscular fatigue for a specific exercise (132), as well as differ from one exercise to another within an individual (133). Both of these studies (132-133) are discussed in our Local Muscular Endurance section. Therefore, the use of a specific percent 1 RM to establish the exact resistance for a specific RM such as 4 RM, 6 RM, 8 RM, or 10 RM is questionable. If each set in this study was not a maximal effort on the last repetition, then Willoughby's (125) description of multiple sets of RM (e.g., 5 sets of 10 RM in group 1) is not accurate. If the subjects in groups 1 and 2 were really able to exert a maximal effort on exactly the last repetition for each of the five sets in group 1 and for the last repetition on each of the six sets in group 2 of the bench press and squat exercises three times a week for 16 weeks, then it would lend support to Willoughby's claim that these multiple-set protocols may have resulted in over-training (125).

In the previous publication (130) of this study (125), Willoughby reported no significant difference in bench press among groups 1, 2 and 3 at 4, 8 and 12 weeks (p. 241). However, Willoughby (130) claimed in his Abstract (p. 233) that the increase in strength to body mass ratio for groups 2 and 3 was significantly greater than group 1 at 12 weeks, and his Table 1 (p. 240) shows groups 1 and 3 significantly greater than group 2 at 12 weeks. Willoughby (130) claimed in his Results (p. 241-3) that group 3 showed greater gains than groups 1 and 2, with group 2 significantly greater than group 1 during weeks 13-16. However, in his Abstract (p. 233) and in Table 1 (p. 240) he reported no significant difference between groups 1 and 2 from weeks 13-16. Willoughby (130) claimed in his Discussion (p. 243-4) that after 12 weeks of training there was no significant difference between groups 1 and 2. However, Willoughby noted in his Abstract (p. 233) that group 2 was significantly greater than group 1 at 12 weeks, and Table 1 (p. 240) showed that group 1 was significantly greater than group 2 at 12 weeks (130).

In the squat exercise, Willoughby (130) reported no significant difference in strength to body mass ratio among groups 1, 2 and 3 during the first eight weeks (p. 243). However, he noted in his Abstract (p. 233), in Table 2 (p. 241), and his Discussion (p. 244) that group 3 showed a significantly greater increase than groups 1 and 2 during weeks four through eight. Willoughby (130) reported in his Results (p. 243) that group 3 was significantly greater than groups 1 and 2, and that group 2 was significantly greater than group 1 at 12 weeks. However, he claimed in his Abstract (p. 233) that groups 2 and 3 were significantly greater than group 1, and in his Discussion (p. 244) claimed that there was no significant difference between groups 1 and 2 at 12 weeks. At 16 weeks group 3 had a significantly greater gain compared with groups 1 and 2 (130).

Willoughby (125) also claimed that previously published resistance training studies (32, 122, 134-135) suggest that so-called periodization programs produce significantly greater strength gains than traditional resistance training. The studies by Stone et al. (122) and Stowers et al. (32) were previously discussed in this section and our Multiple Sets section, respectively. Christian and Seymour (134) trained only one group of subjects. There was no comparative training group or control group. Therefore, this study (134) does not support Willoughby's claim that one training protocol is superior to another (125).

Swanson and Moffatt (135) assigned 32 previously untrained college-age males to one of two training groups (performing similar exercises) or a control group. One group performed 3 x 6 RM and the other used 3 x 10 RM wk 1-2, 3 x 5 RM wk 3-5, and 3 x 3 RM wk 6-8. Both groups trained 2x/wk for eight weeks. There was a significant increase in muscular strength (1 RM bench press and squat) and girth measurements in both groups (data not reported). However, there was no significant difference in strength gains or girth measurement between the two training groups. Contrary to the claim by Willoughby (125), Swanson and Moffatt (135) concluded that periodization was no more effective than traditional strength training for increasing muscular strength and girth size.

Training Volume

Although the term *training volume* is frequently used in the resistance-training literature, people who believe it is relevant to productive resistance training may interpret the term differently. From a conceptual standpoint, it may have little or no relevance to the efficacy of resistance-training protocols. Obviously, some undefined threshold of training volume must be attained to stimulate adaptations in muscular strength, hypertrophy, power, and endurance, but there is very little evidence to suggest that a specific volume of training differentially affects any of these outcomes. Using the exact formula for training volume noted by Willoughby (125, 130), where volume is equal to mass x repetitions per set x sets per session x sessions per week, the following hypothetical scenario demonstrates the lack of relevance, or perhaps the absurdity, in attempting to calculate the volume of exercise, or to compare different protocols based on training volume. If an individual performs one set of 10 RM bench presses with 100 kg 2x/wk, the weekly training volume is equal to 2,000 units (100 x 10 x 1 x 2). However, performing 10 sets of one repetition with 100 kg (the 10 RM) 2x/wk is 2,000 units (100 x 1 x 10 x 2), and 10 sets of 10 repetitions with 10 kg 2x/wk is also 2,000 units (10 x 10 x10 x 2). Based on the existing literature (discussed in other sections of this document), the first example would certainly be an adequate stimulus for adaptations in muscular strength, hypertrophy, power, and endurance, while the last two examples may generally be considered an inadequate stimulus; even though the training volume, as it is described by Willoughby (125, 130), is identical in the three hypothetical examples.

Contrary to the conclusion by Willoughby (124-125, 130) that "periodization" is superior to traditional resistance training, an alternative conclusion is that his studies suggest that a lower-volume resistance-training program (fewer sets) appears to be more effective in producing strength gains than the higher-volume protocols recommended throughout the Position Stand (3-6 sets of each exercise). This study (125,130) raises the question as to possible different outcomes in groups 1 and 2 had they also executed fewer sets throughout the study. Without such a comparison group, the claim by Willoughby (125,130) and in the Position Stand that "periodization" is an important component of a resistance-training program for optimal strength—is unsubstantiated.

The Position Stand claims that advanced resistance trainees have demonstrated a complex, cyclical pattern of training variation in order to optimize performance. Two references are cited (136-137) regarding that claim (p. 373). Hakkinen et al. (136) tested 13 male Finnish weightlifting champions and national record holders who had participated in weightlifting for approximately seven years. Every four months for a duration of one year they were evaluated for maximal bilateral isometric knee-extensor strength, Olympic lifts (snatch, clean and jerk), squat jump, countermovement jump, drop jump, integrated electromyography (IEMG) and fiber composition (muscle biopsies) of the vastus lateralis, as well as body mass, percent body fat, and thigh girth. Following the programs designed by their personal coaches, participants trained 5x/wk for competitive Olympic lifting. The exercises are described as the snatch, clean and jerk, various power lifts, pulling exercises, squat lifts, pressing exercises, and other strengthening exercises for selected muscle groups. No other information is provided regarding specific training protocols (repetition duration, range of repetitions, number of sets, intensity, etc.).

The only improvement was a significant increase (9 %) in squat jump performance (136). There was no significant change in the snatch lift, clean and jerk, isometric knee-extension torque, total mean fiber area, fast-twitch percentage, or mean areas of the fast-twitch and slow-twitch vastus lateralis. Body mass, percent body fat, and thigh girth did not change significantly. There was no significant improvement in countermovement jump, drop-jump performance, or maximal IEMG during the isometric knee extension, squat jump, countermovement jump, or drop-jump performance. Thus, only one of the 17 measured variables showed a significant change after one year of training. More importantly, Hakkinen et al. (136) did not compare different resistance-training protocols.

