Resistance Training for Strength: Effect of Number of Sets and Contraction Speed

JOANNE MUNN[1], ROBERT D. HERBERT[1], MARK J. HANCOCK[1], and SIMON C. GANDEVIA[2]

[1]School of Physiotherapy, The University of Sydney, Lidcombe, NSW, AUSTRALIA; and [2]Prince of Wales Medical Research Institute, University of New South Wales, Randwick, NSW, AUSTRALIA.

ABSTRACT

MUNN, J., R. D. HERBERT, M. J. HANCOCK, and S. C. GANDEVIA. Resistance Training for Strength: Effect of Number of Sets and Contraction Speed. *Med. Sci. Sports Exerc.*, Vol. 37, No. 9, pp. 1622–1626, 2005. **Purpose:** To compare effects on strength in the early phase of resistance training with one or three sets and fast or slow speeds. **Methods:** A total of 115 healthy, untrained subjects were randomized to a control group or one of four training groups: one set fast ($\sim$140°·s^{-1}), three sets fast, one set slow ($\sim$50°·s^{-1}), or three sets slow. All subjects attended training 3× wk^{-1} for 6 wk. Subjects in the training groups performed unilateral elbow flexion contractions with a target six- to eight-repetition maximum load. Control subjects sat at the training bench but did not train. One repetition maximum strength, arm circumference, and biceps skinfold thickness were measured before and after training. **Results:** One slow set increased strength by 25% (95% CI 13–36%, $P < 0.001$). Three sets of training produced greater increases in strength than one set (difference = 23% of initial strength, 95% CI 12–34%, $P < 0.001$) and fast training resulted in a greater increase in strength than slow training (difference = 11%, 95% CI 0.2–23%, $P = 0.046$). The interaction between sets and speed was negative (−15%) and of borderline significance ($P = 0.052$), suggesting there is a benefit of training with three sets or fast speeds, but there is not an additive benefit of training with both. **Conclusions:** Three sets of exercise produce twice the strength increase of one set in the early phase of resistance training. Training fast produces greater strength increases than training slow; however, there does not appear to be any additional benefit of training with both three sets and fast contractions. **Key Words:** MUSCLE STRENGTH, STRENGTH TRAINING, EXERCISE, TRAINING VOLUME

Many people from both healthy and patient populations undertake resistance exercise to develop muscle strength and produce muscle hypertrophy. However, training parameters for resistance exercise have been the subject of surprisingly little research.

Conventionally, strength training involves multiple sets of resistance exercise rather than single sets. (A training "set" is a group of contiguous repetitions of a specified exercise.) The practice of performing multiple sets of resistance exercise is supported by the early and influential work of Berger (3), who suggested that multiple sets produce greater gains in strength than a single set. Evidence to support this premise is ambivalent. Several literature reviews comparing training responses to single and multiple sets of resistance exercise (4,5,10) have concluded that similar increases in strength are produced with both and that there is little scientific evidence to support the use of multiple sets of exercise. However, a recent meta-analysis concluded that three sets are superior to a single set (standardized effect = 0.70) (27). Another meta-analysis (28) concluded that four sets of resistance training produced twice the strength increases of one set. The conclusions from both narrative reviews and meta-analyses include nonrandomized studies, so the reviews' findings are potentially seriously biased (1). Moreover, the meta-analyses by Rhea and colleagues (27,28) involved comparisons between studies, not within studies, which exposes the conclusions to serious risk of confounding (31).

The ambiguity of evidence of the additional benefits of multiple sets may be due to shortcomings in the design of relevant studies. Some studies do not randomly allocate subjects to training groups (3,12), exposing these studies to allocation bias (1), few have adequate sample sizes (13,22), and many have high rates of loss to follow-up (22,32). Another problem is that many studies are confounded by the effects of co-interventions because groups either train at different intensities (17,29,30) or use different resistance exercise equipment (18,19).

