Journal of Exercise Physiologyonline

April 2013
Volume 16 Number 2

JEPonline

Official Research Journal of the American Society of Exercise Physiologists

ISSN 1097-9751

A Critical Analysis of a Review on Strength Training in the Military

Ralph N. Carpinelli

Human Performance Laboratory, Adelphi University, Garden City, NY, USA

ABSTRACT

Carpinelli RN. A Critical Analysis of a Review on Strength Training in the Military. **JEPonline** 2013;16(2):70-81. This critical analysis challenges the validity of evidence cited in a review entitled Strength Training for the Warfighter. Most of the claims and recommendations in that review, especially regarding the size principle of motor unit recruitment, are not supported by resistance training studies. Rather than providing evidence based recommendations for strength training, that review is based primarily on unsubstantiated opinions.

Key Words: Resistance Training, Size Principle, Motor Units

TABLE OF CONTENTS

INTRODUCTION

The Size Principle

Discovered by Denny-Brown and Pennybacker (20) in 1938, tested and defined by Henneman (32) in 1957, the size principle states that when the central nervous system recruits motor units for a specific exercise, it begins with the smallest, most easily excitable motor units. As the exercise becomes more difficult (a greater degree of effort), the recruitment progresses to the larger, more difficult to excite motor units (33). The size principle has been strongly supported over the last half-century by a preponderance of studies (2-4,13-14,17-19,22-28,30-31,34-38,40-41,48,55-58,62,65-66,69,70,72) and most of the evidence strongly suggests that there are no functionally meaningful violations of the size principle (16).

Motor Unit Activation

The interpolated twitch technique estimates the degree of motor unit activation (recruitment and firing frequency) during a voluntary muscular effort. Studies with younger and older, male and female, healthy and infirmed subjects, who performed a maximal effort muscle action for various muscle groups, reported activation levels ranging from 85% to 100% (15,21,39,42,44-47,49,63-64,68,71,73). This was the case despite significantly different levels of external force production within and among the specific demographics. These studies strongly suggest that motor unit activation is primarily dependent on the degree of effort and not the absolute amount of resistance when performing an exercise. However, the degree of effort and motor unit activation required for optimal strength gains is unknown.

Invalid Reverse Inference

Greater motor unit recruitment results in the ability to lift a heavier resistance and maximal force production requires maximal motor unit activation. However, force is not the prerequisite for recruitment. A greater force is the result of greater motor unit activation. The flawed belief that a heavy resistance (high force) is required for maximal motor unit activation was most accurately described as an invalid reverse inference of the size principle (7).

Critical Analysis

This critical analysis is specifically focused on a review entitled *Strength Training for the Warfighter* by Kraemer and Szivak (53). Science places the entire burden of proof on the claimant (Kraemer and Szivak) and all claims should be supported by strength training studies. However, the majority of the claims and recommendations proposed by Kraemer and Szivak are unsubstantiated. They have consistently misinterpreted the size principle of motor unit recruitment throughout their review, which has resulted in the recommendations for unnecessarily heavy, complex, high volume strength training in the military.

KRAEMER AND SZIVAK

In their review, Kraemer and Szivak emphasized that it is important to understand exercise at its most fundamental level and most importantly the concept of the size principle (53). They stated: *"This is paramount for understanding maximal strength and power development because too often exercise is not defined in careful enough terms to be effective for the intended outcome. Thus, it is important to develop a basic understanding of the underlying physiology at work when one exercises or trains the neuromuscular system"* (p. S108). However, in their next paragraph, Kraemer and Szivak exclaimed: *"With resistance training, it is the amount of resistance used in an exercise that dictates how many motor units in that muscle are needed to move the weight in the desired pattern of a lift. In practical* *terms, the importance of this principle is stunning and often times not appreciated!"* (p. S109). The authors may have believed that an exclamation point would provide validity to their claim but the aforementioned clarification of the size principle reveals that it did not help to substantiate their point of view. Kraemer and Szivak also stated the following: *"The amount of muscle that is trained by an exercise is directly related to the amount of external resistance that is used"* (p. S109). They did not cite references to support their statements.

