JEPonline
Journal of Exercise Physiology **online**

Official Journal of the American
Society of Exercise Physiologists (ASEP)

ISSN 1097-9751
An International Electronic Journal
Volume 7 Number 6 December 2004

Review

STRENGTH TRAINING METHODS AND THE WORK OF ARTHUR JONES

DAVE SMITH AND STEWART BRUCE-LOW

University College Chester, University of Liverpool

TABLE OF CONTENTS

ABSTRACT

STRENGTH TRAINING METHODS AND THE WORK OF ARTHUR JONES. **Smith D, Bruce-Low S**. **JEP**online. 2004;7(6):52-68. This paper reviews research evidence relating to the strength training advice offered by Arthur Jones, founder and retired Chairman of Nautilus Sports/Medical Industries and MedX Corporation. Jones advocated that those interested in improving their muscular size, strength, power and/or endurance should perform one set of each exercise to muscular failure (volitional fatigue), train each muscle group no more than once (or, in some cases, twice) per week, perform each exercise in a slow, controlled manner and perform a moderate number of repetitions (for most people, ~8-12). This advice is very different to the strength training guidelines offered by the National Strength and Conditioning Association, the American College of Sports Medicine and most exercise physiology textbooks. However, in contrast to the lack of scientific support for most of the recommendations made by such bodies and in such books, Jones' training advice is strongly supported by the peer-reviewed scientific literature, a statement that has recently been supported by a review of American College of Sports Medicine resistance training guidelines. Therefore, we strongly recommend Jones' methods to athletes and coaches, as they are time-efficient and optimally efficacious, and note that, given his considerable contribution to the field of strength training, academic recognition of this contribution is long overdue.

Key Words: Weight training, Bodybuilding, Power, Muscular endurance, Nautilus, MedX

INTRODUCTION

During the past thirty or so years, the popularity of weight training has increased enormously. Simultaneously, the number of popular books and articles devoted to this topic has also increased, and those interested in improving their muscular size and strength are confronted by a rather bewildering array of information sources, many of which appear to contradict one another. Issues such as how many sets and repetitions individuals should perform, the movement cadence individuals should adopt, frequency of training, and how to specifically target increased power or muscular endurance are discussed regularly in popular weight training magazines and books, with little in the way of agreement between the individuals writing in such publications.

In contrast, an examination of recent exercise physiology textbooks (1-3), most specialist strength and conditioning textbooks (4-10) and of the guidelines produced by certification organisations such as the National Strength and Conditioning Association (11) and the American College of Sports Medicine (12) reveals an apparent academic consensus as to how individuals should perform weight training for optimal results. The guidelines issued by such sources state that experienced trainees should perform –

1. multiple sets of each exercise for best results,
2. low-repetition sets to increase strength and high-repetition sets to increase muscular endurance, and
3. repetitions explosively (i.e. with a relatively fast cadence) for optimal power development.

Also, they argue that for experienced trainees, very frequent, high-volume training up to 4-5 days/week twice/day, for a total of around 21 hours of training/week (12) will produce best results.

However, this consensus on optimal strength training methods is not shared by everyone in this field (13-20). A recent article has, for instance, criticised the ACSM resistance training guidelines for their lack of empirical support (13), and another paper (14) has pointed out that despite claims to the contrary, the available evidence does not favour the multiple-set approach advocated by the ACSM and NSCA. Such criticisms are, however, not new. One individual, who has been offering advice directly contradicting all of the above recommendations for over thirty years, is Arthur Jones, founder and retired Chairman of Nautilus Sports/Medical Industries and MedX Corporation. In the early 1970s, when Jones first developed his Nautilus exercise equipment, he began to publish advice as to how to use this equipment for best results. However, the advice he gave can be (and was intended to be) utilised by those using any kind of weight training equipment. This advice was published in over 100 articles within various fitness magazines and technical journals, and in several books, between 1970 and 1998. Jones' recommendations (15-20), aimed at anyone wishing to increase muscular strength, hypertrophy, power and endurance, can be summarised as follows:

1. Perform one set of each exercise to muscular failure. Additional sets will not provide better results.
2. Train each muscle group no more than twice/week, and many individuals will produce optimal results from training each muscle group no more than once/week.
3. Move slowly and deliberately during each exercise. Such exercise form will produce optimal increases in strength and power.
4. For most individuals, best results will be achieved by performing a moderate number of repetitions (around 8 to 12) rather than very high or low repetitions. This will produce optimal increases in muscle strength and endurance, which are related in that increases in strength will be accompanied by increases in muscular endurance.

Therefore, in summary, Jones' recommendations are to train hard (to muscular failure) but relatively briefly and infrequently to optimise muscular strength, hypertrophy, power and endurance. In contrast to the recommendations of many exercise physiologists, who advocate strength training programs that can consume upwards of twenty hours/week (8,11), Jones recommends training for a maximum of about 90 min/week. It is important to note here that Jones' work has never been published in peer-reviewed scientific journals. Some physiologists have pointed this out in an attempt to discredit Jones' theories (21,22). However, the aim of this article is to point out that his hypotheses have mostly been strongly supported by the peer-reviewed scientific literature. This is in great contrast to the recommendations made in many exercise physiology textbooks and by some prominent exercise certification organisations, which appear to have very little scientific support, and which a great deal of scientific evidence clearly contradicts. The following sections examine the scientific literature relating to each of Jones' training recommendations.

REVIEW OF RESEARCH

Single Versus Multiple Sets

From his earliest writings (15) to his final ones (20), Jones argued that optimal increases in muscular strength and hypertrophy can be produced from one set carried to a point of momentary muscular failure (muscular failure), and that further sets are therefore unnecessary. For example, in his book *The lumbar spine, the cervical spine and the knee: testing and rehabilitation* (18, p. 44), he stated:

> "*How many sets of the exercise? One. Additional sets usually serve no purpose and may produce a state of overtraining with some subjects…The exercise should be stopped when the subject is no longer capable of completing a full-range movement without jerking*"

In contrast, the most recent editions of many popular textbooks (1,4,6,8), and the guidelines of both the NSCA (11) and ACSM (12), advocate the performance of multiple sets of each exercise for best results. For example, Watson (3) suggests that although single sets are useful for beginners *"...the superiority of the multiple-set system has been demonstrated, and this method of training is appropriate for experienced strength trained athletes*" (p. 97). Fleck and Kraemer (8) claim, "*...a single-set system may not promote the cellular adaptations required to support long-term gains in strength and power*" (p. 119). In examining this literature, we have been unable to find a single general exercise physiology textbook that recommends single-set training although Wilmore and Costill (7) and Powers and Howley (23) suggest there is ambiguity within the literature regarding single versus multiple-set training. However, some strength training textbooks (24-27) do recommend single sets.

This general bias in favour of multiple sets is very interesting, given that the great preponderance of scientific studies show that single sets produce results at least as good as those produced by multiple sets, both in previously trained and untrained subjects. For example, Starkey et al. (28) observed there were no significant differences when knee extension and knee flexion were examined with groups that either undertook training 3 days/week utilising either high volume (3 sets) or low volume (1 set). Peak isometric knee extension torque increased by 15.1 % and 14.8 %, and knee flexion by 13.9 % and 16.2 %, using 1 and 3 sets, respectively. In addition, Starkey et al. also reported significant increases in muscle thickness, with no significant between-group differences. Vincent et al. (29) found that a single-set group increased the weight used on the MedX knee extension by 25.6 %, with an increase in peak isometric torque of 35.4 %, whereas a three-set group increased weight used by only 14.7 %, with an increase in torque of 32.1 %. Again, none of these differences were significant.

This was also true of Ostrowski et al. (30) whose subjects used a 1, 2 or 4 set protocol for 10 weeks. There were significant increases in strength for all groups for 1 RM squat (7.5, 5.5 and 11.6 %), 1 RM bench press (4.0, 4.7 and 1.9 %) and bench press power (2.3, 2.3 and 3.1%) for the 1, 2 and 4 set groups respectively. There were no significant differences between the 3 groups. In addition, there were also significant increases in tricep 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 %) for the 1, 2 and 4 set groups respectively, although there were no significant differences between the groups.