The speed at which a resistance exercise is performed is another training variable that may influence effectiveness of strength training. There is no consensus on the effect of movement velocities on strength increases associated with resistance training (for review, see Pereira and Gomes (24)). Even though it is common practice to train by lifting weights (dynamic resistance training), most experimental studies have used isokinetic training to investigate effects of training speed. Few studies have examined the effects of lifting speed on strength with dynamic resistance training. Morrissey and colleagues (20) examined the influence of movement speed with weight training and found greater improvements in strength with fast training (1-s lift phase, 1-s lower

Address for correspondence: Joanne Munn, School of Physiotherapy, The University of Sydney, P.O. Box 170, Lidcombe NSW 1825, Australia; E-mail: J.Munn@fhs.usyd.edu.au
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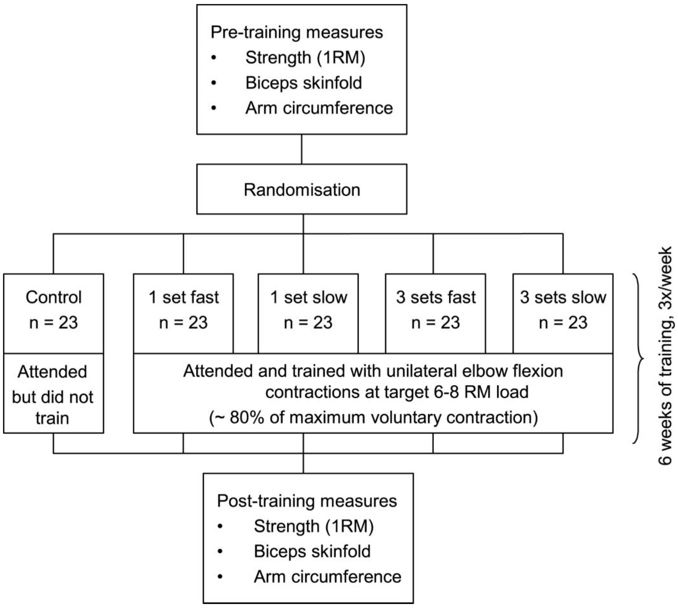

FIGURE 1—Summary of study design. Fast, 1-s lift time, 1-s lower time (average speed ≈ 140°·s^{-1}); slow, 3-s lift time, 3-s lower time (average speed ≈ 50°·s^{-1}); n, number of subjects; RM, repetition maximum.

phase) for isokinetic work, but similar improvements for increases in strength for a specific training exercise.

Given the absence of clear evidence of the number of sets and training speed, this study aimed to determine in the early phases (first 6 wk) of training the effects on dynamic strength, if any, of i), the number of training sets (one or three) and ii) the speed of contractions used in training (slow (~50°·s^{-1}) or fast (~140°·s^{-1})). In addition, we assessed whether the number of sets and speed of contraction affected limb circumference or skinfold measurements of the trained arm.

METHODS

The study design is illustrated in Figure 1.

Subjects. A total of 115 untrained, apparently healthy subjects (21 males and 94 females) with mean (±SD) age 20.6 ± 6.1 yr (height 168.1 ± 9.1 cm and weight 64.2 ± 11.6 kg) participated in the study. Subjects were included if they were deemed able to safely participate in physical activity according to the Physical Activity Readiness Questionnaire (2), free from upper limb injury, and not involved in regular upper limb strength training in the 6 months before commencement of the study. Subjects were instructed of all study requirements and gave written informed consent. Approval for this study was granted by the university's human ethics committee.

Measures. Elbow flexor strength for the right and left arms of each subject was measured. The largest weight a subject could lift only once (one repetition maximum (1 RM)) using a loaded handheld bar from a position of full elbow extension and forearm supination was recorded. Subjects were seated with the testing arm supported on a bench. Before testing, subjects were familiarized with the testing protocol and performed a warm-up consisting of six to eight contractions through full range of elbow motion with a weight estimated to be 50–60% of the individual's 1 RM.