Heavy *vs.* Moderate Resistance

Kraemer and Szivak (53) claimed: *"Resistance loads exist over a continuum and finite cutoffs are really related to the broad spectrum of effects documented in various zones"* (p. S115-6). They did not cite references to support their opinion. Interestingly, three decades ago Kraemer (50) claimed: *"Changing the repetition maximum from a 10 RM to a 5 RM makes a dramatic difference in the strength training outcome"* (p. 58). Again, he did not cite references to support his opinion, which has been refuted by the preponderance of evidence. For example, Jungblut (43) reported that 82 out of the 90 comparative strength training studies she reviewed showed no significant difference in strength gains as a result of training with a heavier resistance compared with a moderate resistance.

Since the review by Jungblut (43) and based on the size principle article by Carpinelli (7), Aarskog and colleagues randomly assigned 62 physically active young males and females (age ~24 yrs) to either a 6-8 RM or 12-14 RM resistance training protocol (1). Both groups performed three sets of the free weight bench press and Smith machine squat two times a week for eight weeks. They performed each set to volitional exhaustion with 2-3 min rest between sets. There was a significant increase in 1 RM bench press and squat with no significant difference in strength gains between groups. Aarskog and colleagues concluded: *"Because both groups in the present study performed each set to volitional exhaustion, the high degree of effort may explain why there was a similar strength gain for 6 RM and 12 RM protocols. And as such, the findings from our experiment support Carpinelli's view"* (p. 184). Their results are antithetical to the aforementioned opinion of Kraemer and Szivak (53). Curiously, the study by Aarskog and colleagues, which was available in December 2011, is missing from the review by Kraemer and Szivak.

Kraemer and Szivak (53) stated: *"Classic to the concept of resistance training is the amount of external load to be lifted"* (p. S111). In an attempt to support that opinion, they cited books by Fleck and Kraemer (29) and Ratamess (61). They did not cite any resistance training studies. Fleck and Kraemer mistakenly believed that a maximal or near maximal resistance is required to recruit the larger motor units. In fact, motor unit activation during a set of resistance exercise is dependant primarily of effort—not the amount of resistance (7). Interestingly, Ratamess (61) created *Myths and Misconceptions* boxes in his book, which supposedly debunk myths and clarify widespread misconceptions about strength and conditioning. In one of those boxes (p. 47), he claimed that heavy resistance training is required for maximal recruitment of type II motor units. However, he failed to cite any reference to support his own misconception of the size principle.

Kraemer and Szivak (53) noted that their Figure 1 (p. S110) provided an overview of the relationship between the size principle and resistance training. The figure depicts a type I motor unit with a 10 RM label. It is enclosed in an area labeled *Power and Endurance*. A type II motor unit has a 5 RM label that is enclosed in an area entitled *Maximal Strength.* Their implication was that training with a 10 RM would specifically enhance power and endurance and that training with a 5 RM is required for maximal strength gains. They did not cite references to support those claims and revealed again their misinterpretation of the size principle. That is, *they failed to develop a basic understanding of the underlying physiology*. In fact, a 5 RM and 10 RM, which by definition (RM = repetition maximum) requires a maximal effort on the last repetition of both protocols, would elicit a similar level of motor unit activation on the last repetition of each set (7) and the preponderance of strength training studies (82 out of 90) reported no significant difference in strength gains as a result of training with a moderate versus a heavier resistance (43).