Pollock et al. (31) showed that single-set training produced very large increases in lumbar extension strength. After a 10-week training program their subjects showed at 0^{o} (full extension) and 72^{o} (full flexion) an increase in strength of 102 % and 42 % respectively when compared to the non-exercising control group. Further work by Pollock et al. (32) showed that a single-set training programme is all that is required in order to obtain an increase in cervical extension strength. The relative percent increases in cervical extension strength observed when subjects trained using 1 set of dynamic exercise either once or twice a week were 35% and 40.9% respectively. This is supported by the findings of Tucci et al. (33) who also observed significant increases in lumbar extension strength following 10 or 12 weeks training when using single-set training. Tucci et al. also observed that this increase in strength can be maintained for an additional 12 weeks by reducing the training frequency to either once every 2 weeks or once every 4 weeks, compared to a 55 % reduction in lumbar strength in subjects who stopped training altogether.

Haas et al. (34) examined the effects of two different strength-training protocols (either 1 or 3 sets of nine exercises, performed three times/week for 13 weeks) on experienced weight trainers who had been training for an average of 6.2 years. Both groups increased isometric knee extension and knee flexion torque, lean body mass and chest and biceps circumference, with no between-group differences on any of these variables.

In a review published in 1998, Carpinelli and Otto (35) concluded that the research to date strongly supports the idea that single sets can produce optimal results. This was the case in 33 out of the 35 studies they reviewed. Carpinelli (36) pointed out that many exercise physiology textbooks cite a 1962 study by Berger (37) as supporting multiple-set training. This study found a small advantage from performing multiple sets on bench press one-repetition maximum (1 RM; 22.3 % increase from 1 set versus a 25.5 % increase from 3 sets, a 3 % difference in strength from 300 % more training). Carpinelli revealed that the subjects in this study were performing other weight training exercises during the study, and Berger did not control the number of sets and repetitions performed on these exercises. Rest times and movement speed were also not controlled. Also, there was no control for exercise intensity: subjects simply performed a designated number of repetitions. All these confounding variables call Berger's conclusions regarding the supposed superiority of multiple sets into question. Therefore, in contrast to Arthur Jones, whose views have been empirically validated by a great deal of peer-reviewed research, many exercise physiologists appear to be making recommendations based on one forty-two-year-old study with numerous confounding variables.

Many of the references cited in books and articles supporting multiple-set training are themselves books and not research studies, and therefore amount to personal opinion rather than scientific evidence. For example, Wathen (38) supports the use of multiple sets using references that are books as opposed to research studies (for example, 39-42). Finally, other studies that have been cited (12,43) as supporting multiple sets are those of Kraemer (44), Kraemer et al., (45), Kramer et al. (46) and Marx et al. (47). However, the results of these studies all have something interesting in common. That is, the results produced by single-set training seem remarkably poor compared to most of the findings in the literature noted above. For example, in Kramer et al.'s 1997 study, the average increase in subjects' 1 RM squat following a 14-week training program was less than 12 %. Contrast this with the findings of Pollock et al. (29), where the lumbar extension strength of subjects more than doubled in the fully flexed position from one set to muscular failure performed once/week for 10 weeks. Hurley et al. (48) demonstrated a 50 % increase in lower body strength and a 33 % increase in upper body strength from a 16-week training regime consisting of a single-set of each exercise to muscular failure. From a similar training regime, this time lasting just 10 weeks, Messier and Dill (49) showed a 30 % and 46 % increase in upper body and lower body strength respectively. In contrast, in the Kraemer et al. (45) study no strength increases occurred after the fourth month of a nine-month training programme. Marx et al. (47) found no strength increases after the 12th week of a 24-week program. One strength coach experienced in single-set programs has commented that such poor results from single-set training make such data rather suspect: that the subjects may not have been supervised adequately (50). One of the authors of the present paper is a former strength coach who has personally trained many athletes and has never experienced strength increases as poor with any one individual as the averages reported in these several studies. In one case (44) there is clear evidence of researcher bias. That is, with one important dependent variable reported by the author, 1 RM hang clean, the multiple-set group practiced this exercise as part of their training protocol but the single-set group did not. Also, two other exercises (leg press and bench press) were performed in 33 % more workouts by the multiple-set group than by the single-set group. Finally, the single-set group performed sets of 8-12 repetitions throughout the study whereas the multiple-set group performed some sets with 3-5 repetitions, again potentially biasing the results of the 1 RM tests. That is, the multiple-set group may well have performed better in the 1 RM tests because the multiple-set subjects were more used to performing low-repetition sets. It appears that this author, whose opposition to single-set training is very clear from the tone of this paper, has allowed his personal preference to influence his research design.

The Marx et al. (47) study also contained numerous confounding variables. In this experiment, untrained females were allocated to either a single-set or multiple-set group for a six-month training programme. The single-set group performed one set of 8-12 repetitions on each of ten machine exercises three times/week, whereas the multiple-set group performed 2-4 sets of free weight and machine exercises four times/week, with varying repetition ranges (8-10 reps twice/week, and a mix of 3-5 reps, 8-10 reps and 12-15 reps twice/week). The multiple-set group showed a significantly greater increase in strength than the single-set group on the I RM leg press and bench press, and a significant increase in lean body mass, which the single-set group failed to demonstrate. However, there are several serious design flaws in this study. First, the multiple-set group practiced both exercises that were used as dependent variables during the study, whereas the single-set group only practiced one of these exercises. Also, as in the Kraemer (44) study, the low-repetition sets practiced by the multiple-set group may have given that group an advantage in the 1 RM strength tests. Finally, the differing training modalities used by the two groups (i.e. free weights and machines versus machines only) may also have confounded the results.

To ensure a valid test of the hypothesis that single and multiple sets will produce differing physiological effects, the only variable that should differ between groups is the number of sets: where this requirement has been met, single sets have almost always been shown to be at least as effective as multiple sets (26-28,32). The only exception is a study by Borst et al. (51), who found that a three times/week training program produced significantly greater strength increases when three sets of each of the seven exercises were performed compared to one set. However, neither group significantly increased body mass or changed body composition, suggesting that though the greater practice gained by the three set group facilitated greater improvement in the performance of the exercises, neither protocol was effective in producing myogenic effects. Therefore, an appropriate conclusion from this would seem to be that the three times/week regimen used was not very effective regardless of whether three sets or one set of each exercise were performed.

The authors of two recent meta-analyses (52,53) claim that their findings support the superiority of multiple sets. Both meta-analyses claim to include all relevant published studies. In the 2002 paper (52), the authors analyse 16 studies that have examined the effects of weight training programmes comprising one and three sets per exercise respectively. The 2003 paper (53) compares the results of 140 studies that have examined the effects of strength training interventions, in an attempt to determine how many sets per muscle group are best. The two meta-analyses in question compare many studies loaded with potentially confounding variables. These include varying numbers of repetitions, different exercises and training modalities, different training intensities (i.e. some studies specify training to muscular failure and others don't), different strength measures, different subject populations (healthy and diseased, sedentary and athletic, young and old), and different dietary constraints. The idea that one can meaningfully compare studies with so many differences is clearly questionable. It is also important to point out that the great majority of the studies in the 2003 meta-analysis were not designed to compare the effects of single and multiple-set weight training: they were actually designed to examine such widely differing topics as the effects of various nutritional supplements, the effects of weight training in different age groups, changes in cardiovascular function as a response to weight training, specificity of training, effect of weight training on bone mineral density, balance, walking speed and many other variables. We contend that comparing such a hodgepodge of studies will simply not provide meaningful results: the idea that the differences between the studies will somehow magically even themselves out to produce a balanced comparison of different training volumes appears very naïve. Indeed, researchers have previously criticised this sort of abuse of meta-analysis ('comparing apples and oranges'; 54,55).