There was a 1-min rest period after the warm-up and before the test period. Instructions were given to ensure the lift was performed correctly to minimize compensatory actions. To ensure maximal effort by the subjects, the procedures suggested by Gandevia (11) were adopted. Subjects were reminded before each lift to perform maximal exertion, they were loudly exhorted by the researcher, and they were able to discount an attempt if they believed a contraction was submaximal. They were informed that a prize would be awarded to the person whose strength, adjusted for gender, weight, and height, was greatest. Testing of the elbow flexors was performed with the subject lifting the weight through full elbow range of motion then lowering the weight back to the starting position. This procedure was repeated to determine the 1 RM to the closest 0.25 kg. A 2- to 3-min rest interval was given between each attempt. The nontest arm remained in a relaxed posture behind the subject's back throughout the testing procedure. Repetition maximum testing for the elbow flexors has been reported previously as highly reliable (7).

Measures of skinfold thickness at the biceps and upper arm circumference were taken. Skinfolds were recorded with Harpenden calipers using standardized methods (21). Arm circumference was measured with a tape measure at the widest circumference of the upper arm with the subject attempting a strong contraction of the elbow flexors in a shortened position (shoulder at 90° flexion with the lower arm at 45° to the horizontal arm) (21).

After baseline measurements subjects were randomly allocated to one of five groups: control (N = 23), three sets fast training (N = 23), three sets slow training (N = 23), one set fast training (N = 23), or one set slow training (N = 23). The training arm was also randomly assigned.

Training protocol. All subjects attended 18 training sessions over a 6- to 7-wk training period. Ideally, subjects completed three sessions on three nonconsecutive days per week within a 6-wk period. When a session was missed, subjects were allowed to make up this session to ensure they completed the target number of training sessions. Subjects in the training groups warmed up before training by performing one set of six to eight repetitions with a weight approximately 50% of the training weight for that session. Subjects trained with a 6- to 8-RM load (approximately equivalent to 80% MVC) to failure (i.e., until the weight could no longer be lifted without compensatory movement) for either one or three sets, according to assignment. When more than eight repetitions could be performed in a set, the training weight was increased by the experimenters for the subsequent training session to maintain a training intensity of 6–8 RM. A maximum of a 2-min rest between each set was given for training with three sets. At each training session, subjects listened to a tape recording that instructed them to keep the nontraining arm relaxed. The tape also set the training pace. In the slow training group, a 3-s lift and 3-s lower time (average speed ≈ 50°·s^{-1}) was required, and

TABLE 1. Pre- and posttraining measures of strength (kg), girth (cm), and biceps skinfold (mm) for the trained arm of control and trained subjects.

	Control (N = 23)		One Set Slow (N = 23)		One Set Fast (N = 23)		Three Sets Slow (N = 23)		Three Sets Fast (N = 23)	
	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining
1 RM (kg)	5.7 ± 1.6	5.9 ± 1.9	5.4 ± 2.0	6.9 ± 1.9	5.8 ± 4.0	8.0 ± 5.1	5.7 ± 2.8	8.0 ± 2.2	5.6 ± 2.3	8.2 ± 3.3
Girth (cm)	29.1 ± 2.7	29.5 ± 2.7	29.0 ± 2.9	29.7 ± 3.1	29.1 ± 4.6	29.5 ± 4.5	28.4 ± 2.6	29.2 ± 2.4	28.4 ± 2.9	28.6 ± 2.6
Biceps skinfold (mm)	8.3 ± 3.5	8.1 ± 3.2	8.4 ± 3.4	8.3 ± 2.8	8.3 ± 4.7	7.4 ± 3.1	7.6 ± 4.4	7.7 ± 4.2	8.2 ± 3.8	7.5 ± 3.2

Data are means and SD.

in the fast training groups a 1-s lift and 1-s lower time (average speed ≈ $40°\cdot s^{-1}$) was required. The tape instructed control subjects to rest the training arm on the training bench and keep both arms relaxed for 4 min (the average time for all training groups). A physical therapist experienced in resistance training was present at all training sessions.

After the training period, all subjects were retested for elbow flexor strength and anthropometric measures of both limbs (as described above). The rest period between the completion of training and retesting was usually between 2 and 5 d but no less than 48 h to minimize the impact of fatigue, and not longer than 7 d to minimize the effect of detraining.

