Athletic Performance Development:
Volume Load—1 Set vs. Multiple Sets,
Training Velocity and Training Variation

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SOME CONTROVERSY (AND CONFUSION) EXISTS CONCERNING THE OPTIMAL NUMBER OF SETS THAT CAN PRODUCE CHANGES IN HYPERTROPHY, BODY COMPOSITION, AND PERFORMANCE PARAMETERS. ALTHOUGH MOST OF THE SCIENTIFIC LITERATURE INDICATES THAT MULTIPLE SETS PRODUCE SUPERIOR RESULTS, SOME AUTHORS (6) AND EXERCISE SCIENTISTS (47, 56) HAVE SUGGESTED THAT ONE SET TO MUSCULAR FAILURE PRODUCES EQUAL RESULTS. FURTHERMORE, THEY (6) SUGGEST THAT MULTIPLE SETS ARE UNNECESSARY AS THEY ARE TIME CONSUMING AND MAY LEAD TO OVERTRAINING.

This review briefly examines the efficacy of single versus multiple sets. Before this question can be adequately addressed, volume and intensity should be defined:

- **Volume** is the amount of work performed per set, per exercise, per day, etc. Work = force × distance. In adults, resistance training volume is best estimated by the volume load (VL = reps × mass lifted).

- **Intensity** deals with power output. Intensity can be separated into training aspects (training intensity) and movement aspects (exercise intensity).

**Training intensity** is the rate at which a training exercise or session proceeds. For example, a lifter performs squats on 2 different days (based on actual data, as shown in Table 1). By comparing these 2 days, we see that Day 1 produced more work (VL = 8,400 vs. 4,750 kg) but a much lower training intensity (35.8 vs. 40.8 kg/s). If one considers the target (non-warm-up, last 3) sets each day, the differences are larger.

**Relative Intensity (RI)** is a % of the one repetition maximum (1-RM) used in training. In the example given in Table 1, obviously heavier weights and therefore higher relative intensities can be used with lower repetitions per set. One should be cautious when using RI to prescribe protocols however, as it is stable only in advanced athletes.

**Exercise intensity** is the actual power output of each movement. Power is defined as the product of force and velocity. In measuring force of contraction and power at increasing resistance, an inverse relationship between force and velocity is found. During this type of experiment, it has been shown that power takes the form of an inverted-U. Peak power typically occurs at about 30–40% of peak isometric force for a given movement, perhaps slightly higher for well-trained individuals. Thus, very heavy or very light weights will have lower power outputs than those in the middle range.

**One Set or More, Is There a Difference?**

To answer this question, we must know the trainee's goals. If maximum strength is the immediate goal, then training intensity must be increased (lift heavy weights). If

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increasing speed, power, and peak rate of force development are the goal, then some training must involve exercise intensities that offer a higher power output. These RIs range from approximately 40 to 80% of 1-RM depending on the type of exercise and one's training status (20, 23).

In this context, Newton's second law, \( F = ma \), is an important consideration (\( F = \) force; \( m = \) mass; \( a = \) acceleration). Except for very light warm-ups, all ballistic exercises should be performed as explosively as possible through the complete range of motion. Additionally, for exercises limited by joint range (e.g., bench press), one should attempt to "accelerate" the bar through the sticking range. This will maximize the exercise intensity for a given resistance and provide an optimum stimulus for adaptation.

Thus, explosive exercise can be conceptualized as ranging from relatively light resistance to heavy-resistance movements, in which force, speed, power, and rate of force development are maximized for each movement (57).

### Discussion

Athletic performance depends on a number of kinetic and kinematic factors which are influenced by biomechanical and physiological parameters. This discussion is primarily concerned with the underlying physiological factors that promote:

1. Changes in body composition and muscle hypertrophy
2. Strength
3. Speed and power
4. Rate of force development

#### Changes in Body Composition

Of importance in this specific discussion of resistance training methods are two factors: (a) volume of training and (b) training to failure (or beyond). Other factors such as training intensity and variation will be discussed later.

**Training Volume.** Changes in LBM and therefore hypertrophy of muscle and connective tissue are related to volume—to a point. Strength and power performances are obviously related to changes in body composition.

Body composition is determined by the amount of lean body mass (LBM) and fat mass contained in the total body mass. There is little doubt that weight training can increase LBM and decrease both % fat and total fat mass (29, 60). Increases in LBM require an appropriate stimulus, which results in an increased net protein synthesis or a reduction in protein catabolism (10). Reductions in fat mass are largely dependent on utilization of fats during or after exercise (40, 68, 69), total energy expenditure (7, 42, 60), and perhaps an increase in resting metabolic rate (29).