The caption for Kraemer and Szivak's Figure 1 (53) noted that a *dashed circle* represents an area encompassing motor units that are affected if high intensity aerobic and strength exercises are employed (so-called *compatibility*). However, there is no *dashed circle.*

Kraemer and Szivak (53) claimed that a heavier resistance is associated with greater strength gains. The only reference they cited was a meta-analysis by Peterson et al. (60) who reported on strength gains in competitive athletes. There are several major problems with the meta-analysis that have been described in great detail elsewhere (59). Briefly, Peterson and colleagues claimed that there was a trend for greater strength gains as a result of training with a greater percent of the 1 RM. In fact, their reported effect sizes for training with 70, 75, 80, and 85% 1 RM were 0.07, 0.73, 0.57, and 1.12, respectively. Their implications were that training with 85% 1 RM would produce twice the strength gains as training with 80% 1 RM and that 75% 1 RM would elicit ~28% greater strength gains than training with 80%1 RM. Perhaps, the authors' most unsubstantiated claim was that training with 75% 1 RM would produce ~10 times greater strength gains compared with 70% 1 RM; that is, a 5% greater resistance performed for one or two fewer repetitions with a similar maximal effort would elicit such phenomenal 10 times greater differences in strength gains.

The Peterson et al. (60) data represent an excellent example of the potential for disconnect between a meta-analysis and the reality of strength training. Although Peterson and colleagues claimed that their meta-analysis unequivocally demonstrated a continuum of strength gains that were elicited by a continuum of increased training resistance (i.e., a greater percent of the 1 RM), their own data failed to support those conclusions (59).

Kraemer and Szivak (53) stated: "*It* [the size principle] *is the fundamental principle in understanding the seminal basis of exercise and even more important in understanding resistance exercise and training*" (p. S108-9). But, unfortunately, their misunderstanding of the size principle resulted in their incorrect opinions and strength training recommendations.

Compatibility

In their writing about the previously mentioned *compatibility*, Kraemer and Szivak (53) claimed that when strength and endurance training are performed concurrently "…*strength might be reduced in magnitude*" (p. S113). They cited only one resistance training study by Kraemer and colleagues (52) to support the claim. It is worth briefly discussing some of the problems in that study.

- One of the groups of young males (age ~23 yrs) performed upper and lower body strength training (ST group) for 12 wks. Another group performed the same strength training protocol combined with running (COM group). Both of these previously untrained groups significantly increased strength in the four exercises tested (leg press, knee extension, bench press, and military press). The ST group showed a significantly greater strength gain than the COM group in only one of the four exercises—the leg press.

- The trainees were subjected to an unnecessarily voluminous amount of exercise. For example, they performed 160 maximal effort sets (RMs) 4 $d \cdot wk^{-1}$ and on the same days as their interval running workouts (200 to 800 m intervals at 95 to 100+% of maximal oxygen consumption).

- They trained most of the major muscle groups on Monday, Tuesday, Thursday, and Friday. Most exercises such as the bench press, military press, lat pull down, arm curl, sit up, knee extension, and calf raise were performed during each of the four weekly sessions.

- In an attempt to justify different numbers of sets and repetitions for different muscle groups such as 2 sets of 10 RM for the upright row compared with 5 sets of 5 RM for the bench press—supposedly to produce muscular hypertrophy and strength gains, respectively—they cited the book by Fleck and Kraemer (29) and only one study (51). However, there was only one protocol (3 sets of 10 RM with 10-sec inter-set rest intervals for 10 exercises) in that acute response study by Kraemer and colleagues (51), which was based on what the authors described as very short inter-set rest intervals commonly used by competitive bodybuilders. They failed to provide additional evidence to support their opinion regarding the number of sets or using a specific RM.

- Tuesday and Friday strength training required almost 3 $hr \cdot d^{-1}$ in the gym (estimated using their reported inter-set and inter-exercise rest intervals). Despite their statement that the cumulative stress of mission demands and extensive physical training can contribute to injury and overtraining of military personnel, Kraemer and Szivak (53) recommended 4 to 5 min inter-set rest intervals on *heavy* training days (Table 1, p. S112) and 6 sets of each exercise (Table 3, p. S114). If the trainees performed the 10 exercises that were used in the previously discussed study by Kraemer and colleagues (52), the amount of time required in the gym on that day would be approximately 5½ hrs. This would be an extremely challenging task for even well-trained highly-motivated military personnel.

