Multiple-joint velocity-spectrum strength/power development consequent to repetition manipulation

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Background. Various repetition strategies are employed in typical weight-training programs. Strength is purportedly best developed using relatively few repetitions against great resistance. Strength in this context has typically been measured isotonically (dynamic constant external resistance or DCER) by performing a one-repetition maximum (1 RM). Multiple-joint isokinetic (velocity controlled) strength assessments are now available which may enable us to emulate movement patterns and velocities with those occurring in everyday activities while providing us with force and power information that heretofore has been difficult to obtain. Therefore, we assessed the effects of various repetition schemes during heavy-resistance training on multiple-joint isokinetic performance.

Methods. Setting: volunteers participated in 12 weeks (36 sessions) of variable-resistance weight training (8 different exercises) in one of the following programs: I-3 sets x 3-4 RM; II-3 x 9-10 RM; III-3 x 15-16 RM; IV, control. Participants: 48 apparently healthy young men (18 to 34 years of age, \(\bar{x} = 23.2\)) who had not participated in systematic heavy-resistance training during the previous year. Measures: pre and post velocity-spectrum tests were conducted for both the squat (0.41, 0.65, 0.90, 1.14, and 1.39 m/s\(^2\)) and bench press (0.50, 0.79, 1.09, 1.39 and 1.69 m/s\(^2\)) at which time peak force and power were measured. Force and power measurements were adjusted to control for body weight (N/kg and W/kg, respectively). Change (delta) scores were used for comparisons.

Results. One-way ANOVA's indicated that when compared to controls, improvements in force were significantly (p<0.05) greater only at the slowest velocity (squats: Group II > Control; bench presses: Groups I, II, III > Control). However, changes in power were significantly (p<0.05) greater than for controls at all 5 velocities tested (squats: Groups I, II > Control; bench presses: Groups I, II > Control except at 1.69 m/sec\(^2\)) where only Group I > Control).

Conclusions. Due to the mixed findings for force improvements consequent to the various repetition schemes, conclusions are somewhat tentative. It appears, however, that strength increases only for slow velocities in young, previously untrained men consequent to 3 months of a relatively wide range of RM schemes using variable-resistance equipment. Power, on the other hand, appears to increase in the same subjects across a velocity spectrum for both squats and bench presses when no more than 10 RM are performed per set.

Key Words: Bench press - Force - Squat - Weight training.

Numerous investigations have been conducted to establish the optimum number of repetitions per set for maximum muscular strength development when training is performed against either a dynamic constant external resistance (DCER) or a variable resistance (VR). It is clear that the interplay between sets and repetitions is critical in this regard. Although it appears that a fairly wide range of variations elicits similar strength increases, repetitions in excess of 10...
per set result in progressively reduced improvements in dynamic strength.\(^1\) Dynamic strength, in this context, has been typically assessed using a one-repetition maximum (1 RM).

In the 1960's, Berger conducted several studies\(^2\)\(^3\)\(^4\) in which he examined the interactions of sets and repetitions on strength development. The findings from his studies have served for years as the primary basis for exercise prescriptions designed to enhance muscular strength, especially as pertains to overall fitness. At one point, he concluded that dynamic muscular strength was best developed by training 3 days per week using three sets of low repetitions (~6) against loads that would elicit near failure on the final successful repetition.\(^5\) Fleck and Kraemer\(^6\) examined numerous related studies and suggested that absent a systematic variation in load, volume, and exercise specificity (collectively called periodization training), strength enhancement is best achieved by completing somewhere between 2 and 10 RM for between 2 and 5 sets.

Although periodization training has supplanted traditional progressive resistance training in athletics, sets and repetitions remain as integral aspects of this model as they are systematically varied during each phase or period in order to achieve specific objectives. However, in order to best accomplish designated objectives, a comprehensive understanding of the effects of each set-and-repetition-manipulation is needed.

Technological advances have made the attainment of a comprehensive picture of strength-related variables more accessible. Multiple-joint velocity-spectrum testing is one such advance in that movements similar to those performed in everyday activities may be assessed.\(^5\)\(^7\) The similarities include both the pattern of movement as well as the velocity at which it is performed. Secondly, both force and power data are readily obtained at multiple velocities (velocity spectrum), so instead of looking at a simplistic concept of strength as related to performance, it may now be dealt with as a much more complex entity.