Data analysis. The sample size of 115 subjects determined *a priori* was estimated to provide an 80% probability of detecting a 10% difference in strength between groups. Data for pre- and posttraining measures for the trained arm were analyzed with a nested factorial ANCOVA using a linear regression approach to determine the effect of number of sets and speed of contraction. The regression model was outcome = $a + b$ (initial value) + c (trained) + d (sets) + e (speed) + f (sets × speed), where *outcome* is the final measure of strength (arm girth or biceps skinfold thickness); *initial value* is the initial measure of strength, arm girth, or biceps skinfold thickness; *trained* indicates whether the subject trained (dummy-coded as 0 or 1 for control and trained subjects, respectively); *sets* indicates whether the subject trained with one or three sets (dummy-coded as 1 for subjects who trained with three sets and 0 for all other subjects); and *speed* indicates whether the subject trained at fast or slow speeds (dummy-coded as 1 for subjects who trained fast and 0 for all other subjects). a, b, c, d, e, and f are coefficients that describe the magnitude of each of these effects. Significance for all statistical analysis was set at $P < 0.05$. Only data for the trained arm are reported in this paper.

RESULTS

Of the 115 randomized subjects, two dropped out before commencement of training (one in the control group and one in the three sets slow training group) as they decided not to adhere to the training protocols. One subject (one set slow training group) only completed 4 wk of training (12 sessions) because she developed neck pain attributed to training. Outcome data were obtained from these subjects and analyzed by intention to treat (15). No other adverse events were reported. All other subjects completed 18 training sessions within a 6- to 7-wk training period.

Strength. Strength measures before and after training are given in Table 1. Changes in strength following the training period for control and trained subjects are illustrated in Figure 2. Training with one set at the slower speed resulted in an increase in strength of 25% of initial strength (1.38 kg, 95% CI 0.75–2.02 kg, $P < 0.001$, Table 2), compared with the control condition. Three sets of training were superior to a single set, increasing initial strength by 48% (2.66 kg, 95% CI 1.40–3.94 kg) or an additional 23% compared with training with one set (1.28 kg, 95% CI 0.65–1.92 kg, $P < 0.001$, Table 2). Fast training resulted in an 11% (0.64 kg, 95% CI 0.01–1.27 kg, $P = 0.046$, Table 2) greater strength increase than slow training. Although of borderline significance ($P = 0.052$), there is a suggestion that the effect for the interaction between sets and speed is negative (effect = −15%), suggesting that there is a benefit of training fast or with three sets but no additional benefit of doing both.

Girth and skinfolds. Data for arm circumference and skinfold thickness are reported in Table 1. Strength training resulted in a small but significant increase in the circumference of the trained arm (mean = 0.5 cm, 95% CI 0.10–0.91, $P = 0.015$). There was not a statistically significant added effect for training three sets compared with one set (0.24 cm, 95% CI −0.17 to 0.64, $P = 0.252$) or for training at a fast

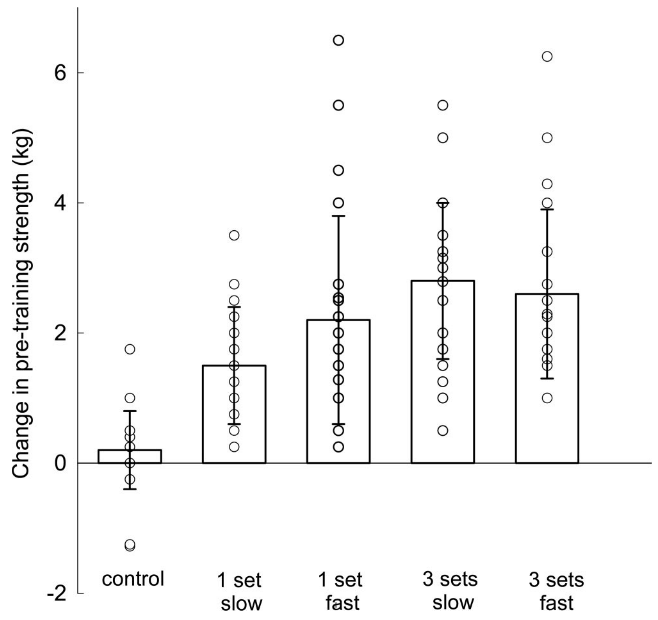

FIGURE 2—Strength changes for the elbow flexors (expressed in kilograms) for control and trained subjects following 6 wk of progressive resistance training. Data are group means and SD. Circles represent individual subjects.