The confounding variables mentioned above make these meta-analyses a questionable exercise at best, even if the studies included were well-designed and controlled, and represented all such published studies. However, neither of these conditions is met. Firstly, the paper includes the Berger (37), Kraemer (44), Kraemer et al. (45) and Kramer et al. (46) studies, the numerous shortcomings of which have been discussed above.

Of even greater concern is the fact that many studies are missing from the analyses of Rhea and colleagues. In the 2002 study, supposedly all English-language studies, including abstracts, published by 2000 and comparing one versus three sets/exercise programs were included. However, this is not the case. At least six studies published prior to 2000 that examined this topic are not included in their meta-analysis. Interestingly, none of these studies found any advantage in performing multiple sets. It is a remarkable coincidence that all these studies ignored by Rhea et al. do not support their conclusions. For example, the Vincent et al. study noted previously is missing from the analysis, as are studies by Terbizan and Bartels (56), Stowers et al. (57), Westcott et al. (58), Welsch et al. (59) and Stadler et al. (60).

Given that only 16 studies were included in the analysis, it is likely that the inclusion of these six studies would have had a major impact on the findings. A similar phenomenon has occurred in their 2003 analysis. That is, a number of studies showing very large strength increases from single-set training are absent. These include the six studies noted above, but also a number of others that again are likely to have impacted upon the results of the meta-analysis. These include the studies by Pollock et al. (31,32), Tucci et al. (33), Graves et al. (61) and Carpenter et al. (62) mentioned elsewhere in this paper, and other studies by Risch et al. (63), Highland et al. (64), Peterson (65), Holmes et al. (66), Ryan et al. (67), Koffler et al. (68), Rubin et al. (69), Capen (70) and Westcott (71). It appears very suspicious that all these studies that have not been included in the meta-analysis have found single-set training to be very effective. It is also remarkable that three studies that were included in the 2002 analysis (72-74) are absent from the 2003 one. In total, therefore, 23 studies, all of which found single-set training to be very effective, are missing from the 2003 analysis. We do not wish to speculate on the possible reasons for these omissions, but simply note that such omissions, in conjunction with the methodological problems noted above, render the authors' conclusions invalid.

Another important point regarding the 2003 analysis is that the study compared single versus multiple sets per muscle group, not per exercise. It is important to note that those advocating one set per exercise, including Jones, do not usually hypothesise that one set for every muscle group would lead to optimal muscle gains. Also, in a well-balanced training program it would be almost impossible to only perform one set/muscle group, as many exercises work more than one muscle. Therefore, these researchers have constructed a 'straw man' (one set/muscle group) to knock down, presumably knowing that most single-set trainees, although performing one set/exercise, perform more than one set/muscle.

Overall, it is clear that the great majority of well-controlled, peer-reviewed studies support Jones' (15,16,18-20) contention that one set per exercise is all that is necessary to stimulate optimal increases in muscle strength and hypertrophy. Though there are exceptions in the research literature, these are few and most suffer from confounding variables and, in some cases, blatant experimenter bias.

Optimal Training Frequency

It is often suggested in the exercise physiology literature that novices train two to three times/week, but that more experienced trainees should engage in more frequent training. For example, the ACSM (12) recommend that advanced bodybuilders, powerlifters and weightlifters should perform a "split" routine (training different muscle groups on different days) involving training four-six days/week, two or three times/day. In a NSCA publication, Binkley (75) also argues that, in the off-season, athletes should perform weight training four-six days/week. Fleck and Kraemer (8) state that in order to increase strength, maximal voluntary muscular actions should be undertaken on a daily basis. They also state that more frequent training sessions result in greater increases in strength. These recommendations contrast vividly with the views of Jones, who in his early work (14,15) advocated training the whole body three times/week, later amended to training each muscle group only once or, at most, twice/week (20). "How many weekly workouts? Not more than two, and some people will produce better results from only one weekly workout. More is not always better, and in the case of exercise is usually worse" (p. 559).

Given the very time-consuming nature of the training methods advocated by the NSCA and others, it seems reasonable to assume that strong scientific proof must have been found to justify their adoption of such methods. At least, the preponderance of scientific evidence must have shown that this high frequency of training produces significantly better results than the lower frequency advocated by Jones. However, a search of the scientific literature will clearly disappoint those who expect bodies such as the NSCA to base their training practices on objective scientific evidence rather than subjective personal preference. For both novice and experienced trainees, there appears to be very little support for the notion that training each muscle group more than once (or in some cases twice)/week provides any additional benefits. For example, Graves et al. (61) examined the effects of 12 weeks of resistance training on the lumbar extension strength of untrained subjects, who performed one set of lumbar extensions either once, twice or three times/week, or once every two weeks. All groups increased significantly in peak isometric torque at all seven joint angles tested, and there were no significant between-group differences in isometric strength increases. These findings were replicated by Carpenter et al. (62). Interestingly, one of the subjects in the three times/week group in the Graves et al. study actually produced large losses in strength from overuse atrophy. This subject was repeatedly forced to reduce the level of resistance to enable her to perform the required repetitions. This illustrates the large inter-individual responses that can occur in exercise tolerance, and the importance of cautiously regulating the frequency of strength training exercise according to the individual's tolerance. However, this issue is not discussed in the NSCA (11) or ACSM (12) guidelines, and NSCA publications (75) offer 'canned' training program with no attention given to the importance of individualising such programs based on the tolerance for exercise which, as the above example shows, can vary dramatically between individuals. Thus, such programs may produce good results for some individuals and very poor results for others. It is also worth noting that Binkley (75), who makes a number of points directly contradicted by the research discussed in this paper, makes no reference to any peer-reviewed scientific research, referencing only four books, all of which were authored by other NSCA advocates.

Similarly to Graves et al. (61) and Carpenter et al. (62), Pollock et al. (32) examined the effects of one set of cervical extensions performed either weekly or twice-weekly, and again found that both protocols significantly increased isometric cervical extension strength, with no significant difference in strength increases at seven of the eight joint angles tested. Of course, it could be argued that such findings may only be applicable to the lumbar and cervical spine muscles. However, when Taafe et al. (76) examined the relative effectiveness of training the whole body once, twice or three times/week for 24 weeks, they found no significant differences in strength increases generated by the three protocols on any of the five upper body and three lower body exercises performed.

For some subjects, it appears that training twice/week produces better results than training three times/week. Carroll et al. (77) compared the effects of training twice/week and three times/week for a total of 18 sessions (i.e. the twice/week group trained for nine weeks and the three times/week group trained for six weeks). Although both groups gained significantly in 1 RM squat, with no significant between-group difference, only the twice/week group increased significantly in isometric and isokinetic knee extension strength; the three times/week group did not increase on either measure.

Optimal training frequency may also differ between muscle groups. DeMichele et al. (78) examined the effect of one set of MedX torso-rotation exercise, performed either once, twice or three times/week for 12 weeks, on isometric torso rotation strength. No significant differences in strength gains were found between the twice and three times/week groups, but both increased to a significantly greater degree than the one time/week group.

What of training frequencies of greater than three times/week? Rozier and Schafer (79) examined the effects of training three and five times/week respectively on the knee extension strength of previously untrained females. In this study, the three times/week group showed greater increases in both isometric and isokinetic torque than the five times/week group, though these differences were not statistically significant. In contrast, in a study that has been discussed previously in the single versus multiple sets section, Marx et al. (47) found that a four times/week training regimen produced significantly greater gains than a three times/week regimen. However, the confounding variables in this study, which were discussed earlier in this paper, call into question the usefulness of the findings.

The studies cited above were all conducted with untrained subjects. As noted above, it has been argued (8,12) that more frequent training will benefit experienced trainees. However, the scientific evidence does not support this claim. McLester et al. (80) examined the effects of a whole-body training program, consisting of nine exercises performed either one or three times/week, on the strength of experienced weight trainers. Subjects had an average of 5.7 years experience in weight training. No significant between-group differences were found in the post-test on eight out of the nine strength measures, leaving McLester et al. to conclude that training once/week is equally as effective as training three times/week.

