

# Differential Functional Adaptations to Short-Term Low-, Moderate-, and High-Repetition Weight Training

LAWRENCE W. WEISS,<sup>1</sup> HARVEY D. CONEY,<sup>2</sup> AND FRANK C. CLARK<sup>3</sup>

<sup>1</sup>*Musculoskeletal Dynamics Lab, Human Performance Laboratories, University of Memphis, Memphis, Tennessee 38152-6223;* <sup>2</sup>*Exercise Science Laboratory, Georgia Southern University, Statesboro, Georgia 30460-8073;*

<sup>3</sup>*Division of Computer Sciences, University of Tennessee, Memphis, Tennessee 38163.*

## ABSTRACT

Previously untrained young men ( $n = 38$ ) were compared in terms of selected changes in leg function following 7 weeks of differential repetition exposures during heavy-resistance training. Subjects were randomly placed into 1 of 4 groups. Groups I, II, and III completed 3 workouts per week, including a warm-up and 4 sets of squats for a 3–5 repetitions maximum (3–5RM), 13–15RM, or 23–25RM, respectively. A fourth (control) group did not participate in formal physical training during this interim. Selected tests of leg function included dynamic constant external resistance (DCER) squat strength, isokinetic knee extension and flexion peak torque at both 60 and 300°·s<sup>-1</sup>, and vertical jump. Following the 7-week training period, both DCER squat strength and knee extension peak torque at 60°·s<sup>-1</sup> were significantly increased in all 3 treatment groups more ( $p < 0.01$ ) than in the control group. In addition, squat strength was improved more in group I than in group III ( $p < 0.05$ ). No significant differences ( $p > 0.05$ ) were found between any of the 4 groups for changes in either vertical jump distance, knee extension and flexion peak torque at 300°·s<sup>-1</sup>, or knee flexion peak torque at 60°·s<sup>-1</sup>. These results indicate that short-term low-, moderate-, and high-repetition heavy-resistance squat training programs have little effect on jumping distance or high-velocity strength but do enhance DCER squat strength and maximal low-velocity knee extension strength. In addition, the low-repetition program appears to be superior to the high-repetition program for improving squat strength. The absence of improvements in vertical jump distance and fast-velocity isokinetic knee extension and flexion peak torque suggests that short-term DCER weight training, performed as described above, may have minimal direct impact on “explosive” physical activities for young men having limited training experience.

**Key Words:** muscular strength, explosive strength, isoinertial, isokinetic, dynamic constant external resistance

**Reference Data:** Weiss, L.W., H.D. Coney, and F.C. Clark. Differential functional adaptations to short-term

low-, moderate-, and high-repetition weight training. *J. Strength Cond. Res.* 13(3):236–241. 1999.

## Introduction

The optimal development of the skeletal muscles involved in particular athletic events is desirable as a means of improving performance and of possibly reducing the potential for injury (9, 13, 21, 24). Many postpubescent athletes become involved in some type of heavy-resistance training in order to increase their levels of muscular strength, endurance, and/or mass. Specific training-elicited improvements are a function of many factors, including such things as the selection of exercises, the nature of the program for executing them, the extent of previous involvement in a particular heavy-resistance program, and the trainability of the individual (11, 14, 15, 21, 25).

Although heavy-resistance training may be used to enhance several aspects of physical performance, it is primarily used as a means of increasing strength. Muscular strength has been generally defined as the maximum force generated against a resistance through a specified range of motion for a nonspecified period of time (2). Alternative expressions of strength have been increasingly used to help clarify (but to sometimes confuse) its meaning during exercise. For example, as the name implies, “explosive strength” involves the rapid generation of force. The more force that can be generated at fast velocities or the faster a given load can be moved, the higher the explosive strength, and successful participation in many activities requires the quick or explosive generation of great force (8). Although reflected in performances such as the shot put and vertical jump, explosive strength is not directly measurable.

An alternative measurement concept that enabled investigators and clinicians to obtain actual measure-

ments that might be used in lieu of nebulous concepts such as “explosive strength” was first reported in 1967 (16, 23). Isokinetic equipment allows strength to be expressed relative to a specific constant joint velocity. When used in this manner, torque or force may be measured at specific preset velocities, ranging from extremely slow to very fast (limited by the equipment). Strength tests involving fast motions more closely resemble the velocities at which many athletic and recreational activities occur, as opposed to the more traditional tests of strength involving either a dynamic constant external resistance (DCER) or isometrics.