Kraemer and Szivak (53) did not cite any other *compatibility* training studies. For example, Shaw and colleagues (67) noted that the previously discussed study by Kraemer and colleagues (52) used a high frequency of training that repeatedly stressed the same muscle groups. Shaw and colleagues recruited 38 healthy males (age ~25 yrs) who had not participated in a regular strength training program for at least 6 months prior to the study. They randomly assigned one of the training groups (ST group) to perform 3 sets of 15 repetitions with 60% 1 RM for 8 upper and lower body free weight and machine exercises 3 $times \cdot wk^{-1}$ for 16 wks. A combined training group (COM group) followed a similar strength training protocol but performed two sets of each exercise plus 22 min of aerobic endurance exercise (treadmill, cycling, etc.) at 60% of age predicted maximum heart rate. Both groups significantly increased strength on all 8 exercises, and there was no significant difference in strength gains between groups for any exercise.

Interestingly, the subjects (all males) in the studies by Kraemer and colleagues (52) and Shaw and colleagues (67) were of similar age, training status and starting strength in the leg press exercise (80 to 85 kg), which was the only exercise that Kraemer and colleagues reported a significantly greater strength gain in the ST group compared with the COM group. The percent increase in leg press strength reported by Shaw and colleagues was about twice as great for the ST and COM groups compared with the strength gains from Kraemer and colleagues, and Shaw and colleagues reported no significant difference in strength gains between the ST and COM groups. In fact, with a considerably lower volume of training, the strength gains reported by Shaw and colleagues in the 4 exercises (leg press, knee extension, bench press, and military press) ranged from ~1.6 to 7 times greater than those exercises in the study by Kraemer and colleagues. Shaw and colleagues noted that their results agreed with some previous studies but were in contrast to others. Kraemer and Szivak (53) failed to cite other references and, in particular, the study by Shaw and colleagues whose results conflicted with the only study they cited (52). They could have cited studies that agreed with their opinion, studies that conflicted with their opinion, and then let the readers decide if their opinion was valid.

Kraemer and Szivak (53) stated: "*Preliminary research points to the concept that those motor units that are stimulated by resistance exercise have their anabolic signaling blunted in some manner when immediately or shortly thereafter followed by aerobic exercise*" (p. S113). However, they failed to cite any references to support that opinion.

Other Unsubstantiated Claims

In addition to the misinterpretation of the size principle by Kraemer and Szivak (53), the following are a few examples of their authoritative sounding but unsubstantiated claims regarding other strength training variables. Clearly, the entire burden of proof was on Kraemer and Szivak.

Free Weights

Kraemer and Szivak (53) claimed that strength training with free weights (barbells, dumbbells, etc.) will influence multidirectional control of the resistance, which will help to develop balance under load and stability with movement. The authors did not cite any references to support their opinion that free weights are superior to strength training machines or that any acquired balance and stability from free weight training would carry over to any other activity.

Order of Exercise

Kraemer and Szivak (53) claimed that the order of performing strength exercises in a training session dictates the quality of motor unit recruitment, and that the order of exercise should be dictated by the specific goals (e.g., maximal strength, maximal power, or muscular endurance). They failed to cite references to support their claim.

Inter-Set Rest Intervals

Kraemer and Szivak (53) claimed that heavier resistance requires longer inter-set rest intervals to optimally recruit motor units, and that if strength gains are the primary goal, then longer rest intervals are required. They recommended different inter-set rest intervals for various amounts of resistance (e.g., light, moderate, heavy, etc.) in their Table 1 (p. S112). However, they did not cite any references to support their opinions or recommendations. There is very little evidence to suggest that various inter-set rest intervals will have any significant effect on strength gains (9).