The only other study to have examined the effects of differing training frequencies on strength in experienced trainees was that of Hoffman et al. (81). This study recruited Division 1 American football players who self-selected a training frequency of three, four, five or six days/week. This lack of randomised allocation of subjects to groups, as well as a great imbalance in group size (for example, there were less than half the number of subjects in the three times/week group than in the five times/week group), calls into question the usefulness of this study. On the basis that the five times/week group was the only group to significantly improve 1 RM bench press (by 3.2 %), Hoffman et al. concluded that the five times/week protocol was best. However, there are some concerns worthy of note here. First, the magnitude of strength increases in this study (i.e. a highest increase of 4.0 % in the bench press and 7.5 % in the squat) appear very low, suggesting either that all the protocols used in this study were rather poorly chosen, or that supervision of the subjects may have been inadequate. Most importantly, all groups improved significantly in nine of the testing variables, contradicting the claim of Hoffman et al. that the five times/week group improved on more variables than the other groups.

Overall, therefore, Jones' claim that optimal training results can be achieved from exercising the whole body twice/week (and, for some muscle groups and some individuals, once/week) is supported by the research literature. Several studies have found no differences between results gained from training once, twice or three times/week (61,62,76,80), one study found training either twice or three times/week to be better than training once/week (78), one study found training twice/week better than training three times/week (77), and another study found training three times/week better than training five times/week (79). The only study that has found high-frequency (i.e. greater than three times/week) training to be more effective is Marx et al. (47), a study loaded with confounding variables. Therefore, it seems reasonable to conclude that for most individuals, training each muscle at the most twice/week (and, in many instances not more than once/week) will provide optimal results.

Speed Of Movement During Exercise

It is commonly suggested by various weight-training authorities (8-12) that to optimally increase muscle strength and (particularly) power, weight-training exercises be performed explosively (i.e. with a relatively fast speed of movement). This, such sources suggest, will lead to greater increases in muscle strength and power than if exercises are performed using a relatively slow, controlled cadence. However, Jones (17,18) advocated a relatively slow lifting speed to reduce momentum and increase muscle tension. He stated (18), "*At the start of the first repetition, muscular contraction should be produced gradually, and should be slowly increased until the start of movement is produced. Once movement at a slow speed has started, the level of effort should remain just high enough to continue slow movement. Do not increase the speed as movement continues*" (p. 44). In practical terms, according to Jones' former Director of Research, Ellington Darden (24), on most exercises such advice translates into duration of at least two seconds for the lifting of the weight and four seconds for the lowering of the weight. Jones (17) argued that such a training style would lead to optimal increases in strength, power and muscle size, and should be coupled with much practice of the specific skill to be performed to optimise sports performance.

A study by Mikesky et al. (82) provided strong support for Jones' viewpoint. Mikesky and colleagues examined the effects of a wrist flexion exercise on the forelimb strength and size of 62 cats. The cats were operantly conditioned to perform the exercise using a food reward, and weights were increased as the cats progressed. When a cat failed to make progress for a certain period of time, the muscles of the forelimbs were removed and weighed. The cats that trained with the heaviest weights showed greater muscle mass increases compared to those training with lighter weights. Also, those using slower lifting speeds showed significantly greater increases in muscle mass than those using faster lifting speeds. Mikesky et al. concluded that slow lifting speeds lead to greater strength increases and hypertrophy than faster lifting speeds.

Although research on humans has not proved as conclusive as the animal research of Mikesky et al., it certainly does not appear to support the idea that faster lifting speeds are more effective for strength development. LaChance and Hortobagyi (83) compared the effects of repetition cadence on the number of push-ups and pull-ups subjects were able to complete. They found that subjects could complete more repetitions when performing fast, self-paced repetitions than when performing two-second concentric and two-second eccentric muscle actions, and that subjects could complete still fewer repetitions when performing two-second concentric and four-second eccentric contractions. Therefore, the difficulty of the exercise decreased as repetition cadence decreased. This suggests that faster repetitions involve less muscle tension, making it difficult to see how a faster speed of movement could be more productive. This view is supported by the findings of Hay et al. (84) who measured joint torque in three males while performing biceps curls. Hay et al. found that with short duration lifts (< 2 s) very little joint torque was required to move the weight through most of the range of motion (ROM), as after the beginning of the movement the weight continued to move under its own momentum. Again, this shows that fast movements do not provide as much muscle tension as slow movements through most of the ROM, suggesting that faster repetitions may not produce optimal strength increases through a muscle's full ROM. This appears to be strongly supported by a study by Westcott et al. (85), in which 147 previously untrained subjects were assigned to either a 'super-slow' condition (4-6 repetitions/set, 10 s concentric contraction, 4 s eccentric) or a 'traditional' (8-12 repetitions/set, 2 s concentric, 1 s isometric and 4 s eccentric) condition. Both groups performed 1 set of 13 exercises 2-3 times/week for 8-10 weeks. The super-slow group increased their strength to a significantly greater degree than the traditional group, suggesting that not only are faster repetitions no more effective, but also that even slower movements than Jones advocated may be best. Better results from slower repetitions were also found by Jones et al. (86), who found significantly greater increases in 1 RM squat resulting from slower repetitions than from faster ones (though precise movement cadence was not reported in this study).

In contrast, Keeler et al. (87) found greater increases in strength on some exercises from the 'traditional' exercise speed noted above than from the 'super-slow' speed, with an average strength gain of 39 % in the traditional group and only 15 % in the super-slow group after 10 weeks of training. However, as the subjects were novices their strength gains from super-slow seem very low. This may be because, in contrast to the Westcott et al. study, all subjects in this study performed 8-12 repetitions/set. Therefore, in this study the different time under load in the two conditions was a major confounding variable. As super-slow repetitions are more difficult than traditional repetitions, requiring lighter resistance, 8-12 repetitions may require the use of a resistance that is too light to stress the muscle sufficiently. Indeed, this is why super-slow advocates (24) often recommend a range of 4-6 repetitions. Thus, alternative interpretations of Keeler et al's findings are that either the use of very light weights, or the employment of a time under load of between 112 s and 168 s, is not an effective strategy for increasing muscle strength. The study design simply does not permit a conclusion regarding the effectiveness of differently paced repetitions.

A number of studies have found no significant difference between slow and fast-paced repetitions in increasing strength development. For example, Berger and Harris (88) compared the effects of fast (1.8 s), intermediate (2.8 s) and slow (6.3 s) repetitions on bench press performance, with one set of the exercise being performed three times per week for 8 weeks by each group. All groups significantly increased strength, with no significant between-group differences. More recently, Young and Bilby (89) compared the effect of slow versus explosive repetitions on performance of barbell squats. Again, both methods significantly increased 1 RM, as well as isometric peak force, vertical jump, thigh circumference and muscle thickness, with no significant between-group differences. Palmieri (90) split subjects into three groups based on repetition cadence (fast cadence, slow cadence and a combination of both) and examined the effects of a 10-week training program, consisting of squats and machine exercises, in each group. The slow cadence group performed the concentric part of each repetition in 2 s or more, the fast cadence group performed it in 0.75 s or less, and the combination group spent the first 6 weeks performing fast cadence repetitions and the last 6 on slow cadence repetitions. Overall, all groups improved significantly and there were no significant between-group differences. Interestingly, however, when the combination group switched to the fast cadence condition they failed to produce any further increases in the dependent measures, 1 RM squat and lower body power.