A drawback associated with isokinetic equipment is that it does not allow for changes in joint velocity or inertia, which characterize most movements in sports. Therefore, although isokinetic testing enables us to gain insight into movements that we otherwise might not easily obtain, it obscures other aspects of these movements. Consequently, although useful, isokinetic testing is not a perfect tool for measuring muscle function.

Although imperfect, the increasingly available technology provides us with the opportunity to gain unique insights into muscular adaptations to training. Since much of the reported research in the area of strength enhancement has been conducted using isometric and DCER assessments, a reexamination of the effects of various traditional heavy-resistance programs using both traditional and alternative assessment tools appears to be warranted.

During the initial weeks and months of DCER training, a substantial amount of latitude appears to exist related to optimal set and repetition schemes for maximizing strength assessed using DCER (12); however, it is less clear what impact these variables have on measures reflective of “explosive” strength, such as the vertical jump and relatively fast tests of isokinetic peak torque. This investigation was designed to monitor the changes in selected measures of strength occurring in young men consequent to short-term participation in DCER training programs, in which the number of repetitions per set was manipulated and the number of sets was held constant. Although a myriad of repetition schemes could have been used under these circumstances, we opted to maximize the difference between independent variables by using a wide variation in repetitions. Repetition counts were considered only when DCER strength had been significantly increased in at least one study in which 3 or fewer sets per exercise per workout were used.

This investigation addresses only the initial phase of heavy-resistance training by previously untrained young men. It does not address the effects of the respective routines subsequent to one or more variations in training volume, intensity, and specificity, which are inherent in periodized heavy-resistance conditioning.

## Methodology

### *Subjects*

Forty-four men, 18 to 30 years of age (average = 21.1,  $SD = 2.09$ ), participated in this investigation. Subjects, all of whom were volunteers, were not actively engaged in any type of systematic physical training involving the legs for a minimum of 3 months before initiation of the study. They also reported that they were free of any musculoskeletal diseases and had not used any exogenous substances thought to produce anabolic effects within the previous 6 months.

Written informed consent that was in accordance with guidelines of Georgia Southern University’s Institutional Review Board was obtained from each subject prior to his participation in the investigation. Prior to the completion of the investigation, a total of 6 men withdrew from the study for personal reasons, thereby reducing the final sample size to 38.

### *Pretraining*

Prior to pretesting, subjects practiced all tests during each of 5 sessions in an effort to thoroughly familiarize themselves with the standardized protocols. Each pretraining session involved 10 to 12 minutes of stretching activities for the leg, hip, and lumbar region of the back, which was followed by 3 to 5 practice sets for each test.

Two general stretching exercises were used for this study. The first was designed to stretch the hamstring, gluteal, and lumbar muscles, whereas the second was designed for the triceps surae muscles. All positions were statically held for 45 to 60 seconds and stretches were performed in series. Each series was performed twice.

Following stretching, the subjects rotated to each of 3 pretesting stations, including DCER squat, isokinetic knee extension and flexion, and vertical jump stations. The subjects were provided with technical instructions for each of the tests and were required to practice each activity for 10 submaximal repetitions. Then, except for those practicing the vertical jump, a minimum of 2 sets and a maximum of 4 sets of approximately 10 repetitions maximum (10RM) were completed. Since many of the subjects were doing these activities for the first time, they often completed somewhat greater or fewer than the desired 10RM. Subjects experiencing difficulty in mastering the testing protocols were normally the only subjects to repeat any of the activities 5 times per session. An exception to this routine occurred when subjects rotated to the vertical jump station. At this station, subjects completed a total of 10 maximal jumps, each of which was followed by a 30-second rest interval.

### *Testing*

Six tests of maximal leg function were conducted before and following the 7-week training period. Tests

included DCER squat strength, isokinetic knee extension and flexion peak torque at both 60 and 300°·s<sup>-1</sup>, and vertical jump distance. Subjects warmed up prior to testing in the same manner as was used for pretraining, except that submaximal sets and vertical jumps were limited in number to 2.