Changes in body composition, particularly loss of fat, are related to energy consumption. There is considerable evidence indicating that higher volumes of resistance exercise will produce superior results (7, 42, 60).

In resistance training, the volume of work accomplished depends on the number of repetitions per set, number of sets, frequency of training per unit time (per day, week, month, etc.), and the size of the muscle mass involved in exercise. Multijoint, large-muscle-mass exercises use more energy and have a greater metabolic impact than single-joint, small-muscle-mass exercises (60). Much of the energy consumption (and fat oxidation) from resistance training occurs during recovery and is volume-dependent (42).
Energy expenditure and training volume data agree with the findings of Stone and O’Bryant (61), who argue (p. 125) that changes in body composition are—to an extent—related to the amount of work accomplished. These data as well as longitudinal data (33, 37) suggest that multiple sets, especially with large-muscle-mass exercise, will produce superior alterations in body composition compared to single sets.

The stimulus for exercise-induced hypertrophy appears to be micro-injury to the connective and muscle tissue created by an appropriate high intensity (38), or as a result of high strain rates during stretch (14, 15). It is apparent that there is some threshold of muscular tension (18) or strain rate that must be met in order to provide an optimum stimulus (35). Thus, typical resistance exercise with relatively light weights will not adequately stimulate muscle hypertrophy.

Research on exercise-induced muscle hypertrophy has been conducted using different modes for inducing a stimulus, and these differences make interpretation of the literature more difficult. For example, several studies used semi-isokinetic devices (e.g., Cybex, Kincom) that do not necessarily produce the same effects as the more common modes of training such as free weights (1, 58).

Although sufficient volumes of concentric exercise will stimulate hypertrophy (25, 26), a near maximum eccentric component of a muscle action can result in higher muscular tension and strain rates and create more damage than the typical concentric actions. It is possible that eccentric exercise, or a combination of eccentric and concentric muscle actions, may offer a superior hypertrophy stimulus (46). However, this effect has not always been found (27, 28).

Obviously the damage stimulus cannot be so great that it destroys the tissue. The damage should be sufficient to set in motion a number of mechanisms leading to increased protein synthesis: metabolic factors, immune system, endocrine system, autocrine and paracrine responses to exercise, and adaptations to training (19, 30, 31, 55). Information to date suggests that, over a reasonable period of training, one set to failure may not increase muscle hypertrophy as readily as multiple sets because it does not provide an optimal volume stimulus.

One important factor, assuming body mass remains relatively stable, is that skeletal muscle hypertrophy and other physiological and performance variables appear to have genetic limits such that, once these limits are reached (if they can be reached), no stimuli will have an effect (2). As these limits are approached, it takes greater stimuli to cause an adaptation. Thus, since the trained state can range from sedentary to elite, the range of stimuli needed for continued adaptation is probably quite large.

The trained state is also important in this discussion. Typically, as one becomes more trained, a greater stimulus is then required to evoke a further adaptation. Thus, lower volumes of training can produce significant increases in hypertrophy, etc., in relatively untrained subjects.

A variety of factors can influence adaptations to a training program, such as intensity, type of exercises, etc. However, over training periods of sufficient length, higher volumes will generally produce greater gains in LBM (hypertrophy), changes in body fat, cellular adaptations, and performance variables such as strength compared to low volume programs, even when the subjects are initially untrained (12, 24, 32, 33, 37, 50, 62).

Furthermore, training volume also appears to influence the rate of decrease in these variables after cessation of training (24). This could have important effects, for example during volume reductions (tapering) for performance peaking or during layoffs due to injury.

Training to Failure (or beyond). Training to failure is defined here as the inability to maintain reasonable technique or to complete a muscle contraction due to temporary fatigue. In this context, exercising and training to failure is intentional. Bodybuilders in particular will exercise to muscular failure or beyond on a regular basis. Yet there is little objective evidence as to its efficacy in producing hypertrophy or increasing maximum strength (59, 65).

The rationale for training to failure is that during a set of resistance training exercise, as some motor units fatigue and drop out, other motor units must be recruited for continued activity (3, 48). Fatigue allows additional motor units to be trained so the resulting gains in hypertrophy and strength are greater (48).

If fatigue and exercise to failure were the critical factor for enhancing strength, rate of force development, power, etc., then one should simply be able to exercise to failure with very light resistances and produce marked gains in hypertrophy and maximum strength. But in practice it quickly becomes obvious that this method would not be very efficient in providing an appropriate stimulus for hypertrophy or strength gains.