TABLE 2. Coefficients, 95% CI, and P values for the linear regression analysis for strength of the trained arm.

Coefficient	Mean effect (kg) (95% CI)	Effect as % of pooled initial value (5.58 kg)	P
Constant	−0.93 (−1.59 to −0.28)	−17%	0.006
Initial strength	1.20 (1.11 to 1.28)	1.20% per % initial	<0.001
Training (one set slow vs control)	1.38 (0.75 to 2.02)	25%	<0.001
Three sets vs one set	1.28 (0.65 to 1.92)	23%	<0.001
Fast vs slow speed	0.64 (0.01 to 1.27)	11%	0.046
Interaction (sets × speed)	−0.88 (−1.77 to 0.01)	−15%	0.052

The regression model is strength (kg) = a + b (initial strength) + c (trained or control) + d (sets 3 or 1) + e (speed fast or normal) + f (interaction sets × speed).

compared with a slow speed (−0.28 cm, 95% CI −0.67 to 0.12, $P = 0.175$). Training had no effect on skinfold thickness.

DISCUSSION

Six weeks of training with three sets of resistance exercise produces about twice the increase in strength (48%) obtained when training with one set (25%) at the same training intensity. This difference is similar to that found with 12 wk of strength training for the lower limb (56% increase in initial strength for three sets compared with 26% for one set (26)). These findings support superior strength increases with larger training volumes in the early phases of training. Increased exposure to the training stimulus (three training sets compared with one) induces further strength adaptations even in the acute phase of training.

One set of contractions produced significantly smaller strength increases than training with three sets. However, strength increases produced by a single set of training may still be large enough to be useful (25% of initial strength, 95% CI 13–36%). Previous research has shown that compliance with training programs is higher in one-set programs than three-set programs (13), and in short programs (25) with fewer exercises (14). Moreover, training with one set is less time-consuming than training with three sets where the same exercises are being performed. Thus, although three sets of resistance exercise clearly produce greater strength gains in the early phases of training, a one-set protocol might sometimes be preferable to a three-set protocol if subject compliance or time prioritization is a concern.

Training at fast speeds resulted in greater strength gains than training at slow speeds. However, the effect of speed on strength was smaller than the effect of number of sets (11% greater strength increase if training fast rather than slow compared with a 23% greater strength increase if training with three sets instead of one). The effect of training speed is consistent with observations made by Paddon-Jones et al. (23) and Farthing and Chilibeck et al. (9), who showed that eccentric training at faster contraction velocities ($180°\cdot s^{-1}$) produced greater increases in strength than training at slow velocities ($30°\cdot s^{-1}$). The mechanisms by which speed of training influences strength adaptations was not investigated in this study, but some authors have speculated that mechanisms could include change in muscle fiber type (16,23) or increased ability to selectively recruit fast-twitch motor units (6). The latter mechanism is unlikely because recruitment order of motor units appears to remain unchanged with fast compared with slow contractions (8). Training with fast speeds leads to higher discharge rates of single motor units and more frequent occurrence of brief interspike intervals (doublet discharges) (33); these phenomena might underlie the greater training response.

Training resulted in a small but significant increase in upper arm circumference. This increase is most likely due to a change in gross muscle size of biceps brachii and brachialis. It is unlikely that other structures (such as bone or subcutaneous tissue) underlying the site of measurement would have undergone adaptive changes that would be reflected by an increase in arm circumference. Previous research on recreational weight lifters has also found increased biceps circumferences following 13 wk of training but only in subjects training with three sets (13). In the current study, there was no evidence that one type of training (i.e., one set or three sets, fast or slow) was superior for increasing arm circumference in the early phase of training.