*DCER Tests.* DCER squat strength was assessed using a 1 repetition maximum (1RM) effort involving only concentric contractions of the muscles most involved in the lift. In order to carry out this test, each subject was aligned in a power rack and beneath a standard Olympic-style bar, which rested posterior to the shoulders at the level of the supraspinatus fossa. The feet were placed shoulder-width apart, and the knees were flexed at a 100° angle (down position). The apex of a stainless-steel manual goniometer was placed over the lateral femoral condyle during both pretraining and pretesting in order to establish the appropriate starting knee angle. When the subject was properly aligned beneath the bar, the appropriate knee position corresponded to a specific peg position on the power rack. Once the peg position was established, the initial testing and training positions could be easily attained. Subjects had the option to wear or not wear a weight-lifting belt; however, both pretesting and posttesting were performed under identical conditions.

The attempted 1RM lift was estimated at 20% above the load used during pretraining. When ready, the subject maximally extended both the hips and knees and plantar flexed the ankle joints. The lift was considered successful if the subject was able to extend both the hip and knee to 180° (fully upright). The same investigator judged the acceptability of lifts for all subjects during both testing and training. A single spotter, situated directly behind the lifter, assisted in returning the bar to its initial position. The lifter continued to increase the load until he was unable to lift it on 2 consecutive attempts or until the lifter indicated that no more weight could be lifted. Subjects were allowed liberal rest intervals between maximal attempts.

*Isokinetic Tests.* Isokinetic knee extension peak torque was assessed at both 60 and 300°·s<sup>-1</sup>. Movement was initiated with the dominant knee in a flexed position at 90° and was terminated just short of full extension (170°). Mechanical stops made of rubber prevented the leg from extending appreciably beyond 170°. The flexion motion was simply the return to the original starting knee position. Movements in both directions involved only concentric contractions. The tests were administered following the manufacturer's guidelines for Cybex II Plus equipment (10). Peak torque was calculated automatically using the Cybex Data Reduction Computer (Lumex, Inc., Ronkonkoma, NY). The isokinetic equipment and data reduction system were calibrated daily during testing.

*Vertical Jump Test.* A standardized vertical jump

protocol was used (17). Briefly described, the subject was weighed while wearing only undergarments, athletic shorts, and a T-shirt. Chalk dust was placed on the distal end of the middle finger of the nondominant hand, after which the subject assumed a flat-footed stance, facing sideways to a vertical wall. The dominant arm was away from the wall and was placed behind the lower back with the hand grasping the top of the back of the shorts. The nondominant arm was closest to the wall and was flexed to 0° at the shoulder. A chalk mark was made on the wall with the nondominant middle finger while the subject stood in this position. Next, in 1 continuous motion, the subject performed a countermovement, at a depth of his own choosing, without any flexion at the lumbar spine and while retaining full shoulder flexion. The subject jumped as high as possible and made a chalk mark on the wall while at the highest point of the jump. The greatest distance from 3 vertical jumps was recorded. Liberal rest intervals were provided between attempts. The testing sequence for all dependent variables was counterbalanced in order to compensate for ordinal fatigue effects.

### *Training Activities*

Following pretesting, subjects were randomly assigned to 1 of 3 different leg-training groups or to a control group in which no leg training of any kind was practiced. Training took place 3 times per week for 7 weeks. Each trainee warmed up in a manner similar to that used prior to testing and then completed 4 sets of barbell squats using either 3–5RM (group I), 13–15RM (group II), or 23–25RM (group III). All training was performed on a power rack, with the lifter controlling the bar in both the ascending and descending phases. Sturdy metal safety pegs were secured in the rack so that the lifter would know when he had reached the appropriate depth (100° of knee flexion) for each repetition. Exercises were closely monitored to ensure that lifts were completed with no bouncing off the safety pegs.

Repetitions were adjusted on a set-by-set basis. Whenever a lifter was able to complete more repetitions than prescribed for his group, the load was increased by 2.27 kg for the subsequent set. Whenever a lifter was unable to complete the minimum number of repetitions prescribed for his group, the load was reduced by 2.27 kg for the subsequent set.