Reviews of the literature indicate that a primary stimulus for strength gains is training inten-
sity and relative intensity (3), especially in experienced weight trainers (34). Increasing the resistance (weight used) also recruits additional motor units, and the training intensity and volume have been correlated with gains in both maximum strength and muscle hypertrophy (12).

One way to address differences in training methods is by carefully observing the training programs of elite strength/power athletes. Many bodybuilders exercise to failure on a regular basis. Powerlifters typically train heavy but do not exercise to failure as often as bodybuilders. Weightlifters train with combinations of heavy and light (high power) contractions; rarely if ever do they intentionally exercise to failure.

Research to date indicates that, although there can be differences in size and number of different fiber types, the average cell size of specific muscles among these three groups is very similar (16, 17, 66). Furthermore, both powerlifters and weightlifters are typically stronger and more powerful than bodybuilders, even when strength is normalized by body mass or cross-sectional area (57, 66). These observations and data suggest that training to failure offers no particular advantage.

Few studies have attempted to make longitudinal comparisons between training to failure vs. not training to failure (32, 34, 43, 50, 64). The results of these studies are somewhat difficult to interpret because different amounts of work were used among comparison groups (e.g., one set vs. multiple sets). However, it appears that training to failure either in single or multiple sets offers no further benefits (43, 59, 64). Additionally, the work of Nimmons et al. (43) suggests that consistently training to failure or beyond (forced reps, etc.) may lead to overtraining.

**Strength**

Strength can be defined as the ability to produce force (57). Relative magnitude ranges from 0 to 100%. Depending on the muscles involved in the contractions, there is also a direction-of-force application.

The resistance encountered and the intensity of voluntary muscle contraction also dictate the speed of movement (\(F = MA\)). Force production in which an object is moved produces Work (\(W = F \times \text{displacement}\)). Work occurs over a period of time and produces a power output (\(P = \text{work}/\text{time}\)). In measuring strength, there can be a high degree of specificity. The underlying mechanisms of strength production (57) are:

1. Number of recruited motor units;
2. Frequency of motor unit activation (rate coding);
3. Synchronization (important in ballistic movements);
4. Degree of inhibition: (a) psychological (fear of injury), (b) receptor feedback;
5. Intermuscular efficiency (skill/technique);
6. Muscle intrinsic factors (fiber type, etc.);
7. Cross-sectional area (degree of hypertrophy);
8. Biomechanical/anthropometric factors (tendon insertion position, pennation angle, limb length, etc.).

Although almost any form of reasonable resistance training can increase strength in initially untrained persons, studies lasting more than a few weeks have shown that multiple sets produce superior gains in strength (and other variables) compared to one set to failure (32, 33, 34, 37, 50, 64).

**Speed and Power**

For most sports, speed and particularly power are likely the most important characteristics to develop. As with maximum strength, development of power and speed of movement are affected by the trained state. There is little doubt that most reasonable weight training programs can improve power and speed in initially untrained persons.

As with other factors, when one becomes more trained, it takes a larger and/or stronger stimulus to produce additional gains. Furthermore, there is a high degree of movement pattern and velocity specificity involved in developing power and speed (22, 57, 58). In this context, multijoint complex exercises typically offer a high degree of movement specificity not offered by single-joint exercises (58).

Reviews of the scientific literature indicate that heavy weight training and high-power weight training affect different portions of the force-velocity curve. The primary effect of high-power weight training is an increased rate of force production, velocity, and power of movement, while traditional heavy weight training primarily increases maximum strength (22, 49). Also, high-power training enhances a wide range of athletic performance variables to a greater extent than does traditional heavy weight training, especially in persons with a reasonable initial level of maximum strength (72).

Longitudinal and cross-sectional (22, 57) data suggest that heavy weight training over a few weeks, followed by speed/strength training (or combination training), can produce superior gains in strength and power compared to either type alone. A recent longitudinal study using college football players (23) indicated that heavy training, followed by combi-
nation training, produces superior gains in maximum strength and athletic performance.

In order to adequately train speed and power, ballistic movements with a high power output and high rate of force development are necessary. Optimum use of such movements is not possible when training to failure.

Training to failure produces considerable fatigue. A fatigued muscle reduces maximum force, peak rate of force production, power, and speed. It can also interfere with movement patterns and increase the chance of injury (13, 54, 57, 67, 70). Fatigue during exercise to failure may help explain the lack of adaptation in speed-related parameters observed in some studies that compared training protocols (50, 64).

**Rate of Force Development**

Rate of force development (RFD) has in the past been overlooked. As with speed and power, peak RFD is likely a more important aspect of performance for many sports than is maximum strength. For example, elite sprinters are required to produce approximately 170–200 kg of vertical force (on one leg) when performing. Furthermore, the average foot contact time in which this occurs is approximately 0.087 sec (36).