In the other study by Hakkinen et al. (137), which involved some of the participants from their previous study (136), they tested nine Finnish weightlifting champions and national record holders who had been training for a similar time of seven years. The training programs and testing intervals were similar to those described in their preceding study (136). After two years, there was a significant increase in the Olympic weightlifting total (2.8 %), thigh girth (1.3 %), and fat-free mass (2.0 %). There was no significant change in maximal isometric torque, maximum IEMG, force-time and IEMG-time curves, mean fiber area of either fast-twitch or slow-twitch fibers, total fiber area, or percentage of fast-twitch fibers (137).

In both of these studies by Hakkinen and colleagues (136-137) the resistance-training programs are not described in any detail, and they resulted in very few improvements in various outcomes. The casual reader of the Position Stand who does not scrutinize the methodology and results of the cited references, and their relevance to how they are being cited, may be unjustly impressed because of the noteworthy authors and the elite population of subjects. Most importantly, there is no comparison of one training program to another in either study. Therefore, neither reference (136-137) supports the superiority of one training program over another.

In summary, none of the aforementioned studies (118-125,136-137) cited in the Position Stand compared the so-called "periodization" protocols with single-set programs that simply varied the order or type of exercises to add some variety to the training. The Position Stand claims that the planned manipulation of program variables in advanced trainees can eliminate natural training plateaus and enable higher levels of muscular strength, hypertrophy, power, and local muscular endurance. That claim, which is central to the overall framework of the Position Stand, has very little supporting evidence (Table 8).

Table 8. Summary of Periodization Research.

Reference	Rating
Baker et al. (118)	↓
Hakkinen et al. (136)	↓
Hakkinen et al. (137)	↓
Herrick & Stone (119)	↓
O'Bryant et al. (121)	↑
Schiotz et al. (120)	↓
Stone et al. (122)	?
Stone et al. (123)	?
Swanson & Moffatt (135)	*
Willoughby (124)	?
Willoughby (125)	?

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.
? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.
↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.
* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

LOCAL MUSCULAR ENDURANCE

Local muscular endurance is defined in the Position Stand as *submaximal local muscular endurance* or *strength endurance* (p. 371). When it is reported as repetitions performed to fatigue with a given amount of resistance pre- and post-training, it is usually referred to as a test of "absolute muscular endurance". If the resistance is adjusted from a specific percent (e.g., 80 %) of the pre-training 1 RM to the same percent of the post-training 1 RM, it is usually referred to as "relative muscular endurance". Predictably, absolute muscular endurance should increase as a result of increased strength. However, the relationship between strength gains and absolute muscular endurance is not linear. For example, if a pre-training 1 RM is 100 kg and the maximal number of repetitions with 80 % 1 RM (80 kg) is 10, and the number of repetitions post-training increases 100 % to 20 with the same resistance (80 kg), the individual has become stronger and each repetition is therefore easier, but the person is not 100 % stronger. A 100 % increase in strength would require a 1 RM of 200 kg, or 10 repetitions with approximately 160 kg (80 % of the post-training 1 RM).

The Position Stand states that limited effects are observed in relative muscular endurance as a result of traditional resistance training (p. 371). One study (138) is cited. Mazzetti et al. (138) matched and randomly assigned 20 males (~24 years) to either a supervised or unsupervised resistance-training program. All the subjects had 1-2 years of resistance-training experience. Both groups performed the same resistance-training protocol of 3 x 12 RM wk 1-2, 3 x 8-10 RM wk 3-6, 3-4 x 6-8 RM wk 7-10, 2-3 x 3-6 RM wk 11-12 using identical equipment (free weights and machines) 3-4x/wk (~8 exercises per session) for 12 weeks. There was a significant increase in 1 RM squat (33 and 25 %) and bench press (22 and 15 %), supervised and unsupervised groups, respectively, with the gains in strength significantly greater for the supervised group. Baseline relative muscular endurance for the free-weight bench press exercise was reported as the number of repetitions performed to fatigue using 80 % of the pre-training 1 RM. After 12 weeks, the resistance for the relative endurance test was increased to 80 % of the post-training 1 RM (33 and 25 % for the squat, and 22 and 15 % for the bench press, supervised and unsupervised groups, respectively). The number of repetitions to fatigue (~7) was similar in both groups pre-training, and remained unchanged post-training (~7). Mazzetti et al. (138) concluded that relative muscular endurance was not compromised (no significant change) as a result of the resistance training.

It should be recognized that the results of Mazzetti et al. (138) could be interpreted in different ways. That is, the relative muscular endurance (maximal number of repetitions with a specific percent of 1 RM) does not appear to change with training—and there is very little evidence to suggest that it should. Or, that the performance of relative muscular endurance increases by the amount of resistance required to equal 80 % of the post-training 1 RM. The former interpretation renders the aforementioned statement in the Position Stand irrelevant; the latter is a contradiction to that statement.

A resistance-training study by Hickson et al. (139) confirmed the validity of both the aforementioned interpretations. Hickson et al. (139) trained eight previously untrained males and females (~28 years) 3x/wk for 16 weeks. Subjects performed five sets of five repetitions with 80 % 1 RM for the free-weight bench press and squat exercises, and 3 x 5 RM for the knee-extension, knee-flexion and elbow-extension exercises on machines, with two minutes rest between sets. The 1 RM and the maximal number of repetitions performed at 40, 60, and 80 % 1 RM for the bench press and squat exercises were tested pre- and post-training. Subjects were tested post-training at the same absolute pre-training resistance. They were also tested post-training with a new adjusted resistance based on the new post-training 1 RM. There was a significant increase in 1 RM bench press (23 %) and squat (37 %). The absolute endurance for the bench press significantly increased ten, eight, and eight repetitions at 40, 60, and 80 % 1 RM, respectively. Similarly, the absolute endurance for the squat significantly increased 25, 17, and 12 repetitions at 40, 60, and 80 % 1 RM, respectively. However, when retested at the same relative intensity (adjusted to post-training 1 RM), the number of repetitions was similar to pre-training for the bench press (~39, 17, and 7) and the squat (~53, 22, and 9) at 40, 60, and 80 % 1 RM, respectively. Hickson et al. (139) concluded that relative muscular endurance remains unchanged following resistance-training induced strength gains. Or, one could conclude that because the resistance for the post-training relative endurance test was increased 23 % for the bench press and 37 % for the squat, the subjects enhanced performance of relative muscular endurance in the bench press and squat by 23 and 37 %, respectively.

The Position Stand claims that lighter resistance coupled with a greater number of repetitions (>20) have been shown to be most effective for enhancing muscular endurance (p. 372), and two studies (140-141) are cited.

Anderson and Kearney (140) randomly assigned 43 previously untrained (described as unable to bench press 120 % of their body mass) males (~21 years) to perform the bench press exercise 3x/wk for nine weeks using one of three training protocols: 3 x 6-8 RM, 2 x 30-40 RM, or 1 x 100-150 RM (low, medium and high-repetition groups, respectively). The maximum number of repetitions with 40 % of the 1 RM was used to test relative muscular endurance, and 27.23 kg was the mass used pre- and post-training to test absolute muscular endurance. The increase in 1 RM bench press for the low-repetition group (~20 %) was significantly greater than the medium (~8 %) and high (~5 %) repetition groups. There was a significant increase in absolute muscular endurance for the low, medium and high-repetition groups, respectively (~24, 39, and 41 %) with no significant difference among the groups. The medium- and high-repetition groups significantly increased their relative endurance (~22 and 28 %, respectively). The claim in their Abstract (p. 1) that there was a decrease in relative endurance in the low-repetition group is not supported by their data. That is, there was no significant change in the low-repetition group. Anderson and Kearney (140) noted that the lack of a significant change in relative endurance for the low-repetition group must be viewed in light of the fact that their maximal strength increased by 20 %, and thus the resistance used for the relative endurance also increased 20 %.