Palmieri's findings on lower body power are particularly interesting given the insistence by some authorities that "explosive" training exercises are better for improving muscle power than traditional, slow weight training. For example, in a NSCA publication, Cissik (91) claimed, "*If an exercise is performed at slow speeds, then we become stronger at slow speeds. However, there is little transfer to faster speeds. If exercises are performed at faster speeds, then we become stronger at faster speeds*" (p. 3). Similar statements can be found in many exercise physiology textbooks and coaching-related books and internet sites, but, as in the case of Cissik, such claims are always made with no supporting scientific evidence, which is not surprising as these views are simply not supported by the peer-reviewed scientific evidence. For example, Liow and Hopkins (92) investigated the effect of slow and explosive weight training on kayak sprint performance. The two programs differed only by the time it took to undertake the concentric action of the movement (slow – 1.7 seconds and explosive - < 0.85 seconds). Both training types showed an increase in performance (mean sprint time over the 15 meters increased by 3.4 % [slow training] and 2.3 % [explosive training]) although there were no significant between-group differences. Blazevich and Jenkins (93) examined varying movement velocities in hip flexion and extension, knee extension and flexion and the squat. They reported that there were no significant differences in torque measurements for hip extension and flexion, or 1 RM for the squat or sprint performance between the slow and explosive training groups.

In addition, Wilson et al. (94) compared the effects of traditional resistance training (3-6 sets of 6-10 RM squats), plyometric training and explosive training (loaded jump squats), performed twice/week for 10 weeks with experienced trainees. Both the traditional and explosive groups significantly improved peak power on a 6 s cycle test, with no significant between-group difference. Both groups also increased significantly on vertical and counter-movement jump, with the explosive group increasing to a greater degree. However, this is hardly surprising given that the explosive group had been practicing jumping and the traditional group had not. Only the traditional group increased significantly on maximal knee-extension force. In a follow-up study, Wilson et al. (95) compared the effects of traditional weight training (squats and bench presses) with plyometric training (depth jumps and medicine ball throws). The experimenters tested the effects of these programs on 14 variables related to strength and power, and the traditional group increased significantly on seven variables whereas the plyometric group increased only on three. Also, both groups increased significantly on counter-movement jump, with no significant between-group difference. Similar findings were reported by Holcomb et al. (96), who compared the effects of resistance training and plyometric-style training involving various types of depth jump. No significant between-group differences were found in increases in jump height or power performance, and the authors concluded that plyometric training was no more effective for increasing power than traditional resistance training.

Some research even suggests that some methods of explosive training may be less effective than slow weight training for increasing power. Newton and McEvoy (97) compared the effect of slow, controlled resistance training and explosive medicine ball throws in Australian baseball players. Only the resistance-training group significantly increased throwing velocity, and this group also increased 6 RM bench press to a significantly greater degree than either the explosive group or control group. Interestingly, there was no significant difference between these latter two groups.

Possibly the most interesting study to compare the effects of resistance training and plyometric-style (depth jumping) exercises was performed by Clutch et al. (98). In this study, half the subjects were members of a weight training class and the other half were volleyball players. Subjects were divided into four groups: a resistance training only group, a resistance training and depth jumping group, a volleyball playing and resistance training group, and a volleyball playing, resistance training and depth jumping group. All groups significantly increased vertical jump after 16 weeks of training, with the exception of the group that only did resistance training. There were no significant differences among the other three groups. The authors concluded that depth jumping provided no additional benefit to performing resistance training and practicing the specific skills involved in volleyball. Therefore, it appears that the only training necessary to optimise performance of a specific skill is the performance of that skill and separate resistance training.

Jones (18) provided an interesting practical example of the efficacy of slow weight training for those involved in 'explosive' sports. In 1973, an Olympic weightlifting team was formed at DeLand High School, Florida. The team trained with only slow (mostly eccentric-only) weight training. Starting in 1973, and with no previous experience in weightlifting, the team established what is probably a world sporting record: the team was undefeated and untied for seven years, winning over 100 consecutive weightlifting competitions. Clearly, the experience of these weightlifters is very much at odds with the view of Cissek (91) and others that slow weight training is not effective in enhancing in enhancing muscle performance at fast speeds.

Overall, therefore, it appears that Jones' (17,18) recommendation that slow, controlled weight training is all that is necessary to enhance both muscle strength and power is correct. Studies have tended to suggest that either slow training is superior to explosive training in enhancing these factors, or that there is no difference between slow and fast speeds. Despite claims made in some strength training textbooks (8,9) and by some exercise certification organisations (11,12) there is no scientific evidence to support the view that resistance exercise performed at very fast speeds is superior for enhancing any aspect of muscle function.

Not only is 'explosive' weight training unnecessary for increasing muscle power, but also such training poses considerable injury risks. For example, Kulund (99) noted that injuries to the wrist, elbow and shoulder were commonplace when individuals performed fast, Olympic-style lifting. Hall (100) found that fast lifting speeds greatly increased shear forces in the lumbar region. Also explosive lifting can apparently lead to spondylolysis (101,102). For example, Kotani et al. (101) found that 30.7% of a sample of weightlifters, all of who performed explosive lifts, suffered from this problem. Therefore, we contend that as well as being unnecessary to enhance performance, advocating explosive lifting is questionable from an ethical standpoint as such training may cause injury. The NSCA and ACSM guidelines are rather ironic in this respect, given that one of the main benefits of strength training is (or at least should be) a reduction in injury risk (103).

Optimal Repetition Ranges For Increasing Muscular Strength And Endurance

It has been claimed (4,6,8,12) that a low number of repetitions per set (< 6) is best for increasing muscular strength, and a high number of repetitions per set (> 20) is best for increasing muscular endurance. In contrast to this common belief, Jones (18) argued that optimal increases in both strength and endurance would result from performance of a moderate number of repetitions (~8-12). Several studies have examined the effect of different repetition ranges on both strength and endurance, and the results strongly support Jones' hypothesis.

As regards the idea that low repetition sets are better for increasing strength, a study by Chesnut and Docherty (104) illustrates that this is not the case. These authors examined the effects of 10 weeks of 4 RM and 10 RM training programs on elbow flexor and extensor strength and arm circumference and cross-sectional area. Strength and muscle size increased significantly in both groups, with no significant between-group differences. In a study of geriatric females, Pruitt et al. (105) examined the effects of training with 7 repetitions at 80 % 1 RM and 14 repetitions at 40 % 1 RM on various exercises three times per week for a year. Both groups significantly improved on all seven dependent variables (1 RM strength measures), with no significant differences between the groups on six of these. The only significant difference was a greater increase in arm strength in the 14 RM group. Graves et al. (106), in a study of identical twins, found that both a 7-10 RM group and a 15-20 RM group significantly increased quadriceps strength from one set of knee extensions performed twice/week for 10 weeks. Again, however, there was no significant difference between the strength increases achieved by the two groups. Several other studies (107-111) have shown similar results, i.e. no significant difference between strength and/or hypertrophy responses to low and moderate repetition ranges. Despite the claims noted above, no study has demonstrated that very low repetitions are superior to a moderate number of repetitions for increasing strength.

Few studies have examined the claim that higher repetition sets are more effective than lower repetition sets for increasing absolute muscular endurance. Anderson and Kearney (110) examined the effects of three different combinations of sets and repetitions on muscular endurance (measured by the number of bench press repetitions subjects could perform with 27.23 kg). Subjects were divided into low repetition (3 sets of 6-8 RM), medium repetition (2 sets of 30-40 RM) and high repetition (1 set of 100-150 RM) groups, and each subject trained three times/week for nine weeks. No significant between-group differences in increases in muscular endurance were found. Stone and Coulter (111) examined the effects of three training protocols (3x6-8 RM, 2x15-20 RM, and 1x30-40 RM) on the muscular endurance of untrained females, each of whom trained three times/week for nine weeks Again, no significant between-group differences in muscular endurance increases were found.

The weight of scientific evidence, therefore, does not support the idea that different numbers of repetitions have differential effects on muscular strength and endurance. A low to moderate number of repetitions has been shown to produce optimal increases in muscular strength and size, with no specific repetition range proving superior. Increases in muscular strength are accompanied by increases in absolute muscular endurance, with no advantage accruing in this regard from the use of a high number of repetitions. Given these research findings, and also given that performing a very low number of repetitions may lead to a greater injury risk due to the heavier weight and thus greater forces imposed on muscle, joints and connective tissues, it appears that Jones' recommendation of a moderate repetition range (~8-12) is efficacious and prudent.