Obviously it takes a very high rate of force development to achieve these values. RFD is not just important in athletes. For example, regaining one's balance is also a function of peak RFD which can be of considerable importance in the elderly.

It should be noted that, as with speed and power, exercise having a high fatigue component is less likely to adequately train RFD. Indeed, training RFD (and speed and power) optimally requires low fatigue levels and high RFD's, as occurs in appropriately designed ballistic training programs (57). One set to failure does not appear to offer an appropriate stimulus.

### Optimum Number of Sets and Reps?

The number of sets (and repetitions per set) per exercise is largely determined by the trainee's goals. Thus the number of sets may be different if the goal is maximum strength, power, or high-intensity exercise endurance. For example, in terms of maximum strength gains, some evidence suggests that 3 to 5 sets (after warm-up) of 3 to 6 reps (3 × 3-6RM) produce the best results and that adaptation to the number of sets is in a "dose-response" manner.

This means that adaptations increase with the number of sets, but only to a point. Once the optimum number of sets is reached, a further increase in number of sets does not yield more gains in performance and can even cause regression or overtraining. This interpretation for optimum number of sets has largely been based on work by Berger (5) and Capen (8) and the practices of elite strength/power athletes (45).

More recent research confirms the concept that multiple sets can produce superior gains in maximum strength (and other variables) compared to single sets performed to failure (32, 33, 37, 50, 64). In terms of high-intensity exercise endurance, evidence again suggests that multiple sets produce superior results (11, 39). However, it is difficult to completely separate out the influence of set number from other aspects of training such as the resistance used or number of repetitions per set (3).

More investigation may be interesting, of course, but the scientific literature and the training programs and experiences of most strength/power athletes indicate that multiple sets produce superior results. Furthermore, increases in maximum strength (and other variables) are asymptotic, i.e., the adaptations increase with the number of sets, to a point.

It should also be remembered that the number of sets used is influenced by the intensity (resistance used), planned volume and intensity variation, number and type of exercise, frequency of training, performance goals, etc. Based on available evidence, it can be concluded that multiple sets produce superior results compared to single-set protocols, and the optimum number of sets appears to be 3 to 5, independent of warm-up sets.

### Direct Comparisons of Training Protocols

In comparing one-set vs. multi-set training protocols, the effects of 5 factors come into play: (a) study length, (b) small-vs. large-muscle-mass exercises, (c) trained vs. untrained subjects, (d) specificity of measurement, and (e) transfer of training effect.

**Study Length**

As noted, there is little doubt that multi-set protocols produce markedly superior results in a variety of physiological and performance factors in initially untrained (5, 37, 50, 64) and trained subjects (32, 33, 34). However, some studies (11, 47, 52, 56) suggest that both protocols produce equal or similar results. Careful scrutiny of the literature suggests several possible reasons as to why these two different protocols may produce similar results over short periods.

**Small- vs. Large-Muscle-Mass Exercises**

Some data (64, 71) suggest that, due to very large intersubject varia-
Table 2
Data Modified From DeHoyos et al.'s Study

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Single-set Group</th>
<th>Multi-set Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 wks</td>
<td>25 wks</td>
</tr>
<tr>
<td>1-RM chest press</td>
<td>108 ± 53</td>
<td>139 ± 60</td>
</tr>
<tr>
<td>1-RM row</td>
<td>131 ± 44</td>
<td>176 ± 63</td>
</tr>
<tr>
<td>1-RM arm curl</td>
<td>52 ± 24</td>
<td>71 ± 30</td>
</tr>
<tr>
<td>1-RM leg ext</td>
<td>131 ± 59</td>
<td>166 ± 20</td>
</tr>
<tr>
<td>1-RM leg curl</td>
<td>95 ± 27</td>
<td>126 ± 48</td>
</tr>
<tr>
<td>Reps/failure CP</td>
<td>9 ± 2</td>
<td>22 ± 3</td>
</tr>
<tr>
<td>LE</td>
<td>9 ± 3</td>
<td>18 ± 4</td>
</tr>
</tbody>
</table>

*Signif. diff., p ≤ 0.05.
Mean % diff. (1-RM) = 9.4 percentage points (28% difference in gain favoring the multi-set group).

...
development, acceleration, velocity parameters, and movement patterns. The more similar a training exercise is to the actual physical performance, the greater the probability of transfer (1, 4, 49, 58).

These relationships hold for performance measurement as well as training (1, 58). Thus, training on one device and then measuring on a different device that requires a different contraction type or movement pattern may mask or attenuate many of the specific training effects, especially over the short-term. Several studies (47, 52, 56) have used this nonspecific testing method, which makes interpretation of their data unclear.