The Position Stand also cites Anderson and Kearney (140) as evidence to suggest that to increase local muscular endurance one should minimize recovery between sets (p. 372). Anderson and Kearney (140) assigned two minutes rest between each of two sets for their high-resistance and medium-resistance groups. There was no comparison of different rest times between groups because both groups rested the same time between sets, and the low-resistance group performed only one set. Anderson and Kearney (140) reported no data relative to different rest time between sets. Therefore, their study (140) does not support the claim in the Position Stand.

Stone and Coulter (141) randomly assigned 50 previously untrained females (~23 years) to perform 3 x 6-8 RM, 2 x 15-20 RM, or 1 x 30-40 RM for each of five exercises (bench press, squat, triceps pushdown, biceps curl, and lat pull) 3x/wk for nine weeks. Strength (1 RM) and muscular endurance for the free-weight bench press and squat were reported. In one test for absolute muscular endurance the subjects used 15.9 kg in the bench press and 25 kg in the squat for both the pre- and post-training assessments. Stone and Coulter (141) claimed that muscular endurance in the bench press (45 % 1 RM) and squat (55 % 1 RM) was also tested with Load 1, which was based on the pretest 1 RM, and Load 2 based on posttest 1 RM. Because it would be difficult to establish the resistance for Load 1 before actually testing the 1 RM, we assume that Stone and Coulter (141) are referring to the pre-training and post-training 1 RMs. The authors also claimed that Load 2 was based on the post-training 1 RM. However, pre-training and post-training data were reported for Load 2 in their Table 1 (p. 233). The absence of a more specific description of the testing procedure renders the exact nature of the Load 2 dependent variables unknown. However, we assume that for this test of muscular endurance the resistance for the post-training test was adjusted to either 45 or 55 % of the new post-training 1 RM. Therefore, this was the only true test of relative muscular endurance.

In their Methods section (p. 232), Stone and Coulter (141) claimed that all 50 subjects completed the entire training program. However, in their Discussion section (p. 233), Stone and Coulter (141) claimed that their dropout rate of 42 % in nine weeks was higher than normally reported in supervised exercise programs; a discrepancy in reporting at best. There are asterisks next to five of the values reported by Stone and Coulter (141) in their Table 1 (p.233). However, there is no description in the legend or the narrative of what the asterisks represent.

The three training programs produced a significant increase in 1 RM bench press (18.9, 16.7, and 11.6 %) and squat (33.0, 30.9, and 25.1 %), low, medium, and high-repetition groups, respectively, with no significant difference in strength gains among the groups for either exercise (141). In their Abstract (p. 231) Stone and Coulter (141) claimed that the low-repetition high-resistance protocol produced greater gains in strength, and in their Practical Applications section (p. 234) they claimed that the strength-training professional must rely on low-repetition high-resistance training to maximize strength. However, their own descriptive data (Table 1, p.233) and statistical analyses (Table 2, p. 233) fail to support these claims.

Absolute muscular endurance for the bench press with the pre-training resistance (15.9 kg) increased significantly in the low-repetition (31.0 %) and medium-repetition group (41.2 %). Absolute endurance for the squat with 25 kg significantly increased in the low-repetition (84.3 %) and high-repetition group (80.1 %). However, there was no significant difference in the post-training gains in absolute muscular endurance among the three groups for either exercise (141). Absolute muscular endurance (described by Stone and Coulter (141) as "Relative Endurance Load 1") that was based on 45 % of the pre-training 1 RM bench press and 55 % of the pre-training 1 RM squat significantly increased for the low-repetition (24.8 %) and high-repetition group (30.4 %) in the bench press, and 65.9 and 82.6 % in the squat for the low-repetition and high-repetition groups, respectively. There was no significant difference among the three groups for either exercise. In addition, there was no significant change in the only true measure of relative muscular endurance for any of the groups in either the bench press or squat, as assessed by what Stone and Coulter (141) described as "Relative Endurance Load 2".

Contrary to their claim in the Discussion section (p. 233) that there was a 6.9 % loss of relative muscular endurance for the high-resistance low-repetition group, Stone and Coulter (141) reported that the pre- to post-training difference of three repetitions in this group was not statistically significant (Table 1, p. 233). Regardless of how the muscular endurance tests were defined or how they are interpreted, Stone and Coulter (141) stated in their Results section that there were no significant post-training differences among the three training programs (low, medium, and high-repetition groups) in strength, absolute endurance, or relative endurance in Loads 1 and 2. In fact, contrary to their conclusion that the statistical results do not unequivocally support a strength/endurance continuum of strength training, they actually reported no evidence to support their conclusion.

In summary, the claim in the Position Stand that a greater number of repetitions are more effective for enhancing muscular endurance is not supported by the results reported by Stone and Coulter (141).

The Position Stand claims that moderate- to low-resistance training coupled with a high number of repetitions has been shown to be most effective for improving absolute and relative local muscular endurance (p. 371). Two studies (140, 142) are cited in an attempt to support the claim. The study by Anderson and Kearney (140) was previously discussed. Huczel and Clarke (142) measured muscular strength and absolute muscular endurance in 30 untrained and resistance trained females (18-34 years), and concluded that that the resistance-trained females were stronger and had greater muscular endurance than untrained females. There was no comparison of different training protocols, and no report on the resistance-training program for the previously trained females. More importantly, this was not a longitudinal resistance-training study (142). Therefore, it does not support the claim in the Position Stand.

The Position Stand claims that high-volume programs have been shown to be superior for enhancing muscular endurance, although it is not stated whether this refers to absolute or relative endurance (p. 372). Four studies (34-35, 139, 143) are cited in an attempt to support this claim. The study by Hickson et al. (139), which was previously discussed, does not support the claim in the Position Stand.

Two of the previously discussed Experiments #2 and #4 by Kraemer (35) involved male (~20 years) American football players. In Experiment #2, 40 Division I players performed either one set or three sets of 8-12 RM for each of 10 exercises 3x/wk for 10 weeks. The number of repetitions with 80 % 1 RM for the bench press and 85 % 1 RM leg press were assessed pre- and post-training. There was no significant change in relative muscular endurance for either exercise in the 1-set group. The 3-set group significantly increased relative muscular endurance 32.2 % in the bench press and 35.7 % in the leg press. In Experiment #4, 44 Division III players performed either one set of 8-12 RM for each of approximately 10 exercises 3x/wk for 24 weeks, or 2-4 sets of either 3-5, 8-10, or 12-15 RM for each of approximately 10 exercises 4x/wk for 24 weeks. There was a similar rest time between sets (1-2 minutes) for both groups. Relative muscular endurance tests at 80 % 1 RM for the bench press and 85 % 1 RM leg press were assessed pre- and post-training. There was a significant increase in relative muscular endurance in the bench press (37.6 and 56.2 %) and leg press (22.5 and 41.3 %), single-set and multiple-set groups, respectively, with the increase significantly greater for the multiple-set group. In other words, the number of repetitions significantly increased in spite of the increase in resistance, which was based on the post-training 1 RM. These remarkable changes in relative muscular endurance reported by Kraemer (35) in both Experiment #2 and Experiment #4 are unlike those in any of the other cited studies.

Marx et al. (34) randomly assigned 34 previously untrained females (~23 years) to single-set or multiple-set resistance training for six months. The single-set group performed one set of 8-12 RM for each exercise on two alternating circuits of 10 machine exercises 3x/wk. The multiple-set group trained 4x/wk and performed 2-4 sets of 8-10 RM on Tuesday and Friday, and 3-5 RM, 8-10 RM, or 12-15 RM on Monday and Thursday, using 7-12 free-weight and machine exercises. Muscular endurance was measured for the bench press and leg-press exercises using 80 % 1 RM. Bench press endurance significantly increased for the single-set (1 repetition) and multiple-set (2.3 repetitions) groups, and leg-press endurance significantly increased for the single-set (2.1 repetitions) and multiple-set (7.3 repetitions) groups, with the multiple-set group significantly greater than the single-set group in both exercises. Marx et al. (34) did not report an adjustment in the resistance based on the post-training 1 RM. Therefore, readers do not know if the data for muscular endurance was absolute or relative.