The intent of this investigation, therefore, was to return to the simple concept of ascertaining the effectiveness of various repetition schemes (number of sets held constant) on selected aspects of muscular dynamics which were not readily obtainable or used by previous researchers. The velocity-spectrum data obtained for both force and power will shed new light on the effects of repetition manipulation. This, in turn, may subsequently require us to rethink our intervention strategies for heavy-resistance training based upon the particular needs of a given individual.

### Materials and methods

**Subjects**

Forty-eight young, apparently-healthy men (18 to 34 years of age, \(\bar{x} = 23.2\) years), who for the previous year had not been actively engaged in a formalized heavy-resistance training program, voluntarily served as subjects in this investigation. Subsequent to both written and oral explanations of the specific nature of each volunteer's potential involvement, a medical history questionnaire was completed and written informed consent obtained following guidelines established by our Institutional Review Board. Additionally, all volunteers were screened via auscultation for hypo- and hypertension prior to their designation as subjects.

**Procedures**

Velocity-spectrum tests for the squat and bench press were performed subsequent to three pre-training/familiarization sessions and again following 36 sessions of variable-resistance (VR) weight training carried out over a 12-week period. Subjects were randomly assigned to one of four groups, one of which was a nontraining control group while the other three performed different training routines in which the number of repetitions was controlled. Both force and power were assessed at each of five different test velocities for each of the two lifts.

**Testing protocols**

Pre and post velocity-spectrum tests (Ariel Multi-function dynamometer) [Ariel Dynamics, Inc., Trabuco Canyon, CA, USA] were conducted at which time peak force and peak power were measured during the concentric phase for both the squat (0.41, 0.65, 0.90, 1.14, and 1.39 m s\(^{-1}\)) and bench press (0.50, 0.79, 1.09, 1.39 and 1.69 m s\(^{-1}\)). These velocities were such that a load range could be achieved by all participants at all velocities.
Baltzopoulos and Brodie had previously noted that for single-joint isokinetic devices, between two and six repetitions were required to establish an individual's maximum torque output. Based on this and pilot work in our laboratory, we decided a 3 RM set was appropriate for locating the repetition at which the highest force and power output could be performed on a multiple-joint exercise. All force and power measurements were adjusted for body weight (relative peak force and relative peak power).

Body positioning was standardized for both lifts so that pre- and post-tests would be performed in the same manner. For the squat, the body was aligned vertically to establish foot placement. Force and power measurements were obtained during ascension from 90° to 30° of knee flexion (established with a manual goniometer). Subjects were trained to maintain an essentially upright torso during all phases of the squat, although some minor variations were apparent. For the bench press, the body was supine with knees flexed at 90°. Force and power measurements were obtained during ascension from the nipple level until 40° of elbow flexion (established with a manual goniometer). A loud audible signal alerted subjects when starting and finishing positions were attained for both lifts.

Although validity was not directly assessed in this investigation, the reliability in previous studies using the Ariel dynamometer to obtain peak force and peak power values from 1 RM bench presses and squats was quite high ($r \geq 0.95$ and 0.96, respectively for bench presses; $r \geq 0.98$ and 0.96, respectively for squats). In addition, assessments of dynamic force calibration for the dynamometer in the same two studies were quite consistent using two different loads (inter-test CV for 54.2 kg and 101.1 kg were 1.2% and 0.6%, respectively, and 1.3% and 0.7%, respectively).

Training protocols

Following pretesting, subjects were randomly assigned to one of the following four groups, three of which participated in VR weight training [Nautilus Sports/Medical Industries, Inc., Independence, VA] each Monday, Wednesday and Friday for 12 weeks: Group I, 3 sets of 3-4 repetitions maximum (3 x 3-4 RM); Group II, 3 x 9-10 RM; Group III, 3 x 15-16 RM; Group IV, Control). Progressive-resistance training was employed for this investigation in that the load was increased by 5 kg every time a subject was able to complete more than the allotted number of repetitions designated for a particular group. Subjects in all treatment groups performed light stretching and 3-4 minutes of warm-up calisthenics before completing three circuits of eight different training exercises in which 3.5 to 4.0 minutes rest was taken between exercises. The training circuit included the following exercises: (assisted squat on multifunction machine, arm cross, torso arm, abdominal curl, leg press, decline chest press, arm curl, and overhead press).