### *Statistical Analyses*

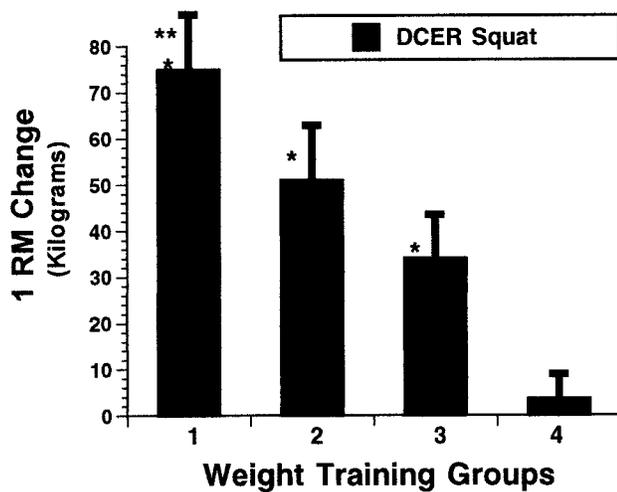
Absolute changes in performance (difference scores) for each dependent variable for the 4 experimental groups were compared using a one-way analysis of variance. Student–Newman–Keuls multiple comparison tests were calculated when appropriate (*f*-ratio, *p* ≤ 0.05).

**Table 1.** Mean changes (posttest minus pretest) for various aspects of leg function consequent to low- (I), moderate- (II), and high-repetition (III) DCER squat training and nontraining control (IV) conditions. Values are mean  $\pm$  SD.

Performance variables	Experimental groups				<i>f</i> -ratio one-way ANOVA
	I ( <i>n</i> = 7)	II ( <i>n</i> = 10)	III ( <i>n</i> = 11)	IV ( <i>n</i> = 10)	
Barbell squat strength (kg)	75.0 $\pm$ 31.2	51.1 $\pm$ 37.1	34.1 $\pm$ 30.9	3.6 $\pm$ 16.7	8.73*
Slow knee extension (N·m)	17.8 $\pm$ 35.7	26.2 $\pm$ 30.7	11.5 $\pm$ 31.6	-22.6 $\pm$ 18.1	5.24*
Fast knee extension (N·m)	3.5 $\pm$ 12.8	0.8 $\pm$ 14.7	-2.4 $\pm$ 15.0	4.9 $\pm$ 20.6	0.50**
Slow knee flexion (N·m)	11.2 $\pm$ 19.5	6.4 $\pm$ 24.9	7.4 $\pm$ 16.9	6.8 $\pm$ 17.7	0.10**
Fast knee flexion (N·m)	2.3 $\pm$ 22.2	-2.0 $\pm$ 6.8	2.2 $\pm$ 9.6	6.1 $\pm$ 15.1	0.54**
Vertical jump (m)	0.028 $\pm$ 0.041	0.037 $\pm$ 0.024	0.024 $\pm$ 0.047	0.006 $\pm$ 0.040	1.07**

\*  $p < 0.01$ .

\*\*  $p < 0.05$ .

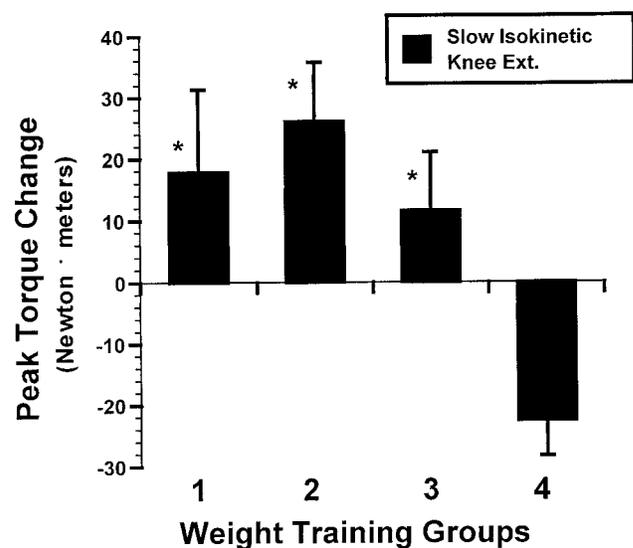


\* Significantly ( $p < .01$ ) greater than Group 4.  
 \*\* Significantly ( $p < .05$ ) greater than Group 3.  
 Other groups are not different ( $p > .05$ ).