The caption for Kraemer and Szivak's Figure 3 (53) states: "*Responses of catecholamines after a short rest, high-intensity exercise workout performed by trained bodybuilders and powerlifters as control subjects could not make it through the workout*" (p. S112). They cited a study by Kraemer and colleagues (52), which contained nothing related to bodybuilders or powerlifters. In fact, the data in their Figure 3 are from the previously mentioned study by Kraemer and colleagues (51). They recruited 9 competitive male bodybuilders and 8 power-lifters (age ~22 yrs) who performed three sets of 10 RM for each of the 10 free-weight and machine exercises with 10 sec rest between sets and alternating 30 and 60 sec rest between exercises. Although the powerlifters reported a significantly greater incidence of dizziness and nausea compared with the bodybuilders, there was no significant difference between groups in the total amount of work performed during the session. Heart rate, plasma volume, lactic acid, epinephrine, norepinephrine, dopamine, and rating of perceived exertion significantly increased from pre-exercise to post-exercise in both groups. There was no significant difference between the groups for any of these variables. Even if Kraemer and Szivak had cited the correct reference (51), their claim that the powerlifters could not make it through the session is incorrect.

CONCLUSIONS

The review by Kraemer and Szivak was one of 13 articles related to the military published in a special supplement to the *Journal of Strength and Conditioning Research* (53). The articles were submitted by scientists from the *2nd International Congress of Soldiers' Physical Performance.* As guest editors, Kyrolainen and Nindl (54) claimed that all the articles were *carefully evaluated* in their peer review process before acceptance. However, the majority of the claims and recommendations by Kraemer and Szivak (53) are not supported by strength training studies. In fact, their review is an accumulation of unsubstantiated opinions and, therefore, challenges the editors' claim that the manuscripts were *carefully evaluated*.

There is very little evidence to suggest that the very heavy, time consuming, complex protocols, and voluminous amount of strength training recommended by Kraemer and Szivak (53) are any more effective than simple, moderate resistance, low volume guidelines such as those recommended for any healthy demographic—civilian or military personnel (12).

- Select one or two free weight or machine exercises for each muscle group that provide an overload throughout a pain free range of motion.

- Use a repetition duration that is conducive to maintaining consistent good form throughout each repetition (e.g., 3 sec lifting, 3 sec lowering the resistance).

- Choose a range of repetitions between 3 and 20 (e.g., 3 to 5, 6 to 8, 9 to 12, etc), which may vary from exercise to exercise or session to session.

- Continue each exercise until it becomes difficult to maintain proper form during the concentric phase of a repetition. The level of effort required for optimal strength gains is unknown.

- Perform one set of each exercise. There is very little evidence to suggest that multiple sets of each exercise are superior to a single set for strength gains (5-6,8,10-12,59).

- Allow enough rest between exercises to execute proper form.

- Depending on individual recuperation and response, train each muscle group 1 to 3 times·wk^{-1}.

Combat military personnel deserve recommendations for training that are based on the preponderance of strength training studies. Kraemer and Szivak (53) failed to meet the burden of proof and provide substantial evidence to support their opinions and recommendations.

Address for correspondence: Ralph N. Carpinelli, EdD, PO Box 241, Miller Place, NY 11764
Email: ralphcarpinelli@optonline.net.

REFERENCES

1. Aarskog R, Wisnes A, Wilhelmsen K, et al. Comparison of two resistance training protocols, 6RM versus 12RM, to increase the 1RM in healthy young adults. A single-blind, randomized controlled trial. ***Physiother Res Int.*** 2012;17:179-186.

2. Adam A, DeLuca CJ. Recruitment order of motor units in human vastus lateralis muscle is maintained during fatiguing contractions. ***J Neurophysiol.*** 2003;90:2919-2927.

3. Akaboshi K, Masakado Y, Chino N. Quantitative EMG and motor unit recruitment threshold using a concentric needle with quadrifilar electrode. ***Muscle Nerve.*** 2000;23:361-367.

4. Bawa P, Binder MD, Ruenzel P, et al. Recruitment order of motoneurons in stretch reflexes is highly correlated with their axonal conduction velocity. ***J Neurophysiol.*** 1984;52:410–20.