McGee et al. (143) assigned 29 males (17-26 years), who were involved in a college weight-training class (resistance training experience not described), to perform the squat exercise 3x/wk for seven weeks using one of three protocols: 1 x 8-12 RM, 3 x 10, or 3 x 10 wk 1-2, 3 x 5 wk 3-5, 3 x 3 wk 6-7. Maximal mass lifted in the squat exercise increased pre- to post-training by 6, 7, and 9 %, 1-set, 3-set, and varied multiple-set groups, respectively, with the 7 and 9 % increase statistically significant. There was no significant difference among the groups. A greater number of repetitions post-training (11, 15, and 17, respectively) were reported for the three groups, but the increase of 11 repetitions was not statistically significant. However, McGee et al. (143) noted that there was no significant difference among the groups in any post-training outcome.

The Position Stand claims that the duration of rest intervals between sets and exercises (1-2 min rest between sets of 15-20 repetitions, and less than 1 min rest between sets of 10-15 repetitions) affects muscular endurance, and that bodybuilders who typically train with high volume and short rest periods demonstrate a lower fatigue rate compared with power-lifters who typically train with low to moderate volume and longer rest periods between sets and exercises (p. 372). A study by Kraemer et al. (144) is cited in an attempt to support the superiority of high-volume resistance training with shorter rest periods.

Kraemer et al. (144) matched nine male bodybuilders and eight power-lifters (~22 years) who had been involved in competitive lifting from 4-6 years. Resistance training was monitored for six months prior to the study. The training sessions prior to this study (144) were characterized as sets of 6-12 RM with 10-90 seconds rest for the bodybuilders, and 1-8 RM with 120-420 seconds rest between sets and exercises for the power-lifters. The experimental session involved the performance of three sets of 10 RM for each of 10 free-weight and machine exercises, with 10 seconds rest between sets and alternating 30 and 60 seconds rest between exercises. Results showed that the only significant differences during the exercise session were that the power-lifting group exhibited a significantly greater incidence of dizziness and nausea compared with the bodybuilders. The power-lifters were significantly stronger than the bodybuilders in the bench press and leg press, but they used a lower percent of their 1 RM to perform the exercises. However, there was no significant difference between groups in the total amount of work (described as resistance x vertical displacement) performed during the session. Heart rate, plasma volume, lactic acid, epinephrine, norepinephrine, dopamine, and rating of perceived exertion significantly increased pre- to post-exercise in both groups, with no significant difference between groups. The results of this study (144), and specifically the absence of any report of muscular endurance or fatigue rate, render the claim in the Position Stand unfounded.

Although not stated in the Position Stand, the research strongly suggests that relative muscular endurance varies with different exercises (132-133), and that the relationship between muscular strength and local relative muscular endurance does not appear to change as a result of resistance training (145). Hoeger et al. (132) reported the maximal number of repetitions performed in 38 untrained males (~35 years) on seven different free-weight and machine exercises using 40, 60, and 80 % 1 RM. There was a significant difference in the maximal number of repetitions with different exercises. For example, the subjects performed an average of 9.8 repetitions in the bench press and 15.2 repetitions in the leg press, using 80 % 1 RM for both trials. Hoeger et al. (132) concluded that the maximal number of repetitions performed at selected percentages of the 1 RM is not the same for all exercises.

Hoeger et al. (133) evaluated 25 resistance-trained males (~29 years), 40 untrained females (~37 years), and 26 trained females (~24 years). The experience in the resistance-trained subjects ranged from two months to four years. Hoeger et al. (133) also included data for untrained males from their previous investigation (132). The maximal number of repetitions was recorded on seven free-weight and machine exercises at 40, 60, and 80 % 1 RM. Hoeger et al. (133) reported a significant difference in the maximal number of repetitions among the seven exercises. For example, 12.2 repetitions in the bench press and 19.4 in the leg press at 80 % 1 RM. Although this was a cross-sectional comparison of different groups, and some of the exercises showed a significant difference in the maximal number of repetitions between the resistance-trained and untrained males, there was no significant difference in the bench press or leg press exercises at 80 % 1 RM. Hoeger et al. (133) concluded that when comparing trained and untrained males, there was no significant difference in the maximal number of repetitions performed at a specific percent of 1 RM.

Mayhew et al. (145) trained 70 males (~20 years) and 101 females (~20 years) in a college fitness class 3x/wk for 14 weeks. Subjects performed free weight and machine exercises for the chest, arms, back, abdomen, and lower body using a 5-12 RM (number of sets not reported). There was a significant increase in the 1 RM free-weight bench press for males (13.7 %) and females (25.9 %). With the same percent of 1 RM pre-and post-training (~77 %), and a resistance adjusted to post-training 1 RM (+13.7 % and 25.9 %, males and females, respectively), the number of maximal repetitions was similar pre- and post-training in males (10.8 and 11.0 repetitions, pre- and post-training, respectively) and females (12.4 and 12.6 repetitions, pre- and post-training, respectively). Mayhew et al. (145) concluded that there was no change in the relationship between strength and relative muscular endurance as a result of resistance training, and that the maximal number of repetitions can be used to assess improvements in strength (1 RM).

Table 9. Summary of Local Muscular Endurance Research.

Reference	Rating
Anderson & Kearney (140)	?
Hickson et al. (139)	↓
Hoeger et al. (132)	*
Hoeger et al. (133)	*
Huczel & Clarke (142)	↓
Kraemer (35)	?
Kraemer et al. (144)	↓
Marx et al. (34)	?
Mayhew et al. (145)	*
Mazzetti et al. (138)	?
McGee et al. (143)	↓
Stone & Coulter (141)	↓

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.
? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.
↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.
* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

These studies (132-133, 139, 145) illustrate the dominant role played by genetic factors. That is, although the relationship between 1 RM and relative muscular endurance may differ among people and among exercises within an individual (132-133), increased strength does not appear to significantly affect this relationship (139, 145).

In summary, any reasonable range of repetitions (e.g., 3-6 RM, 8-10 RM, 12-15 RM) will enhance muscular strength and absolute muscular endurance. As measured by the number of repetitions performed with a specific percent of pre-training and adjusted post-training 1 RM, there is very little evidence, either theoretically or empirically, that relative muscular endurance changes as a result of resistance training (Table 9), unless the increase in post-training resistance is considered.

POWER

For advanced power training the Position Stand recommends a varied multiple-set (3-6 sets) power protocol consisting of 1-6 repetitions, which they claim should be integrated into a resistance-training program (p. 371). There is no reference that supports this recommendation.

The Position Stand claims that heavy resistance training may actually decrease power output unless explosive movements are also performed, and one study (146) is cited (p. 371). Bobbert and Van Soest (146) conducted a simulated investigation of vertical jumps, with muscle stimulation as input and movement dynamics as output. This was not a training study. Bobbert and Van Soest (146) noted that the conclusions of their study were hypotheses. Therefore, the study (146) does not support the claim in the Position Stand.