**Figure 1.** Posttest minus pretest changes in concentric 1 repetition maximum (1RM) dynamic constant external resistance back squats. Error bars depict 1 SEM. Group 1 = 4  $\times$  3-5RM; group 2 = 4  $\times$  13-15RM; group 3 = 4  $\times$  23-25RM; and group 4 = control.

## Results

Comparisons of group changes for the 6 dependent variables are presented in Table 1. Results indicated that improvements were significantly ( $p < 0.01$ ) greater than those experienced by the controls only for DCER squats and isokinetic knee extension at 60°·s<sup>-1</sup>. For squats, all training groups outperformed the control group (group IV). In addition, the group training with 4  $\times$  3-5RM (group I) showed significantly greater ( $p < 0.05$ ) improvement than the group training with 4  $\times$  23-25RM (group III). For slow-velocity knee extension performance, all 3 training groups outperformed the control group ( $p < 0.01$ ), and no differences ( $p > 0.05$ ) existed between the training groups (see Figures 1 and 2).



\* Significantly ( $p < .01$ ) greater than Group 4.  
 Other groups are not different ( $p > .05$ ).

**Figure 2.** Posttest minus pretest changes in unilateral concentric isokinetic knee extensions performed at 60°·s<sup>-1</sup>. Error bars depict 1 SEM. Group 1 = 4  $\times$  3-5RM; group 2 = 4  $\times$  13-15RM; group 3 = 4  $\times$  23-25RM; and group 4 = control.

## Discussion

From the early 1960s until recently, a number of investigations have been conducted to determine the comparative effects of various set and repetition strategies (during DCER training) on muscular strength. Berger (4-7) was especially involved in this process and eventually concluded that various set and repetition combinations could be used during DCER training to elicit similar results. In 1963, he (6) conducted a 9-week training study, in which young men trained 3 times per week using either 6 sets of 2 repetitions maximum (6  $\times$  2RM), 3  $\times$  6RM, or 3  $\times$  10RM. Both training and testing involved DCER bench presses. The results indicated that the 3 workout routines were

equally effective ( $p > 0.05$ ) in improving strength as measured by DCER 1RMs. In 1966, O'Shea (18) conducted a study similar in nature to the 1963 study of Berger, except that the routines involved  $3 \times 2RM$ ,  $3 \times 5RM$ , and  $3 \times 10RM$ , and the exercise used for training and testing was the DCER squat. As before, all groups improved significantly ( $p < 0.05$ ), and treatments elicited similar ( $p > 0.05$ ) improvements. In 1970, Withers (26) carried out another study in which sets and repetitions were manipulated, but in this case, the different routines were roughly equivalent with regard to training volume. In his study, young men performed either  $3 \times 7RM$ ,  $4 \times 5RM$ , or  $5 \times 3RM$  twice a week for 9 weeks on the arm curl, bench press, and deep back squat. When strength was expressed relative to body weight, all groups improved significantly ( $p < 0.05$ ), but no groups were different ( $p > 0.05$ ). In 1982, Anderson and Kearney (1) reported on the effects of 3 set and repetition strategies on DCER bench press strength in young men. DCER training interventions included 3 days per week of  $3 \times 6-8RM$ ,  $2 \times 30-40RM$ , and  $1 \times 100-150RM$  for 9 weeks. The group performing  $3 \times 6-8RM$  made greater gains ( $p < 0.05$ ) in strength than did the other 2 groups. In 1994, Stone and Coulter (22) investigated the effects of 3 set and repetition routines on DCER bench press and squat strength in young women who had trained 3 days per week for 9 weeks. As in the Withers (26) study, some effort to equate training volume appears to have been made, as subjects performed either  $3 \times 6-8RM$ ,  $2 \times 15-20RM$ , or  $1 \times 30-40RM$ . Results indicated that 1RM DCER strength was significantly improved ( $p < 0.05$ ) in all training groups but that improvements were similar ( $p > 0.05$ ).