5. Carpinelli RN. Berger in retrospect: Effect of varied weight training programmes on strength. ***Br J Sports Med.*** 2002;36:319-324.

6. Carpinelli RN. Science versus opinion. ***Br J Sports Med.*** 2004;38:240-242.

7. Carpinelli RN. The size principle and a critical analysis of the unsubstantiated heavier-is-better recommendation for resistance training. ***J Exerc Sci Fit.*** 2008;6:67-86.

8. Carpinelli RN. Challenging the American College of Sports Medicine 2009 position stand on resistance training. ***Med Sport.*** 2009;13:131-137.

9. Carpinelli RN. A critical analysis of the claims for inter-set rest intervals, endogenous hormonal responses, sequence of exercise, and pre-exhaustion exercise for optimal strength gains in resistance training. ***Med Sport.*** 2010;14:126-156.

10. Carpinelli RN. Critical review of a meta-analysis for the effect of single and multiple sets of resistance training on strength gains. ***Med Sport.*** 2012;16:122-130.

11. Carpinelli RN, Otto RM. Strength Training. Single versus multiple sets. ***Sports Med.*** 1998;26: 73-84.

12. Carpinelli RN, Otto RM, Winett RA. A critical analysis of the ACSM position stand on resistance training: insufficient evidence to support recommended training protocols. ***JEPonline.*** 2004;7:1-64.

13. Clamann PH, Henneman E. Electrical measurement of axon diameter and its use in relating motoneuron size to critical firing level. ***J Neurophysiol.*** 1976;39:844-851.

14. Clamann PH, Gillies JD, Skinner RD, et al. Quantitative measures of output of a motoneuron pool during monosynaptic reflexes. ***J Neurophysiol.*** 1974;37:1328-37.

15. Connelly DM, Rice CL, Roos MR, et al. Motor unit firing rates and contractile properties in tibialis anterior of young and old men. ***J Appl Physiol.*** 1999;87:843-852.

16. Cope TC, Pinter MJ. The size principle: Still working after all these years. ***Physiology.*** 1995; 10:280-286.

17. Cope TC, Sokoloff AJ. Orderly recruitment among motoneurons supplying different muscles. ***J Physiol (Paris).*** 1999;93:81-85.

18. Cope TC, Sokoloff AJ, Dacko SM, et al. Stability of motor-unit force thresholds in the decerebrate cat. ***J Neurophysiol.*** 1997;78:3077-3082.

19. DeLuca CJ, LeFever RS, McCue MP, et al. Control scheme governing concurrently active human motor units during voluntary contractions. ***J Physiol.*** 1982;329:129-142.

20. Denny-Brown D, Pennybacker JB. Fibrillation and fasciculation in voluntary muscle. ***Brain.*** 1938;61:311-334.

21. De Serres SJ, Enoka RM. Older adults can maximally activate the biceps brachii muscle by voluntary command. ***J Appl Physiol.*** 1998;84:284-291.

22. Desmedt JE, Godaux E. Fast motor units are not preferentially activated in rapid voluntary contractions in man. ***Nature.*** 1977;267:717-719.

23. Desmedt JE, Godaux E. Voluntary motor commands in human ballistic movements. ***Ann Neurol.*** 1979;5:415-421.

24. Desmedt JE, Godaux E. Spinal motoneuron recruitment in man: Rank deordering with direction but not with speed of voluntary movement. ***Science.*** 1981;214:933-935.

25. Duchateau J, Enoka RM. Human motor unit recordings: Origins and insight into the integrated motor system ***Brain Res.*** 2011;1409:42-61.

26. Edstrom L, Grimby L. Effect of exercise on the motor unit. ***Muscle Nerve.*** 1986;9:104-126.

27. Enoka RM, Fuglevand AJ. Motor unit physiology: Some unresolved issues. ***Muscle Nerve.*** 2001;24:4-17.

28. Feiereisen P, Duchateau J, Hainaut K. Motor unit recruitment order during voluntary and electrically induced contractions in the tibialis anterior. ***Exp Brain Res.*** 1997;114:117-123.