Resistance training for 6 wk with either one or three sets had no effect on skinfold thickness. Several studies have shown reduced skinfold thickness after resistance training, but these studies used exercises incorporating several muscle groups (13). The effect of training on skinfold thickness is likely to be related to the total caloric expenditure of the exercise program and not the individual resistance exercise at the target site. In the present study, only one exercise was performed that may be why no change in skinfold thickness was detected.

In conclusion, a one-set strength training program for elbow flexor strength at a slow training speed (average speed $\approx 50°\cdot s^{-1}$) performed $3\times$ wk^{-1} for 6 wk will increase strength of untrained subjects by about 25%, and this effect is doubled if three sets are performed. Training with fast repetitions (average speed $\approx 140°\cdot s^{-1}$) results in an 11% greater strength increases than training with slow repetitions. There is no additional benefit of performing fast contractions if training with three sets. It is recommended that three-set programs be used in preference to single-set programs if the aim is to maximize strength gains. If one-set programs are adopted, fast rather than slow repetitions will produce larger gains in strength. These findings may have implications for clinical populations where strength training forms part of rehabilitation or health promotion intervention.

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REFERENCES

1. ALTMAN. D. G. Randomisation essential for reducing bias. *BMJ.* 302:1481–1482, 1991.
2. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription,* 6th Ed. Philadelphia: Lippincott Williams & Wilkins, 2000, pp. 22–32.
3. BERGER. R. Effect of varied weight training programs on strength. *Res. Q.* 33:168–181, 1962.
4. CARPINELLI, R. N. Berger in retrospect: effect of varied weight training programmes on strength. *Br. J. Sports Med.* 36:319–324, 2002.
5. CARPINELLI, R. N., and R. M. OTTO. Strength training single versus multiple sets. *Sports Med.* 26:73–84, 1998.
6. COYLE, E. F., D. C. FEIRING, T. C. ROTKIS, et al. Specificity of power improvements through slow and fast isokinetic training. *J. Physiol.* 61:1437–1442, 1981.
7. CURETON, K. J. M. A. COLLINS, D. W. HILL, and F. M. MCELHANNON, JR. Muscle hypertrophy in men and women. *Med. Sci. Sports Exerc.* 20:338–334, 1988.
8. ENOKA, R. M., and A. J. FUGLEVAND. Motor unit physiology: some unresolved issues. *Muscle Nerve* 24:4–17, 2001.
9. FARTHING, J. P., and P. D. CHILIBECK. The effects of eccentric and concentric training at different velocities on muscle hypertrophy. *Eur. J. Appl. Physiol.* 89:578–86, 2003.
10. FEIGENBAUM, M. S., and M. L. POLLOCK. Prescription of resistance training for health and disease. *Med. Sci. Sports Exerc.* 31:38–45, 1999.
11. GANDEVIA, S. C. Spinal and supraspinal factors in human muscle fatigue. *Physiol. Rev.* 81:1725–1789, 2001.
12. GRAVES, J. E., B. L. HOLMES, S. H. LEGGETT, D. M. CARPENTER and, M. L. POLLOCK. Single versus multiple set dynamic and isometric lumbar extension training. In: *Proceedings of the XIth International Congress of World Confederation of Physical Therapy.* London: 1991, pp 1340–1342.
13. HAAS, C. J., L. GARZARELLA, D. DE HOYOS, and M. L. POLLOCK. Single versus multiple sets in long-term recreational weightlifters. *Med. Sci. Sports Exerc.* 32:235–242, 2000.
14. HENRY, K. D., C. ROSEMOND, and L. B. ECKERT. Effect of number of home exercises on compliance and performance in adults over 65 years of age. *Phys. Ther.* 78:270–277, 1998.