Viewed collectively, the preceding reports suggest that the various short-term set and repetition routines performed by previously untrained individuals may elicit similar significant improvements in muscular strength, assessed using DCER. With the exception of 2 studies (1, 22), repetition numbers by any of the training groups were not particularly high. In the Anderson and Kearney study, subjects were all male, and those performing  $2 \times 30-40RM$  or  $1 \times 100-150RM$  did not improve in strength. In the Stone and Coulter study, subjects were all female, and those performing  $3 \times 6-8RM$ ,  $2 \times 15-20RM$ , and  $1 \times 30-40RM$  improved significantly, though not differently, in terms of DCER strength. The only direct conflict between the results of these 2 studies was for groups that performed 30-40RM. However, in the Anderson and Kearney study, greater volume was attained, since their subjects performed 2 sets, as compared with the Stone and Coulter study, in which subjects performed only 1 set. Surprisingly, the group performing a lower number of sets apparently achieved better results. Although subjects for both studies were previously untrained, it may be that the women in the Stone and

Coulter study were even less trained than were the men in the Anderson and Kearney study. So, when exposed to an apparently weak training stimulus, the subjects who were further from their maximum potential for strength development may have been able to demonstrate significant improvements (11). However, since we have no way of determining this for the subjects in question, the preceding explanation is purely speculation.

In the current investigation, DCER squats were improved in training groups performing  $4 \times 3-5RM$  (low repetition),  $4 \times 13-15RM$  (medium repetition), and  $4 \times 23-25RM$  (high repetition), in comparison with the controls, while the low-repetition group improved more than did the high-repetition group. This generally supports previous reports that suggest that a fairly wide range of repetitions may elicit similar significant improvements in DCER strength, although the range appears to be somewhat lower for men than for women.

Vertical jump was not improved in any of the training groups. This appears to conflict with Baker's (3) training model for jumping, in that he suggests that squat training may elicit improvements in vertical jumping performance in untrained individuals but will seldom do so in well-trained ones. However, the squatting depth in the current investigation was rather shallow ( $100^\circ$  of knee flexion) in our untrained men, and it is unclear whether a deeper squat would elicit a different training effect. In addition, Baker's suggestion that squat training "may" increase vertical jumping performance in untrained individuals intimates that the effect on this type of performance is not particularly strong.

Isokinetic performance was significantly improved only for the slow-velocity ( $60^\circ \cdot s^{-1}$ ) knee extension test. Knee flexion peak torque at low and high ( $300^\circ \cdot s^{-1}$ ) velocities and knee extension peak torque at the identical high velocity were not significantly improved. Since the hamstring's direct role in shallow squats is to assist the gluteus maximus with hip movements while the quadriceps primary role is to control the knees, it is not too surprising that isokinetic knee flexion performance was not improved. Furthermore, since our training included only the DCER squat exercise and the isokinetic tests involved 2 separate single-joint exercises, it would not have been too surprising if significant improvements had been found only for the DCER squats. Therefore, the significant improvements by all 3 training groups for both squats and low-velocity knee extension peak torque were noteworthy.

## Practical Applications

When the following factors are considered collectively, a pattern appears to have emerged from this and other

investigations: 1RM DCER squats occur at relatively slow velocities (19, 20); isokinetic knee extension improves only at the slowest velocity; up to 4 sets of 25RM will improve 1RM DCER squats and slow-velocity knee extensions, although the higher repetition squatting program is less effective than the lower repetition program for improving 1RM DCER squats; and none of the squat-training programs described in this study are likely to elicit significant improvements in fast-velocity isokinetic or vertical jump tests.

For short-term heavy-resistance squat training by young, previously untrained men, it appears that completion of 4 sets of between 3 and 25RM for 3 days per week will elicit similar training effects. 1RM DCER squat performance and knee extension peak torque at  $60^{\circ}\cdot\text{s}^{-1}$  are likely to be significantly improved consequent to all 3 training protocols, although the lower number of repetitions appears to be superior to the high number of repetitions in terms of increasing 1RM DCER strength. In addition, vertical jumps and high-velocity knee-joint isokinetic performance appear to be unaffected by this type of training. These results suggest that short-term DCER weight training by young, untrained men using from 3 to 25RM per set will increase strength, but such a program is of limited direct practical value when the generation of high levels of force at high velocities is important.