29. Fleck SJ, Kraemer WJ. ***Designing Resistance Training Programs.*** (3rd Edition). Champaign, IL: Human Kinetics, 2004.

30. Freund HJ, Budingen HJ, Dietz V. Activity of single motor units from human forearm muscles during voluntary isometric contractions. ***J Neurophysiol.*** 1975;38:933-946.

31. Goldberg LJ, Derfler B. Relationship among recruitment order, spike amplitude, and twitch tension of single motor units in human masseter muscle. ***J Neurophysiol.*** 1977;40:879-890.

32. Henneman E. Relation between size of neurons and their susceptibility to discharge. ***Science.*** 1957;126:1345-1347.

33. Henneman E. Peripheral mechanisms involved in the control of muscle. In: Mountcastle VB, ed. ***Medical Physiology.*** (12th Edition). St. Louis, MO: CV Mosby, 1968.

34. Henneman E, Olson CB. Relations between structure and function in the design of skeletal muscles. ***J Neurophysiol.*** 1965;28:581-598.

35. Henneman E, Somjen G, Carpenter DO. Functional significance of cell size in spinal motoneurons. ***J Neurophysiol.*** 1965;28:560-580.

36. Henneman E, Somjen G, Carpenter DO. Excitability and inhibility of motoneurons of different sizes. ***J Neurophyiol.*** 1965;28:599-620.

37. Henneman E, Clamann PH, Gillies JD, et al. Rank order of motoneurons within a pool: Law of combination. ***J Neurophysiol.*** 1974;37:1338-1349.

38. Houtman CJ, Stegeman DF, Van Dijk JP, et al. Changes in muscle fiber conduction velocity indicate recruitment of distinct motor unit populations. ***J Appl Physiol.*** 2003;95:1045-1054.

39. Hurley MV, Rees J, Newham DJ. Quadriceps function, proprioceptive acuity and functional performance in healthy young, middleaged and elderly subjects. ***Age Aging.*** 1998;27:55-62.

40. Ivanova T, Garland SJ, Miller KJ. Motor unit recruitment and discharge behavior in movements and isometric contractions. ***Muscle Nerve.*** 1997;20:867-874.

41. Jabre JF, Spellman NT. The demonstration of the size principle in humans using macro electromyography and precision decomposition. ***Muscle Nerve.*** 1996;19:338-341.

42. Jakobi JM, Rice CL. Voluntary muscle activation varies with age and muscle group. ***J Appl Physiol.*** 2002;93:457-462.

43. Jungblut S. The correct interpretation of the size principle and its practical application to resistance training. ***Med Sport.*** 2009;13:203-209.

44. Kent-Braun JA, Le Blanc R. Quantitation of central activation failure during maximal voluntary contractions in humans. ***Muscle Nerve.***1996;19:861-869.

45. Kent-Braun JA, Ng AV. Specific strength and voluntary muscle activation in young and elderly women and men. ***J Appl Physiol.*** 1999;87:22-29.

46. Klass M, Baudry S, Duchateau J. Aging does not affect voluntary activation of the ankle dorsiflexors during isometric, concentric, and eccentric contractions. ***J Appl Physiol.*** 2005;99:31-38.

47. Klein CS, Rice CL, Marsh GD. Normalized force, activation, and coactivation in the arm muscles of young and old men. ***J Appl Physiol.*** 2001;91:1341-1349.

48. Knaflitz M, Merletti R, De Luca CJ. Inference of motor unit recruitment order in voluntary and electrically elicited contractions. ***J Appl Physiol.*** 1990;68:1657-1667.

49. Knight CA, Kamen G. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. ***J Electromyography Kinesiol.*** 2001;11:405-412.