The Position Stand claims that a program consisting of movements with high power outputs and relatively light loads are more effective for improving vertical jump than traditional resistance training (p. 371). Two references (147-148) are cited. Hakkinen and Komi (147) trained eleven males (~25 years) who had earlier experience with resistance training (not specified) 3x/wk for 24 weeks. Subjects performed the barbell squat for 1-10 repetitions per set using 70-100 % 1 RM for a total of 18-30 repetitions at each session. During the 3rd, 5th, and 6th training months, they also performed 3-5 eccentric-only squats with 100-120 % 1 RM. The resistance training produced a significant increase in 1 RM squat (30.2 %) and vertical jump (7.3 %). In a follow-up study, Hakkinen and Komi (148) trained ten males (~27 years), who were accustomed to resistance training, 3x/wk for 24 weeks. With a maximal effort, the subjects executed five different types of jumping exercises for a total of 100-200 jumps per session. Jump training produced a significant increase in 1 RM squat (6.9 %) and vertical jump (21.2 %).

Not surprisingly, the group in the second study by Hakkinen and Komi (148) who practiced jumping for 24 weeks (7,200-14,400 jumps) had a greater increase in vertical jump than the group from the previous study (147) that did not practice jumping. However, Hakkinen and Komi (147-148) did not randomly assign subjects to either a resistance-training or jump-training group, nor did they statistically compare one training group with the other. Each training group was compared with a control group. The absence of a statistical comparison of jump training with traditional resistance training in either study (147-148) renders the claim in the Position Stand unsubstantiated.

The Position Stand claims that loaded jump squats with 30 % 1 RM have been shown to increase vertical jump height more than traditional back squats and plyometrics (p. 371). In one of the references cited, Wilson et al. (149) randomly assigned 64 subjects (~23 years), who were currently weight training for at least one year, to one of four groups: traditional resistance training consisting of 3-6 sets of 6-10 RM squat exercise, depth-jump training (plyometric group), 3-6 sets of explosive resistance training (loaded jump squats) with 30 % of maximal isometric force (max power group), or no training. After training 2x/wk for 10 weeks there was a significantly greater increase in vertical jump (14.8 %) and countermovement jump (17.6 %) in the group who performed 3-6 sets of weighted jump squats (max power group). None of the groups significantly increased the rate of force development or decreased 30-meter sprint time. The traditional (6.5 %) and max-power group (5.2

%) significantly increased peak power for the 6-second cycle test—perhaps the only true power measurement reported—with no significant difference between groups. The max-power group was the only group to significantly increase isokinetic (5.2 rad/s) peak torque (7.0 %). However, the data presented raises the question of why the increase in peak torque for the traditional group (8.7 %), with a smaller standard deviation both pre- and post-training and a greater number of subjects (n = 15) compared with the max-power group (n =13), did not show a statistically significant difference. The traditional group produced a significant increase in vertical jump (6.8 %) and countermovement jumps (5.1 %). The traditional weight-training group was the only group to significantly increase maximal knee-extension force (14.4 %). The results of this study by Wilson et al. (149) actually show that with the exception of the questionable difference in isokinetic knee-extension torque, the only significantly greater increases in the max-power group were the jump movements; perhaps simply because the subjects practiced jumping for 10 weeks.

In a later study by Wilson et al. (150), 45 males (~23 years), who were weight training for at least one year, were randomly allocated to one of three groups: traditional resistance training, plyometric training, or control. The resistance-training group performed 3-6 sets of 6-10 RM squats and bench presses, and the plyometric group executed 3-6 sets of 6-10 depth jumps (20-70 cm) and medicine-ball throws (4-10 kg). Both groups trained 2x/wk for 8 weeks. The resistance-training group significantly increased 1 RM squat (20.9 %), counter-movement jump (21.2 %), isoinertial jump height with 50 % body mass (6.1 %), 1 RM bench press (12.4 %), average force in the push-up (6.8 %), isoinertial bench-press throw (8.4 %), and upper-body rate of force development (15.5 %). The plyometric group significantly increased lower-body rate of force development (27.5 %), counter-movement jump (18.1 %), and average force in the push-up (8.0 %). The resistance-training group significantly increased in seven out of 14 tested variables, while the plyometric group significantly gained in only three out of 14 variables. Most notably, there was no significant difference in the increase in counter-movement jump between groups. This study by Wilson et al. (150) was not cited in the Position Stand.

It appears that resistance training coupled with practice of the specific skill to be enhanced (such as jumping) is all that is required to enhance that specific activity. For example, Clutch et al. (151) randomly assigned 16 males from a weight-training class and 16 males from a volleyball team (~21 years) to either a resistance-training program with no depth jumping or a program of resistance training and depth jumping. Resistance training consisted of 3 x 6 RM for the squat, bench press, and dead-lift exercises. The depth-jump protocol required performing four sets of ten depth jumps from heights of 0.75-1.10 meters. The groups trained 2x/wk for 16 weeks. Three of the four groups significantly increased vertical jump height: resistance trainees who performed resistance training and depth-jump training (3.73 cm), volleyball players who performed resistance training (4.25 cm), and volleyball players who performed resistance training and depth jumps (3.21 cm), with no significant difference among the three groups. The volleyball players who performed resistance training had similar gains in vertical jump as the volleyball players who performed resistance training and depth jumping exercises. The group in the weight-training class that performed resistance training and did no jumping was the only group to show no significant improvement in vertical jump. Clutch et al. (151) concluded that a program of depth jumping adds nothing to a program that already includes resistance training and other jumping movements, such as those inherent in volleyball.

Two references are cited in the Position Stand (p. 371) in an attempt to support the claim that loaded jump squats with 30 % 1 RM have been shown to increase vertical jump performance. One is a study by Kaneko et al. (152), and the other is the previously discussed study by Moss et al. (15). There was no report of vertical jump performance in either of these studies, perhaps because the subjects trained the elbow flexors. Therefore, these studies (15, 152) fail to substantiate the claim in the Position Stand.

The Position Stand recommends inclusion of total-body exercises such as the power-clean and push-press exercises for developing muscular power, and claims that these exercises have been shown to require rapid force production. The Position Stand also claims that the quality of effort for each repetition, which is defined in the Position Stand as maximal velocity, is critical to the performance of these exercises (p. 371). A study by Garhammer and Gregor (153) is cited. Garhammer and Gregor (153) tested the vertical force-time of four male Olympic weightlifters performing snatch lifts on a force plate and compared the results to nine male athletes (including three Olympic lifters), who also executed vertical jumps on the force plate. The power clean and the push-press exercises were not used in this investigation (153), and it was not a training study. That is, Garhammer and Gregor (153) compared the acute exercise responses, and not specific chronic adaptations to resistance training. Therefore, the study (153) does not support the recommendation in the Position Stand.

It should be noted that based on mechanical physics, the vertical jump and counter-movement jumps are not actually indices of power because force and time are not typically measured. The jumps may simply be measures of some specific functional performance tasks. Furthermore, none of the aforementioned studies has shown any carry-over from an increase in jump height to any other physical activity.

If ground reaction forces and time are measured on a force platform during a jump, power can be estimated. For example, Holcomb et al. (154) randomly assigned 51 previously untrained college-age males to one of four training groups (resistance training, counter-movement jump, plyometric, modified plyometric) or a control group. The resistance-training group performed three sets of 8 RM (wk 1-3), 6 RM (wk 4-6) and 4 RM (wk 7-8) knee-flexion, knee-extension, plantar-flexion and leg-press exercises. The counter-movement jump, plyometric, and modified plyometric groups executed nine sets of eight repetitions for the counter-movement jump, depth jumps (40-60 m, wk 1-8), and three different types of depth jumps, respectively. The groups trained 3x/wk for eight weeks. Vertical jump and counter-movement jump were measured on a force platform, and the ground reaction forces were used to estimate power and jump height. The four training groups (resistance, counter-movement, plyometric, and modified plyometric, respectively) significantly increased vertical jump height (10.5, 7.9, 12.2, 11.0 %) and estimated peak power (3.1, 2.5, 7.4, 6.8 %), counter-movement jump (7.3, 9.5, 12.3, 9.3 %) and estimated peak power (4.7, 4.0, 6.5, 4.5 %). Holcomb et al. (154) concluded that no one method of training was superior to another for increasing jump height or power performance. This study (154) was not cited in the Position Stand.