There is also evidence that the time course of adaptation for a particular type of strength measurement (e.g., 1-RM, isometric, isokinetic) may differ with the length of training, frequency of training, or the recovery period from the last training session until the measurement is taken (9). Thus many studies may have missed significant differences in adaptations because the maximum strength measurements were not taken at the appropriate time, or inappropriate measures (nonspecific) were used.

**Transfer of Training Effects**

The most important aspect of any training program is "transfer of training effect." Transfer of training effect deals with how well a training program transfers to other performance variables, for example, transfer of strength from leg extensions or speed squats training to vertical jump performance. As would be expected, a high degree of mechanical specificity is involved (1, 58).

Studies addressing adaptation (32, 33, 37, 50, 64) have clearly shown that multi-set protocols produce a greater transfer than single-set protocols. Variables evaluated have included vertical jumps and Wingate cycle power tests. A volume effect has been shown in both previously trained (33, 34) and untrained subjects (32, 37, 50, 64). However, other variables such as running speed and agility need to be evaluated. Another important factor is recovery and the need for variation.

**Programmed Variation**

Recovery from training is always an issue. The ability to recover is enhanced by training, but this can be offset to an extent by increasing training loads. Advanced trainees or athletes typically use higher volumes and/or intensities than lower level athletes. As training progresses, adaptation makes it necessary to increase the volume and intensity to provide an appropriate overload stimulus.

Since advanced athletes train with high volume/intensity, they may experience higher fatigue levels and are closer to the threshold of overtraining. This requires greater planned variation in the training program.

Several studies have shown the superiority of periodized (planned variation) over nonperiodized programs (32, 34, 37, 44, 50, 62, 63, 64, 71). Periodized training is a nonlinear approach that offers variation in volume and intensity at several levels. This variation can occur across a macrocycle (typically 1 year), mesocycle (months), or microcycle (day-to-day variation).

Variation deals not only with changes in exercise selection and sets and repetitions but also involves changes in exercise intensity (differences in training velocity, power, etc.). Evidence suggests that proper sequencing of changes in training volume, intensity factors, and exercise selection can offer marked advantages in performance (23, 41).

Another factor that may influence fatigue and recovery ability is consistent training to failure (or beyond, i.e., force reps, negatives). Variation—and not constantly training to failure—is likely a major factor in the results of many comparisons between single- and multi-set protocols.

Planned variation can help the athlete remain in a relatively nonfatigued state during the training program. As noted, reduction in fatigue is related to a decrease in the potential for overtraining and a possible enhancement in power production and RFD.

**Summary and Recommendations**

Based on available research and the opinions of the majority of coaches and athletes, one set to failure will not produce the same effects on strength, power, or high-intensity exercise endurance compared to multiple sets, especially among trained individuals.

Based on current information, then, we recommend the following:

1. Training programs should use multiple sets, typically 3–5 not including warm-up sets.

2. Variation in training volume and intensity is a critical factor, especially for advanced athletes. The degree of variation needed depends on the athlete's goals and trained state. Beginners (first 3 mos) need less variation for adaptation than advanced trainees, and periodic (every 4–8 wks) alterations in repetition and set number usually suffice.

We have used the following program with beginners and have had excellent success: high volume preparation (sets of 10 reps: 4 wks), basic strength (sets of 5
reps: 4 wks), strength peaking (sets of 3 reps: 4 wks). Advanced trainers and elite athletes should use a periodized approach to training that includes variation at several levels—macrocycle, mesocycle, microcycle.

3. The planned variation should also consider changes in the type of exercise and velocity of movement in keeping with specified goals. Typically, a mesocycle should progress from general to specific. For example, if speed and power are the goal of the training program for moderately and highly advanced athletes, a typical sequence of training can be: strength/endurance, 2–4 wks; basic strength, 4 wks; combination training (strength + speed/strength), 4 wks; and peaking (speed/strength), 2 wks.

These manipulations of exercise speed and power should be carried out simultaneously with alterations in the set and rep number to ensure that fatigue is minimized during periods of high velocity/high power training (23). With the exception of very light warm-up sets, all exercises should be executed with maximal force through a complete range of motion; this will maximize speed/power and RFD for a given resistance.

4. Training exercises should be based on multijoint, large-muscle-mass, free-weight exercises with kinematic and kinetic similarities to performance (58, 61). During typical training sessions, in order to maximize the stimulatory effects of primary exercises, isolated and single-joint movements should be performed after multi-joint exercises (51, 58, 61).

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