50. Kraemer WJ. Exercise prescription in weight training: Manipulating program variables. ***NSCA J.*** 1983;5:58-59.

51. Kraemer WJ, Noble BJ, Clark MJ, et al. Physiologic responses to heavy-resistance exercise with very short rest periods. ***Int J Sports Med.*** 1987;8:247-252.

52. Kraemer WJ, Patton JF, Gordon SE, et al. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. ***J Appl Physiol.*** 1995;78:976-989.

53. Kraemer WJ, Szivak TK. Strength training for the warfighter. ***J Strength Cond Res.*** 2012;26 (suppl 7):S107-118.

54. Kyrolainen H, Nindl BC. Preface. ***J Strength Cond Res.*** 2012;26(suppl 7):S1.

55. Masakado Y, Akaboshi K, Nagata M, et al. Motor unit firing behavior in slow and fast contractions of the first dorsal interosseous muscle of healthy men. ***Electroencephalography Clin Neurophysiol.*** 1995;97:290-295.

56. Maton B. Fast and slow motor units: Their recruitment for tonic and phasic contraction in normal man. ***Eur J Appl Physiol.*** 1980;43:45-55.

57. Milner-Brown HS, Stein RB, Yemm R. The orderly recruitment of human motor units during voluntary isometric contractions. ***J Physiol.*** 1973;230:359-370.

58. Moritani T, Muro M. Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. ***Eur J Appl Physiol.*** 1987;56:260-265.

59. Otto RM, Carpinelli RN. A critical analysis of the single versus multiple set debate. ***JEPonline.*** 2006;9:32-57.

60. Peterson MD, Rhea MR, Alvar BA. Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. ***J Strength Cond Res.*** 2004;18:377-382.

61. Ratamess NA. ***ACSM's Foundations of Strength Training and Conditioning***. Philadelphia, PA: Lippincott Williams & Wilkins, 2011.

62. Riek S, Bawa P. Recruitment of motor units in human forearm extensors. ***J Neurophysiol.*** 1992;68:100-108.

63. Roos MR, Rice CL, Connelly DM, et al. Quadriceps muscle strength, contractile properties, and motor unit firing rates in young and old men. ***Muscle Nerve.*** 1999;22:1094-1103.

64. Sasaki K, Tomioka Y, Ishii N. Activation of fast-twitch fibers assessed with twitch potentiation. ***Muscle Nerve.*** 2012;46:218-227.

65. Schmied A, Morin D, Vedel JP, et al. The "size principle" and synaptic effectiveness of muscle afferent projections to human extensor carpi radialis motoneurons during wrist extension. ***Exp Brain Res.*** 1997;113:214-229.

66. Scutter SD, Turker KS. Recruitment stability in masseter motor units during isometric voluntary contractions. ***Muscle Nerve.*** 1998;21:1290-1298.

67. Shaw BS, Shaw I, Brown GA. Comparison of resistance and concurrent resistance and endurance training regimes in the development of strength. ***J Strength Cond Res.*** 2009;23:2507-2514.

68. Suter E, Herzog W, Huber A. Extent of motor unit activation in the quadriceps muscles of healthy subjects. ***Muscle Nerve.*** 1996;19:1046-1048.

69. Thomas CK, Ross BH, Stein RB. Motor-unit recruitment in human first dorsal interosseous muscle for static contractions in three different directions. ***J Neurophysiol.*** 1986;55:1017-1029.

70. Thomas CK, Ross BH, Calancie B. Human motor-unit recruitment during isometric contractions and repeated dynamic movements. ***J Neurophysiol.*** 1987;57:311-324.

71. Vandervoort AA, McComas AJ. Contractile changes in opposing muscles of the human ankle joint with aging. ***J Appl Physiol.*** 1986;61:361-367.

72. Wakeling JM, Kaya M, Temple GK, et al. Determining patterns of motor recruitment during locomotion. ***J Exp Biol.*** 2002;205:359-569.

73. Wilder MR, Cannon J. Effect of age on muscle activation and twitch properties during static and dynamic actions. ***Muscle Nerve.*** 2009;39:683-691.