CONCLUSIONS

In his writings over a 30-year period, Arthur Jones provided a series of weight training guidelines that have stood the test of time and have been strongly supported by scientific research. Specifically, Jones' recommendations to perform one set of each exercise to muscular failure, to train each muscle group no more than twice/week (and in most cases once/week), to perform weight training exercises with a relatively slow, controlled cadence and to perform a moderate range of repetitions to increase muscular strength, size, endurance and power, have all been validated by a great deal of peer-reviewed research. The same cannot be said of the high-volume, explosive training protocols that are currently in vogue amongst many exercise physiologists and strength-training professionals.

We note that previous articles advocating evidence-based training protocols (35,36) have met with the objection that NSCA-style, high-volume training is much more popular than Jones' approach among the athletic fraternity (21,112). We anticipate similar reactions to this paper, and therefore would like to make a couple of points regarding the argument that the popularity of the training methods advocated by the NSCA and others indicate that such methods are more efficacious than those of Jones and colleagues. Essentially, such individuals have argued that because the majority of athletes train in a particular manner, this must be the best way to train. This begs the question, why bother to perform scientific research at all? If such an argument is carried to its logical conclusion, rather than performing research to determine optimal training protocols, the time and money would be better spent conducting a poll of trainees to determine which method is most popular. This would then be the one that scientists should advocate. We contend that such individuals resort to such arguments purely because the scientific research does not support their position.

It is also interesting to note that Jones has had a major influence on the training methods of many accomplished individual athletes, sports teams and organisations, though these are still in the minority. For example, organisations such as the United States Military Academy, the United States Naval Academy, the sport teams at Princeton University, Penn State University, Rutgers University and many other educational establishments, and many teams in the US National Football League, have used Jones' methods extensively.

The list of bodybuilders who have been heavily influenced by Jones reads like a Who's Who of the sport. Dorian Yates (six times Mr Olympia), Sergio Oliva (twice Mr Olympia), Mike Mentzer (Mr Universe), Ray Mentzer (Mr America) and Casey Viator (Mr America) are among the professional bodybuilders who have cited Jones as a major influence on their training. Thus, despite the efforts of the NSCA (11), ACSM (12) and others (8,44,45) to discredit Jones' ideas, many athletes, from novice to collegiate and professional level, have applied Jones' principles with considerable success. We strongly recommend that other athletes follow their example and apply Jones' training advice. Individuals should also take the time to examine the relevant scientific research at first hand rather than relying on the interpretations and recommendations of prominent exercise physiologists which are based on personal bias rather than scientific evidence. Specifically, we would strongly dissuade athletes and coaches from following the recommendations of the ACSM and NSCA, and instead suggest that they follow the research-based guidelines that are presented in Table 1, together with references to supporting research.

Table 1. Summary of research-based strength training recommendations.

Variable	*Recommendation*	*Rationale*	*Exceptions*	*References**	*Supporting Research*
Number of sets/exercise	One set to muscular failure	All well-controlled studies show no advantage in performing multiple sets	None	15,16,18, 19, 20	28,29,30,34,56, 57,58,59,60
Frequency of training/muscle	Once/week for most muscles	Great majority of studies show training each muscle once/week to produce optimal improvements	The muscles that rotate the torso appear to benefit more from training twice/week	20	32,61,62,76, 78, 80
Speed of movement	Slow, non-explosive	Explosive repetitions involve more momentum and less muscle force, do not produce greater increases in power and may involve greater injury risk	None	17,18,24	82,83,84,85,86, 88,89,90,92,93, 94,95,96,97, 99, 100, 101, 102
Number of repetitions/set	~8-12	Varying the number of repetitions higher or lower does not produce differing effects on strength or muscular endurance	None	18	104,105,106, 107,108, 109,110,111

*Original references published by Arthur Jones
The reference numbers in the Table refer to the corresponding numbers in this paper's reference list.

Address for correspondence: Dave Smith, Ph.D., Department of Sport and Exercise Sciences, University College Chester, Parkgate Road, Chester CH1 4BJ, UK; Phone: 44 1244 375444 x3449; FAX: 44 1244 392889; Email: d.smith@chester.ac.uk

REFERENCES

1. McArdle WD, Katch FI, Katch VL. ***Exercise physiology***. Baltimore: Lippincott Williams and Wilkins, 2001.
2. Ritzdorf W. Strength and power training in sport: In Elliot B, editor. ***Training in sport: applying sport science***, pp 189-238. Chichester, UK: Wiley, 1999.
3. Wilmore JH, Costill DL. ***Physiology of sport and exercise***. Champaign, IL: Human Kinetics, 1999.
4. Baechle TR, editor. ***Essentials of strength training and conditioning***. Champaign, IL: Human Kinetics, 1994.
5. Bompa T. ***Serious strength training: periodisation for building muscle power and mass***. Champaign, IL: Human Kinetics, 1998.
6. Aaberg E. ***Resistance training instruction***. Champaign, IL: Human Kinetics, 1999.
7. Watson AWS. ***Physical fitness and athletic performance***. London: Longman, 1995.
8. Fleck SJ, Kraemer WJ. ***Designing resistance training programs*** (2nd edition), Champaign, IL: Human Kinetics, 1997.

9. Zatsiorsky V. ***Science and practice of strength training***. Champaign, IL: Human Kinetics, 1995.
10. Earle RW, Baechle TR. ***NSCA's essentials of personal training***. Champaign, IL: Human Kinetics, 2004.
11. National Strength and Conditioning Association. ***NSCA Position Statements 2003***. http://www.nsca-lift.org.
12. American College of Sports Medicine. Kraemer WJ, Writing Group Chairman. Position Stand: progression models in resistance training for healthy adults. ***Med Sci Sports Exerc*** 2002;34:364-80.
13. Carpinelli RN., Otto RM,. Winett RA. A critical analysis of the ACSM position stand on resistance training: insufficient evidence to support recommended training protocols. ***JEP****online* 2004;7(3):1-60.
14. Winett RA. Meta-analyses do not support performance of multiple sets or high volume resistance training. ***JEP****online*. 2004;7(5):10-20.
15. Jones A. ***Nautilus bulletin #1***., DeLand, FL: Nautilus Sports/Medical Industries, 1970.
16. Jones A. ***Nautilus bulletin #2***. DeLand, FL: Nautilus Sports/Medical Industries, 1971.
17. Jones A. Specificity in strength training: the facts and fables. In Peterson JA, editor. ***Total fitness the Nautilus way***, pp. 169-180. New York: Leisure Press, 1982.
18. Jones A. ***The lumbar spine, the cervical spine and the knee: testing and rehabilitatio***n. Ocala, FL: MedX Corporation, 1993.
19. Jones A. My first half-century in the iron game part 3: the myth of isokinetics. ***Ironman***: 1993 (October), 107-111.
20. Jones A. My first half-century in the iron game part 54. In ***The Arthur Jones collection***, pp. 740-741. Ontario: Bodyworx, 2003 (originally published in *Ironman* magazine, 1996).
21. Berger RA. Response to: Berger in retrospect: effect of varied weight training programmes on strength. ***Br J Sports Med*** 2003;37:372-3.
22. Johnston BD, Hurley B. Point and counterpoint. In B Johnston (Ed.), ***Synergy 2003,*** pp. 177-186. Ontario: Bodyworx, 2003.
23. Powers SK, Howley ET. ***Exercise physiology: theory and its application to fitness and performance***. London: McGraw-Hill, 2001.
24. Darden E. ***High-intensity strength training***. New York: Perigree, 1992.
25. Brzycki M. ***A practical approach to strength training***. Chicago, IL: Masters Press, 1995.
26. Riley D (ed.). ***Strength training by the experts*** (2nd edition). Champaign, IL: Leisure Press, 1982.
27. Peterson JA, Bryant CX, Peterson SL. ***Strength training for women***. Champaign, IL: Human Kinetics, 1995.
28. Starkey DB, Pollock ML, Ishida Y, Welsch MA, Brechue WF, Graves JE et al. Effect of resistance training volume on strength and muscle thickness. ***Med Sci Sports Exerc*** 1996;28:1311-1320.
29. Vincent K, De Hoyos D, Garzarella L, Hass C, Nordman M, Pollock M. Relationship between indices of knee extension strength before and after training. ***Med Sci Sports Exerc*** 1998;30(5 Suppl.):S163.
30. Ostrowski KJ, Wilson GJ, Weatherby R., Murphy PW, Little AD. The effect of weight training volume on hormonal output and muscular size and function. ***J Strength Conditioning Res*** 1997;11:148-154.
31. Pollock ML, Leggett SH, Graves JE, Jones A, Fulton M, Cirulli J. Effect of resistance training on lumbar extension strength. ***Am J Sports Med*** 1989;17:624-629.
32. Pollock ML, Graves JE, Bamman MM, Leggett SH, Carpenter DM, Carr C, Cirulli J, Matkozich J, Fulton M. Frequency and volume of resistance training: Effect on cervical extension strength. ***Arch Phys Med Rehabil*** 1993;74:1080-1086.
33. Tucci JT, Carpenter DM, Pollock ML, Graves JE, Leggett SH. Effect of reduced frequency of training and detraining on lumbar extension strength. ***SPINE*** 1992;17:1497-1501.
34. Haas CJ, Garzarella L, De Hoyos D, Pollock, ML. Single versus multiple sets in long term recreational weightlifters. ***Med Sci Sports Exerc*** 2000;32:235-242.
35. Carpinelli RN, Otto RM. Strength training: single versus multiple sets. ***Sports Med*** 1998;26(2):73-84.
36. Carpinelli RN. Berger in retrospect: effect of varied weight training programmes on strength. ***Br J Sports Med*** 2002;36(5):319-24.
37. Berger RA. Optimum repetitions for the development of strength. ***Res Q*** 1962;33:334-338.
38. Wathen D. Rest Periods. In: Baechle TR (ed.). ***Essentials of strength training and conditioning***, pp 451-454. Champaign, IL: Human Kinetics, 1994.