The Position Stand first notes the importance of resistance training for sport-specific activities, and in the next sentence stresses the importance of strength and ballistic resistance training for sport-specific activities such as throwing velocity. There are five references cited (155-159) in an attempt to support that claim (p. 373). Fleck et al. (155) reported correlations between peak concentric isokinetic torque and throwing velocity. They recommended a resistance-training program to increase concentric torque capability of the muscles involved in shoulder extension, internal rotation, horizontal abduction and adduction, and elbow flexion and extension. There was no reference to ballistic training, and more importantly, this was not a training study (155).

Hoff and Almasbakk (156), Lachowetz et al. (157), and McEvoy and Newton (158) compared ballistic resistance training with control groups. There was no comparison of the ballistic programs with traditional resistance training.

Only one (159) of these five references (155-159) cited in the Position Stand compared traditional resistance training with ballistic training. Newton and McEvoy (159) randomly assigned 24 previously untrained male Australian National League baseball players (~19 years) to eight weeks of resistance training, ballistic medicine ball throwing, or normal baseball throwing (control group). The resistance-training group performed 3 x 8-10 RM wk 1-4 and 3 x 6-8 RM wk 5-8 in the barbell bench press and pullover exercises. They were instructed to perform the lifts using what the authors describe as relatively slow, controlled movements. The medicine-ball group performed three sets of eight repetitions wk 1-4 and three sets of ten repetitions wk 5-8 of maximal effort, explosive chest press and overhead throws with a 3 kg medicine ball. Both experimental groups trained 2x/wk and all the groups participated in normal baseball practice 2x/wk. The medicine-ball group significantly increased 6 RM free-weight bench press (8.9 %), but it was not significantly greater than the control group (3.4

%, n.s.). The resistance-training group significantly increased bench press strength (22.8 %), which was significantly greater than the medicine-ball group and the control group. The resistance-training group was the only group to increase maximal throwing velocity (4.1 %). Newton and McEvoy (159) concluded that conventional free-weight resistance training significantly improved strength and throwing velocity more than the group that trained explosively with medicine balls.

Four of the five studies cited in the Position Stand regarding throwing velocity do not support their statement (155-158), and one study (159) contradicts their statement, thereby rendering the claim in the Position Stand unsubstantiated.

The Position Stand claims that an increase in power enables older adults to improve performance in activities requiring a rapid rate of force development, and that there is support for resistance training specific for power development in healthy older adults (p. 373). Five references (160-164) are cited in an attempt to support that claim. Bassey et al. (160) reported correlations of knee-extension power and functional performance in elderly males (~89 years) and females (~87 years). They concluded that measurement of knee-extension power in frail elderly people could be useful in selecting effective rehabilitation programs. However, this was not a training study.

Table 10. Summary of Muscular Power Research.

Reference	Rating
Bassey et al. (160)	↓
Bobbert & Van Soest (146)	↓
Clutch et al. (151)	↑
Fleck et al. (155)	↓
Garhammer & Gregor (153)	↓
Hakkinen & Hakkinen (161)	↓
Hakkinen & Komi (147)	?
Hakkinen & Komi (148)	?
Hakkinen et al. (162)	↓
Hakkinen et al. (163)	↓
Hoff & Almasbakk (156)	↓
Holcomb et al. (154)	*
Kaneko et al. (152)	↓
Kraemer et al. (164)	↓
Lachowetz et al. (157)	↓
McEvoy & Newton (158)	↓
Moss et al. (15)	↓
Newton & McEvoy (159)	↓
Wilson et al. (149)	?
Wilson et al. (150)	*

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

Hakkinen and Hakkinen (161) reported maximal knee-extension force, force-time curves, rate of force development, relaxation-time curves, electromyographic activity, quadriceps cross-sectional area, body mass, and percent body fat after 12 weeks of combined heavy resistance and explosive training in middle-aged (43-57 years) and older (64-73 years) males and females. Only one training protocol was used in this study. There was no comparison of resistance training specific for power development versus non-explosive resistance training.

Hakkinen et al. (162) compared 12 weeks of unilateral or bilateral knee-extension heavy resistance training in middle-aged (43-57 years) and older (59-75 years) males and females. There was no description of any type of explosive, ballistic, or power-development program, and no measurement of power was reported.

Hakkinen et al. (163) reported maximal knee-extension and knee-flexion isometric force, rate of force development, force-time curves, cross-sectional area, and electromyographic activity, body mass and percent body fat after six months of combined heavy resistance and explosive training in middle-aged (~41 years) and elderly (~70 years) males and females. There was only one training protocol used in this study, and consequently, no comparison of non-explosive versus explosive resistance training.

Kraemer et al. (164) reported the hormonal responses in younger (~30 years) and older (~62 years) males after 10 weeks of strength-power training. There was no comparative training protocol and no power measurement reported.

None of these studies (160-164) cited in the Position Stand compared traditional resistance training with explosive power training in younger, middle-aged, or older subjects, and none of the four training studies (161-164) reported measures of functional performance. Therefore, the claim in the Position Stand that resistance training in older populations should be specific for power development, as compared with slower, non-explosive resistance training, is not supported with any comparative resistance-training studies.

In summary, there is very little evidence cited in the Position Stand to support the claim that explosive, multiple-set protocols are required to enhance the ability to produce power (Table 10), or enhance specific sport skills or functional ability. Some of the citations in the Position Stand (15, 152, 155, 160) are entirely irrelevant to the claims.

MUSCULAR HYPERTROPHY

The Position Stand recommends high-volume resistance training for maximal muscle hypertrophy (p. 370). A study by McCall et al. (165) is cited to show that acute resistance exercise-induced increases in growth hormone concentration are highly correlated with the magnitude of muscle hypertrophy.

McCall et al. (165) trained 11 males (18-25 years), with recreational resistance training experience, 3x/wk for 12 weeks. Subjects performed three sets of 10 RM for each of eight free weight and machine exercises, four of which primarily involved the elbow flexors. They were instructed to lift to concentric fatigue for each set, with 1-minute rest between sets and exercises. Elbow flexion strength (25 %), and biceps brachii elbow flexor cross-sectional area (12.7 %) significantly increased. There was no significant difference in resting hormone concentrations (growth hormone, testosterone, insulin-like growth factor-I, and sex hormone-binding globulin) pre- to post-training, except for a significant decrease in cortisol. McCall et al. (165) claimed that the decrease in resting cortisol concentration was 16.7 % in the training group and a control group, which comprised eight males (19-29 years) who did not participate in resistance training. However, the data in their Table 1 (p. 101) show a decrease of 22.0 % for the training group and 8.4 % for the control group. Resting hormone concentrations of growth hormone, IGF-I, testosterone and sex hormone-binding globulin were not significantly correlated with either total biceps brachii hypertrophy or muscle fiber hypertrophy.