15. HOLLIS, S, and F. CAMPBELL. What is meant by intention to treat analysis? Survey of published randomised controlled trials. *BMJ.* 319:670–674, 1999.
16. HORTOBAGYI, T., J. BARRIER, D. BEARD, et al. Greater initial adaptations to submaximal muscle lengthening than shortening. *J. Appl. Physiol.* 81:1677–1682, 1996.
17. KRAMER, J. B., H. S. STONE, M. H. O'BRYANT, et al. Effects of single vs. multiple sets of weight training: impact of volume intensity and variation. *J. Strength Cond. Res.* 11:143–147, 1997.
18. LEIGHTON, J. R., D. HOLMES, J. BENSON, B. WOOTEN, and R. SCHMERER. A study on the effectiveness of ten different methods of progressive resistance exercise on the development of strength, flexibility, girth and bodyweight. *J. Assoc. Phys. Ment. Rehabil.* 21:78–81, 1967.
19. MESSIER, S. P., and M. E. DILL. Alterations in strength and maximal oxygen uptake consequent to Nautilus circuit weight training. *Res. Q. Exerc. Sport.* 56:345–351, 1985.
20. MORRISSEY, M. C., E. A. HARMAN, P. N. FRYKMAN, and K. HOON HANN. Early phase differential effects of slow and fast barbell squat training. *Am. J. Sports Med.* 26, 1998.
21. NORTON, and K. T. OLDS. (Eds.). *Anthropometrica: A Textbook of Measurement for Sports and Health Courses.* Sydney: University of New South Wales Press, 1996, pp. 50–55.
22. OSTROWSKI, K. J., G. J. WILSON, R. WEATHERBY, P. W. MURPHY, and A. D. LYTTLE. The effect of weight training volume on hormonal output and muscular size and function. *J. Strength Cond. Res.* 11:148–154, 1997.
23. PADDON-JONES, D., M. LEVERITT, A. LONERGAN, and P. ABERNETHY. Adaptation to chronic eccentric exercise in humans: the influence of contraction velocity. *Eur. J. Appl. Physiol.* 85:466–471, 2001.
24. PEREIRA, M. I., and P. S. GOMES. Movement velocity in resistance training. *Sports Med.* 33:427–438, 2003.
25. POLLOCK, M. L. Prescribing exercise for fitness and adherence. In: *Exercise Adherence: Its Impact on Public Health.* Dishman R. K. (Ed.). Champaign, IL: Human Kinetic Books, 1988, pp. 259–277.
26. RHEA, M. R., B. A. ALVAR, S. D. BALL, and L. N. BURKETT. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *J. Strength Cond. Res.* 16:525–529, 2002.
27. RHEA, M. R., B. A. ALVAR, and L. N. BURKETT. Single versus multiple sets for strength: a meta-analysis to address the controversy. *Res. Q. Exerc. Sport* 73:485–488, 2002.
28. RHEA, M. R., B. A. ALVAR, L. N. BURKETT, and S. D. BALL. A meta-analysis to determine the dose response for strength development. *Med. Sci. Sports Exerc.* 35:456–464, 2003.
29. SANBORN, K., R. BOROS, J. HRUBY, et al. Short-term performance effect of weight training with multiple sets not to failure vs. a single set to failure in women. *J. Strength Cond. Res.* 14:328–331, 2000.
30. SILVESTER, L. J., C. STIGGINS, C. MCGOWN, and R. BRYCE. Effect of variable resistance and free-weight training programs on strength and vertical jump. *Natl. Strength Cond. Assoc. J.* 3:30–33, 1981.
31. SMITH, G. D., and M. EGGER. Going beyond the grand mean: subgroup analysis of randomised trials. In: *Systematic Reviews in Health Care: Meta-analysis in Content,* 2nd Ed. Egger, M., G. D., Smith, and D.G. ALTMAN (EDS.). LONDON: BMJ, 2001.
32. STARKEY, D. B., M. L. POLLOCK, Y. ISHIDA, et al. Effect of resistance training volume on strength and muscle thickness. *Med. Sci. Sports Exerc.* 28:1311–1320, 1996.
33. VAN CUTSEM, M., J. DUCHATEAU, and K. HAINAUT. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J. Physiol.* 513:295–305, 1998.