39. Stone M, O'Bryant H. ***Weight training***. Minneapolis, MN: Burgess International, 1987.
40. Fleck SJ, Kraemer WJ. ***Designing resistance training programs***. Champaign, IL: Human Kinetics, 1987.
41. Garhammer J. ***Sports Illustrated strength training***. New York: Harper and Row, 1986.
42. Komi PV. ***Strength and power in sports***. Oxford: Blackwell Scientific, 1992.
43. Stone MH, Plisk SS, Stone ME, Schilling BK, O'Bryant HS, Pierce KC. Athletic performance development: Volume load – 1 set vs multiple-sets, training velocity and training variation. ***Strength and Conditioning*** 1998;20:22-31.
44. Kraemer WJ. The physiological basis for strength training in American football: fact over philosophy. ***J Strength Conditioning Res*** 1997;11:131-142.
45. Kraemer WJ, Newton RU, Bush J, Volek J, Triplett NT, Koziris LP. Varied multiple-set resistance training produces greater gains than single-set programme. ***Med Sci Sports Exerc*** 1995;27:S195.
46. Kramer J, Stone M, O'Bryant HS, Conley MS, Johnson RL, Nieman DC et al. Effect of single vs multiple sets of weight training: impact of volume, intensity and variation. ***J Strength Conditioning Res*** 1997;11:143-147.
47. Marx JO, Ratamees NA, Nindl BC, Gotshalk LA, Volek JS, Dohi, K et al. Low volume circuit versus high volume periodised resistance training in women. ***Med Sci Sports Exerc*** 2001;33:635-643.
48. Hurley BF, Seals DR, Ehsani AA, Cartier LJ, Dalsky GP, Hagberg JM, Holloszy JO. Effects of high intensity strength training on cardiovascular function. ***Med Sci Sports Exerc*** 1984;16:483-488.
49. Messier SP, Dill M. Alterations in strength and maximal oxygen uptake consequent to Nautilus circuit weight training. ***Res Q Exerc Sport*** 1985;56:345-351.
50. Brzycki M. Flaws in research design and interpretation. In B Johnston (ed.), ***Fitness fraud: exposing the exercise and nutrition industries***, pp. 57-76. Ontario: Bodyworx, 2000.
51. Borst SE, DeHoyos DV, Garzarella L, Vincent K., Pollock, BH, Lowenthal, DT et al. Effects of resistance training on insulin like growth factor-1 and IGF binding proteins. ***Med Sci Sports Exerc*** 2001;33:648-653.
52. Rhea MR, Alvar BA, Burkett LN. Single versus multiple sets for strength: a meta-analysis to address the controversy. ***Res Q Exerc Sport*** 2002;73:485-488.
53. Rhea, MR, Alvar BA, Burkett, LN, Ball, SD, A meta-analysis to determine the dose response for strength development. ***Med Sci Sports Exerc*** 2003;35:456-64.
54. Eysenck, HJ. Meta-analysis: an abuse of research. ***Journal of Special Education*** 1984;18: 41-59.
55. Eysenck HJ. Meta-analysis and its problems. ***Br Med J*** 1994;309:789-792.
56. Terbizan DJ, Bartels RL. The effect of set-repetition combinations on strength gains in females age 18-35. ***Med Sci Sports Exerc*** 1985; 7(2 Suppl.):267.
57. Stowers T, McMillan J, Scala D, Davis V, Wilson D, Stone, M. The short-term effects of three different strength-power training methods. ***Nat Strength Conditioning Assoc J*** 1983;5:24-27.

58. Westcott WL, Greenberger K, Milius D. Strength training research: Sets and repetitions. ***Scholastic Coach*** 1989;58:98-100.
59. Welsch MA, Brechue WF, Pollock ML et al. ***Med Sci Sports Exerc*** 1994;26 (Suppl 5):S189.
60. Stadler Jr LV, Stubbs NB, Vokovich MD. A comparison of a 2-day and 3-day per week resistance training program on strength gains in older adults. ***Med Sci Sports Exerc*** 1997;20(5 Suppl.):S254.
61. Graves JE, Pollock ML, Foster D, Leggett SH, Carpenter DM, Vuoso R, Jones A. Effect of training frequency and specificity on isometric lumbar extension strength. ***SPINE*** 1990;15:504-509.
62. Carpenter DM, Graves JE, Pollock ML, Leggett SH, Foster D, Holmes B, Fulton MN. Effect of 12 and 20 weeks of resistance training on lumbar extension torque production. ***Phys Therapy*** 1991;71:580-588.
63. Risch SV, Norvell NK, Pollock ML, Risch ED, Langer H, Fulton M et al. Lumbar strengthening in chronic low back pain patients. ***SPINE*** 1993;18:232-238.
64. Highland TR, Dreisinger TE, Vie LL, Russell GS. Changes in isometric strength and range of motion of the isolated cervical spine after eight weeks of clinical rehabilitation. ***SPINE*** 1992;17;S77-S82.
65. Peterson JA. Total conditioning: a case study. ***Athletic J*** 1975;56: 40-55.
66. Holmes B, Leggett S, Mooney V, Nichols J, Negri S, Hoeyberghs A. Comparison of female geriatric lumbar-extension strength: asymptomatic versus chronic low back pain patients and their response to active rehabilitation. ***J Spinal Disorders*** 1996; 9: 17-22.