## References

- ANDERSON, T., AND J. KEARNEY. Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Res. Q.* 53:1-7. 1982.
- ATHA, J. Strengthening muscle. In: *Exercise and Sport Sciences Reviews*. D. Miller, ed. Philadelphia: The Franklin Institute Press, 1981. pp. 1-73.
- BAKER, D. Improving vertical jump performance through general, special, and specific strength training: A brief review. *J. Strength Cond. Res.* 10:131-126. 1996.
- BERGER, R. Effect of varied weight training programs on strength. *Res. Q.* 33:168-181. 1962.
- BERGER, R. Optimum repetitions for the development of strength. *Res. Q.* 33:334-338. 1962.
- BERGER, R. Comparative effects of three weight training programs. *Res. Q.* 34:396-398. 1963.
- BERGER, R. Application of research findings in progressive resistance exercise to physical therapy. *J. Assoc. Phys. Ment. Rehabil.* 19:200-203. 1965.
- CAIOZZO, V., J. PERRINE, AND V. EDGERTON. Training-induced alterations of the *in vivo* force-velocity relationship of human muscle. *J. Appl. Phys. Res. Environ. Exerc. Phys.* 51:750-754. 1981.
- CLARKE, H. Strength development and motor-sports improvement. In: *Physical Fitness Research Digest*. President's Council on Physical Fitness and Sports. Washington, DC: U.S. Government Printing Office, 1974, pp. 1-17.
- CYBEX II PLUS. *Operations Manual*. Ronkonkoma, NY: Lumex Corp., 1983.
- EKBLOM, B. Physical training in normal boys in adolescence. *Acta Paediatr. Scand. Suppl.* 217:60-62. 1971.
- FLECK, S., AND W. KRAEMER. *Designing Resistance Training Programs* (2nd ed.). Champaign, IL: Human Kinetics, 1997, pp. 18-24.
- GRIMBY, G. Clinical aspects of strength and power training. In: *Strength and Power in Sport*. P. Komi, ed. Boston: Blackwell Scientific Publications, 1992. pp. 340-343.
- HENRY, F., AND L. SMITH. Simultaneous vs. separate bilateral muscular contractions in relation to neural over-flow theory and neuromotor specificity. *Res. Q.* 32:42-46. 1961.
- HENRY, F., AND J. WHITLEY. Relationships between individual differences in strength, speed and mass in an arm movement. *Res. Q.* 31:24-33. 1960.
- HISLOP, H., AND J. PERRINE. The isokinetic concept of exercise. *Phys. Ther.* 47:114-117. 1967.
- JOHNSON, B., AND J. NELSON. *Practical Measurements for Evaluation in Physical Education*. New York: MacMillan, 1986, pp. 210-212.
- O'SHEA, J. Effects of selected weight training programs on the development of strength and muscle hypertrophy. *Res. Q.* 37:95-102. 1966.
- PERRIN, D. *Isokinetic Exercise and Assessment*. Champaign, IL: Human Kinetics, 1993.
- PERRINE, J. The biophysics of maximal muscle power outputs: Methods and problems of measurement. In: *Human Muscle Power*. N. Jones, N. McCartney, and A. McComas, eds. Champaign, IL: Human Kinetics, 1986, pp. 15-25.
- RUTHERFORD, O., C. GREIG, A. SARGEANT, AND D. JONES. Strength training and power output: Transference effects in the human quadriceps muscle. *J. Sports Sci.* 4:101-107. 1986.
- STONE, W., AND S. COULTER. Strength/endurance effects from three resistance training protocols with women. *J. Strength Cond. Res.* 8:231-234. 1994.
- THISTLE, H., H. HISLOP, M. MOFFROID, AND T. LOHMAN. Isokinetic contraction: A new concept of resistive exercise. *Arch. Phys. Med. Rehabil.* 48:279-282. 1967.
- WESTCOTT, W. *Strength Fitness: Physiological Principles and Training Techniques*. Dubuque, IA: Wm. C. Brown Publishers, 1991, p. 1.
- WHITLEY, J., AND L. SMITH. Influence of three different training programs on strength and speed of limb movement. *Res. Q.* 37:132-142. 1966.
- WITHERS, R. Effect of varied weight training loads on the strength of university freshmen. *Res. Q.* 41:110-114. 1970.