After correcting for exercise-induced changes in plasma volume, there was no significant exercise-induced change in IGF-I, testosterone, or sex hormone-binding globulin (165). There was a significant correlation of acute exercised-induced growth hormone increase and the relative degree of type I ($r = 0.74$) and type II ($r = 0.71$) biceps brachii fiber hypertrophy. However, there was no significant correlation between acute exercised induced changes of the other hormones and the indices of muscular strength or hypertrophy. McCall et al. (165) concluded that only the acute exercise-induced growth hormone elevations were correlated with the magnitude of muscle fiber hypertrophy following training. In reporting additional results from this study (165), McCall et al. (166) noted that there was no correlation between the increase in biceps brachii cross-sectional area and type I ($r = 0.197$), type II ($r = 0.353$) or mean ($r = 0.191$) muscle fiber area. They concluded that the overall muscle hypertrophy was not related to the magnitude of muscle fiber hypertrophy (166).

More importantly, McCall et al. (165) did not compare adaptations or hormonal responses to a lower-volume group; that is, there was no comparison to a group performing fewer exercises per muscle group and fewer sets per exercise. In an attempt to support a high-volume training philosophy, the authors of the Position Stand apparently selected one piece of information from the study by McCall et al. (165) and neglected to report the other results, almost all the results, from this study that did not support the opinion in the Position Stand.

The Position Stand claims that the types of protein synthesized may have a direct impact on various designs of resistance training programs; for example, body building compared with strength training (p. 369). The Position Stand also claims that the total work involved with traditional strength training may not maximize hypertrophy (p. 370). No resistance-training studies are cited. The only reference cited to support both claims is a book by Zatsiorsky (108). There are no references cited in Zatsiorsky's book to support his opinions, or the opinions in the Position Stand.

The Position Stand recommends 3-6 sets of each exercise to increase muscle hypertrophy in advanced trainees (p. 370). No references are cited to substantiate this volume of training. Contrary to this unsupported recommendation, the previously discussed study by Ostrowski et al. (53) is especially noteworthy because the training program encompassed the modality and protocols recommended in the Position Stand, and the subjects were currently weight training for 1-4 years. The subjects performed free-weight exercises and followed a split routine (2 days upper body and 2 days lower body each week) for 10 weeks. The only difference in training variables among the three programs was the number of sets (1, 2, or 4 sets of each exercise), with all sets performed to muscular fatigue and 3-minutes rest between sets. Ostrowski et al. (53) concluded that the results demonstrated that low, moderate, and high volume protocols showed no significant difference in their effect on body mass, upper-body and lower-body muscular strength, power, and hypertrophy (rectus femoris hypertrophy and triceps brachia thickness) over the 10-week training period in resistance-trained males.

The Position Stand claims that programs for enhancing muscular hypertrophy require moderate to very heavy loads and high volume (p. 370). A book chapter by Kraemer (167) is the only reference cited.

The Position Stand claims that greater muscular hypertrophy in resistance-trained individuals is associated with high-volume, multiple-set programs compared with low-volume, single-set programs (p. 370), and three references (34-35, 37) are cited. The remarkable results from the Experiments by Kraemer (35) are discussed in our Multiple Sets section. Contrary to the claim in the Position Stand, the studies by Kraemer et al. (37) and Marx et al. (34) involved previously untrained participants.

The Position Stand claims that the amount of work and force are associated with gains in muscular hypertrophy (p. 370). Three references (15, 168-169) are cited in an attempt to support that belief. The study by Moss et al. (15) (previously discussed in our Repetition Duration section) reported a small significant increase (2.8 %) in muscle cross-sectional area in a group who trained with 35 % 1 RM compared with no significant gain in muscular hypertrophy for a group that used 90 % 1 RM. The results reported by Moss et al. (15), which showed that a lighter resistance was more effective than a heavier resistance, are contrary to the claim in the Position Stand.

Shinohara et al. (168) instructed five previously untrained males (~23 years) to perform isometric knee-extensor muscle actions for three minutes (2s contraction, 3s relaxation) at 40 % maximal voluntary contraction 3x/wk for four weeks. One limb was subjected to 250 mmHg tourniquet pressure to induce ischemia, while the contra-lateral limb was not restricted. There was a significant increase in maximal voluntary contraction (~26 %) and maximal rate of torque development (~60 %) in the limb subjected to the ischemia, and no significant increase in the unrestricted limb. Shinohara et al. (168) did not report any measurement of muscle hypertrophy. Therefore, this study does not support the claim in the Position Stand.

Smith and Rutherford (169) instructed 10 previously untrained males and females (~20 years) to perform four sets of 10 repetitions of concentric-only leg-press exercise with one limb and eccentric-only muscle actions with the contra-lateral limb (3 seconds each) 3x/wk for 20 weeks. Subjects performed the concentric muscle action with the foot placed on the lower portion of the footplate and the contra-lateral eccentric muscle action with the foot placed on the upper part of the plate. The authors noted that the foot placement resulted in a 35 % greater resistance for the eccentric limb. Isometric strength gains were significantly greater in the concentrically trained limb (43.7 %) compared with the contra-lateral limb (22.9 %). Dynamic (isokinetic) strength significantly increased in two out of eight test velocities in the concentric limb and five out of eight in the eccentric limb, with no significant difference between limbs. There was a significant increase in proximal quadriceps muscle cross-sectional area in the concentric (4.6 %) and eccentric limbs (4.0 %), with no significant difference between limbs. Smith and Rutherford (169) stated that their results suggest that it is not muscle force per se that is the stimulus for increasing muscular strength and hypertrophy. That is, the 35 % greater resistance in the eccentrically trained limb did not produce greater muscular hypertrophy. Therefore, their results do not support the claim in the Position Stand.

In summary, out of the three resistance-training studies (15, 168-169) cited in the Position Stand to support the use of heavier resistance and a greater training volume for muscular hypertrophy, one study (168) did not measure muscle hypertrophy, one study (169) showed no difference in hypertrophic gains with greater resistance, and one study (15), which contradicts the claim in the Position Stand, showed a significantly greater gain in muscular hypertrophy with a lighter resistance. Therefore, the claim in the Position Stand that heavy loads and high-volume resistance training are required for maximal muscular hypertrophy is unsubstantiated (Table 11).

Table 11. Summary of Muscular Hypertrophy Research.

Reference	Rating
McCall et al. (165)	↓
Moss et al. (15)	↓
Shinohara et al. (168)	↓
Smith & Rutherford (169)	↓

↑ Studies cited in the Position Stand that actually support the primary claim or recommendation.

? Studies cited in the Position Stand that support the primary claim or recommendation but contain serious flaws in the methodology or data.

↓ Studies cited in the Position Stand that fail to support the primary claim or recommendation.

* Studies not cited in the Position Stand that repudiate the primary claim or recommendation.

CONCLUSIONS

The ACSM has taken a definitive stand on resistance training. Therefore, the entire burden of proof is on the ACSM and the authors of the Position Stand to support their recommendations with peer-reviewed resistance-training studies that were available throughout the preparation of the Position Stand. They failed to meet that responsibility. Many of the recommendations are without any scientific foundation. The Position Stand fails to meet the standards for a scientifically based, methodologically sound, consensus statement.

We document numerous examples that specifically demonstrate how the authors of the Position Stand selectively reported the results of resistance-training studies. That is, they cite a couple of references that support their opinion and neglect to cite the studies that do not support it. Or, they use one or two results of a study that support their point of view and neglect to report other results from that study that do not support their opinion—a disservice to dedicated researchers at best. A number of their references have absolutely no relevance to their claims.

Readers are encouraged to scrutinize all the original resistance-training studies cited in the Position Stand. That is, carefully read the entire study, look for flaws in the methodology, decide whether the results actually support a particular hypothesis, and try to recognize when the discussion or practical application section conflicts with the reported data.