67. Ryan AS, Pratley RE, Elahi D, Goldberg AP. Resistive training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women. ***J Appl Physiol*** 1995; 79: 818-823.
68. Koffler KH, Menkes A, Redmond RA, Whitehead WE, Pratley RE, Hurley BF. Strength training accelerates gastrointestinal transit in middle-aged and older men. ***Med Sci Sports Exerc*** 1992; 24: 415-419.
69. Rubin MA, Miller JP, Ryan AS, Treuth MS, Patterson KY, Pratley RE et al. Acute and chronic resistive exercise increase urinary chromium excretion in men as measured with an enriched chromium stable isotope. ***J Nutr*** 1998: 128: 73-8.
70. Capen EK. Study of four programs of heavy resistance exercise for development of muscular strength. ***Res Q*** 1956: 27: 132-42.
71. Westcott WL. 4 key factors in building a strength program. ***Scholastic Coach*** 1986: 55: 104-5, 123.
72. Leighton JR, Holmes D, Benson J, Wooton B, Schememer R. 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 Mental Rehabil*** 1967: 21: 78-81.
73. Silvester LJ, Stiggins C, McGown C , Bryce GR. The effect of variable resistance and free-weight training programs on strength and vertical jump. ***Nat Strength Conditioning Assoc J*** 1982:3(6):30-3.
74. DeHoyos DV, Herring D, Garzarella L et al. Effect of strength training volume on the development of strength and power in adolescent tennis players. ***Med Sci Sports Exerc*** 1997;29(5 Suppl.):S164.
75. Binkley HM. Strength, size or power? ***NSCA's Performance Training Journal*** 2002;1(4):14-18.
76. Taafe DR, Duret C, Wheeler S, Marcus R. Once weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. ***J Am Geriatric Soc*** 1999;47:1208-1214.
77. Carroll TJ, Abernethy PJ, Logan PA, Barber M, McEniery MT. Resistance training frequency: strength and myosin heavy chain responses to two and three bouts per week. ***Eur J App Phys*** 1998;78:270-275.
78. DeMichele PL, Pollock ML, Graves JE, Foster DN, Carpenter, D, Garzarella L et al. Isometric torso rotation strength: effect of training frequency on its development. ***Arch Phys Med Rehabil*** 1997;78:64-69.
79. Rozier CK, Schafer DS. Isokinetic strength training: comparison of daily and three times weekly patterns. ***Inter J Rehabil Res*** 1981;4:345-351.
80. McLester JR, Bishop P, Guilliams ME. Comparison of 1 day and 3 days per week of equal-volume resistance training in experienced subjects. ***J Strength Conditioning Res*** 2000;14:273-281.
81. Hoffman JR, Kraemer WJ, Fry AC, Deschenes M, Kemp M. The effect of self-selection for frequency of training in a winter conditioning programme for football. ***J App Sports Sci*** 1990;4:776-82.
82. Mikesky AE, Matthews W, Giddings CJ, Gonyea WJ. Muscle enlargement and exercise performance in the cat. ***J App Sport Sci Res*** 1989;3:85-92.
83. LaChance PF, Hortobagyi T. Influence of cadence on muscular performance during push up and pull up exercises. ***J Strength Conditioning Res*** 1994;8:76-79.
84. Hay JG, Andrews JG, Vaughan CL. Effects of lifting rate on elbow torques exerted during arm curl exercises. ***Med Sci Sports Exerc*** 1983;15:63-71.
85. Westcott WL, Winett RA, Anderson ES, Wojcik, JR, Loud, RLR, Cleggett E et al. Effects of regular and super-slow speed resistance training on muscle strength. ***J Sports Med Phys Fitness*** 2001;41:154-158.
86. Jones K, Bishop P, Hunter G, Fleisig G. The effects of varying resistance training loads on intermediate and high velocity specific adaptations. ***J Strength Conditioning Res*** 2001;15:349-356.
87. Keeler LK, Finkelstein LH, Miller W, Fernhall, B. Early phase adaptations to traditional speed vs superslow resistance training on strength and aerobic capacity in sedentary individuals. ***J Strength Conditioning Res*** 2001;15:309-314.
88. Berger RA, Harris MW. Effects of various repetitive rates in weight training on improvements in strength and endurance. ***J Assoc Phys Mental Rehabil*** 1966;20:205-207.
89. Young WB, Bilby GE. The effect of voluntary effort to influence speed of contraction on strength, muscular power and hypertrophy development. ***J Strength Conditioning Res*** 1993;7:172-178.
90. Palmieri GA. Weight training and repetition speed. ***J Appl Sports Sci Res*** 1987;1:36-38.
91. Cissik JM. Basic principles of strength training and conditioning. ***NSCA's Performance Training Journal*** 2002;1(4):7-11.
92. Liow DK, Hopkins WG. Velocity Specificity of weight training for kayak sprint performance. ***Med Sci Sports Exerc*** 2003;35(7):1232-1237.

93. Blazevich AJ, Jenkins DG. Effect of the movement speed of resistance training exercises on sprint and strength performance in concurrently training elite junior sprinters. ***J Sports Sci*** 2002;20(12):981-990.
94. Wilson GJ, Newton RU, Murphy AJ, Humphries BJ. The optimal training load for the development of dynamic athletic performance. ***Med Sci Sports Exerc*** 1993;25:1279-1286.
95. Wilson GJ, Murphy AJ, Giorgi A. Weight and plyometric training: effects on eccentric and concentric force production. ***Canadian J Appl Phys*** 1996;21:301-315.
96. Holcomb WR, Lander JE, Rutland RM, Wilson GD. The effectiveness of a modified plyometric programme on power and the vertical jump. ***J Strength Conditioning Res*** 1996;10:89-92.
97. Newton RU, McEvoy KP. Baseball throwing velocity: a comparison of medicine ball training and weight training. ***J Strength Conditioning Res*** 1994;8:198-203.
98. Clutch D, Wilton M, McGowan C, Bryce GR. The effect of depth jumps and weight training on leg strength and vertical jump. ***Res Q*** 1983;54:5-10.
99. Kuland DH. ***The injured athlete***. Philadelphia: JB Lippencott Co., 1982.
100. Hall S. Effect of lifting speed on forces and torque exerted on the lumbar spine. ***Med Sci Sports Exerc*** 1985;17:44-444.
101. Kotani PT, Ichikawa N, Wakabayaski W, Yoshii T, Koshimuni M. Studies of spondylolysis found among weightlifters. ***Br J Sports Med*** 1971;6:4-8.
102. Duda M. Elite lifters at risk of spondylolysis. ***Physician Sportsmed*** 1977;5(9):61-67.
103. Peterson J. Strength training: health insurance for the athlete. In Riley DP, editor. ***Strength training by the experts*** (2nd ed.). Champaign, IL: Leisure Press, 1982:7-9.
104. Chestnut JL, Docherty D. The effects of 4 and 10 repetition maximum weight-training protocols on neuromuscular adaptations in untrained men. ***J Strength Conditioning Res*** 1999;13:353-359.
105. Pruitt LA, Taaffe DR, Marcus R. Effects of a one year high intensity versus low intensity resistance training program on bone density in older women. ***J Bone Mineral Res*** 1995;10:1788-1795.
106. Graves JE, Pollock ML, Jones AE, Jones WE, Colvin A. Number of repetitions does not influence the initial response to resistance training in identical twins. ***Med Sci Sports Exerc*** 1999; 26(Suppl. 5):S74.
107. O'Shea P. Effects of selected weight training programmes on the development of strength and muscle hypertrophy. ***Res Q*** 1966;37:95-102.
108. Weiss LW, Coney HD, Clark FC. Differential functional adaptations to short term low, moderate and high repetition weight training. ***J Strength Conditioning Res*** 1999;13:236-241.
109. Weiss LW, Coney HD, Clark FC. Gross measures of exercise induced muscular hypertrophy. ***J Orthop Sports Phys Ther*** 2000;30:143-148.
110. Anderson T, Kearney JT. Effects of three resistance training programmes on muscular strength and absolute and relative endurance. ***Res Q Exerc Sport*** 1982;53:1-7.
111. Stone WJ, Coulter SP. Strength/endurance effects from three resistance training protocols with women. ***J Strength Conditioning Res*** 1994;8:23-234.
112. Byrd R. Strength training: single versus multiple sets. ***Sports Med*** 1999;27:409-416.