Assuming that the goals of healthy, advanced trainees are realistically within their genetic potential, there is very little evidence to suggest that intermediate or advanced trainees need to spend several hours a day performing resistance training or obsessively manipulating the training variables to attain specific goals such as muscular hypertrophy. If the goal is not within their genetic capability, no amount of resistance training will produce the desired results. For example, Van Etten et al. (170) recruited 21 previously untrained males (~36 years) and based on their initial body build expressed as a fat-free mass index (fat-free mass$\cdot$height^{-2}), classified them as a *solid* group or a contrasting *slender* group. All the subjects performed 1-3 sets of 10-15 repetitions for each of 14 exercises 2x/wk for 12 weeks. Absolute strength (~13 %) as well as strength relative to fat-free mass (~13 %) significantly increased at all angular velocities and movements tested, with no significant difference between groups for any of these changes. Both groups showed comparable decreases in fat mass (11.3 and 10.5 %, solid and slender groups, respectively). The entire group of trainees showed a significant increase in fat-free mass (1.0 kg). However, when analyzed separately the solid group significantly increased fat-free mass (1.6 kg), while the slender group did not change significantly (0.3 kg). The difference between groups was significant. The solid group also showed a significantly greater increase in body build (0.75 kg$\cdot$m^{-2}) compared with the slender group (0.26 kg$\cdot$m^{-2}). Van Etten et al. (170) concluded that the potential to increase free-fat mass, as well as the difference between groups in initial fat-free mass, are genetically determined. Unfortunately, genetic limitations of muscular strength, hypertrophy, power, and endurance are never addressed in the Position Stand.

Table 1 (p. 374) in the Position Stand, which is entitled: Summary of Resistance Training Recommendations: An Overview of Different Program Variables Needed for Progression with Different Fitness Levels (http://www.acsm-msse.org/pt/pt-core/template-journal/msse/media/0202.pdf), presents an outline of the ACSM's highly complex recommendations. The training protocols include the types of exercise (single and multiple joint), order of exercise, a specific percent of the 1 RM, repetition duration, range of repetitions, number of sets for each exercise, rest time between sets and exercises, frequency of training, and so-called periodization programs. The ACSM claims that the training protocols should vary for novice, intermediate and advanced trainees, and are dependent on specific goals such as enhanced muscular strength, hypertrophy, power, and endurance. If obsessive manipulation of these training variables really had a significant effect on specific outcomes, it would be evident in the preponderance of resistance-training studies. However, as we have specifically documented in each of the previous sections, there is very little scientific evidence to suggest that any particular program described in Table 1 (p. 374) of the Position Stand will elicit a specific adaptation such as increased muscular strength, hypertrophy, power, or endurance (Table 12).

Table 12. Summary of Resistance Training Research.

8	Studies cited in the Position Stand actually support the primary claim or recommendation.
16	Studies cited in the Position Stand support the primary claim or recommendation but contain serious flaws in the methodology or data.
59	Studies cited in the Position Stand fail to support the primary claim or recommendation.
56	Studies not cited in the Position Stand repudiate the primary claim or recommendation.

Because most advanced trainees would like to improve year round in all of the aforementioned variables (muscular strength, hypertrophy, power, and endurance), following the ACSM's recommendations is not only a daunting task for most healthy adults, but also a deterrent for compliance even in the most dedicated trainees or for elite athletes who devote a great amount of time training for their specific sport. Many people would be forced to relinquish almost every other form of physical activity in order to achieve—according to the Position Stand—a hypothetical 10 % improvement. It appears that the intention of this Position Stand is to recommend what is required for trainees to determine how much exercise they can tolerate, rather than guiding people to establish the amount of exercise required to stimulate the desired adaptations that will improve health and enhance muscular strength, hypertrophy, power, and endurance.

The Position Stand claims that a general program of resistance training used by a novice will not have the same effect in an advanced trainee, but the majority of the references cited did not involve advanced trainees.

Although there are eight studies (10, 33-34, 36, 38, 95, 121, 151) out of 139 citations in our summary Table 12 that actually support the primary claim or recommendation in the Position Stand (a mere 5.8 %), three of those studies used subjects who had undisclosed recreational experience with resistance training (36), basic experience (either 3-6 months or minimal of 6 months) in resistance training (38), or were enrolled (time not reported) in a college weight-training class (151). The other five studies involved previously untrained subjects (10, 33-34, 95, 121). Consequently, none of the eight studies (10, 33-34, 36, 38, 95, 121, 151) that support the primary recommendation in the Position Stand actually involved advanced trainees.

This ACSM Position Stand was published with so little supporting scientific evidence because the entire peer-review system failed. That is, the ACSM's Writing Group for the Position Stand failed to support their opinions with sufficient evidence; the reviewers of the Position Stand, presumably with expertise in resistance training and exercise physiology, failed to challenge a single reference; the ACSM Pronouncements Committee, Board of Trustees, and Administrative Council failed to monitor the review process effectively; and the Editor-in-Chief of *Medicine and Science in Sports and Exercise* chose to publish a document that is bereft of scientific evidence to support the claims and recommendations. Thus, it is our opinion that the problems within the ACSM are far more egregious than a highly flawed Position Stand.

RECOMMENDATIONS

What is really known about the science of resistance training is contrary to the opinions expressed in the Position Stand. That is, the preponderance of research strongly suggests that gains in muscular strength, hypertrophy, power, and endurance are the result of the following simple guidelines:

- **Select a mode of exercise that feels comfortable throughout the range of motion**. *There is very little evidence to support the superiority of free weights or machines for increasing muscular strength, hypertrophy, power, or endurance.*
- **Choose a repetition duration that will ensure the maintenance of consistent form throughout the set**. *One study showed a greater strength benefit from a shorter duration (2s/4s) and one study showed better strength gains as a result of a longer duration (10s/4s), but no study using conventional exercise equipment reports any significant difference in muscular hypertrophy, power, or endurance as a result of manipulating repetition duration*.
- **Choose a range of repetitions between three and 15** (e.g., 3-5, 6-8, 8-10, etc.). *There is very little evidence to suggest that a specific range of repetitions (e.g., 3-5 versus 8-10) or time-under-load (e.g., 30s versus 90s) significantly impacts the increase in muscular strength, hypertrophy, power, or endurance.*
- **Perform one set of each exercise**. *The preponderance of resistance-training studies shows no difference in the gains in muscular strength, hypertrophy, power, or endurance as a result of performing a greater number of sets.*
- **After performing a combination of concentric and eccentric muscle actions, terminate each exercise at the point where the concentric phase of the exercise is becoming difficult, if not impossible, while maintaining good form**. *There is very little evidence to suggest that going beyond this level of intensity (e.g., supramaximal or accentuated eccentric muscle actions) will further enhance muscular strength, hypertrophy, power, or endurance.*
- **Allow enough time between exercises to perform the next exercise in proper form**. *There is very little evidence to suggest that different rest periods between sets or exercises will significantly affect the gains in muscular strength, hypertrophy, power, or endurance.*
- **Depending on individual recovery and response, choose a frequency of 2-3 times/week to stimulate each targeted muscle group. One session a week has been shown to be just as effective as 2-3 times/week for some muscle groups**. *There is very little evidence to suggest that training a muscle more than 2-3 times/week or that split routines will produce greater gains in muscular strength, hypertrophy, power, or endurance.*

In reality, progression in resistance training is simply adding enough resistance, which is a *consequence* of getting stronger—not a requisite—to stay within the desired range of repetitions and maintain a specific degree of effort. This is achieved while maintaining the precise exercise form for each aspect of the chosen protocol. Complex manipulation of any or all of the previously discussed resistance-training variables in an attempt to enhance gains in muscular strength, hypertrophy, power, or endurance in novice, intermediate or advanced trainees is primarily based on unsubstantiated opinions, and lacks sufficient scientific evidence - empirical or theoretical - for support.

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