Statistical analyses

Following post-testing, groups were statistically compared on change (delta) scores for force and power at all five velocities for the squat and bench press using a one-way ANOVA and Student Newman-Keuls multiple comparison tests when indicated ($\alpha \leq 0.05$). ANCOVAR using pretest scores as covariates was considered and then rejected as a means for analyzing this data since pretest scores for force and power were not significantly correlated ($p > 0.05$) in all cases with their respective post tests.

Results

Comparisons of group changes are presented in Figures 1-4. Results indicated that improvements in force were significantly ($p < 0.05$) better than for controls only at the slowest test velocity for squats (Group II > Control) and bench presses (Groups I, II, III > Control). On the other hand, changes in power were significantly ($p < 0.05$) better at each of the five velocities tested for squats (Groups I, II > Control) and bench presses (Groups I, II > Control except at 1.69 m/sec where only Group I > Control).

Discussion and conclusions

From the mid 1940s until recently, research involving heavy-resistance training was primarily focused on the assessment of changes in muscular strength. As late as the 1960s, some professionals considered exercising to fatigue with relatively high numbers of repetitions as a viable mechanism for gaining strength. For example, Hellebrandt and Houtz suggested that...
the daily performance of 10 sets of 25 repetitions was appropriate for enhancing “muscle function” of the forearm supinators. It is likely the authors intended muscle function to be interpreted broadly in this context.

DeLorme 11 was one of the first to suggest that lower numbers of repetitions with higher resistance performed in a progressive manner would elicit better strength gains. Berger 2-4 endeavored to test and refine DeLorme’s general set and repetition scheme for maximizing muscular strength. At one point, he 4 concluded that dynamic muscular strength appeared to be best developed by performing heavy-resistance exercise three days per week using three sets of approx-
imately six repetitions maximum (6 RM). Later on, however, Berger 12 suggested that numerous set and rep schemes would elicit non-differentiated increases in strength.

The standard test of dynamic strength at that time primarily involved performing a 1 RM against either a dynamic constant external resistance (DCER) or variable resistance (VR), often using free weights or Universal Gyms. However, in 1967, a new approach to assessing muscular dynamics (isokinetics) was introduced.13 14 By using specialized equipment, velocity could be held constant while force varied throughout a given range of motion. This “accommodative resistance” involved adjusting the load with a nearly instantaneous electronic feedback loop so that velocity could be maintained at a designated level. In an attempt to reduce ambiguities associated with this type of measurement, kinetic chains were limited to one link so that musculoskeletal output could be readily explained. For the same reason, stringent measures were used to insure joint action isolation was also practiced.

However, since very few joint actions during everyday activities involve isolated single joints, the utility of research using this approach is questionable if extrapolated beyond a very narrow context. Furthermore, when heavy-resistance training is performed using one modality and testing occurs with another, strength gains are frequently obscured or masked due to a lack of modality specificity.15 16

On the positive side, performance may be analyzed at multiple velocities using isokinetic equipment, thereby yielding a substantially more comprehensive picture of an individual’s capabilities under a myriad of conditions. In addition, both force or torque and power can be readily measured at each test velocity. Recently, multiple-joint tests have also been reliably performed over a velocity spectrum.5 7 This appears to have largely overcome the “applicability” shortcomings of previous strength training investigations involving single-joint isokinetic equipment. If reliable data can be obtained over a velocity spectrum for multiple-joint exercises, then it is likely the data will be more reflective of “real life” capabilities than that obtained using single-joint protocols.

In the current investigation, multiple-joint, velocity-spectrum testing was used to assess the effects of different repetition-schemes on maximal strength and power. It appears 3 months (36 sessions) of variable-resistance weight training involving 3 sets each of various repetition schemes elicits differential changes in muscular performance depending upon whether strength (force) or power is examined over a velocity spectrum. Significant increases in muscular force occurred only at the slowest test velocity, but the repetition schemes eliciting this depended upon whether bench presses or squats were considered. Slow-velocity bench press force improvement was greater than that of the control group for all three repetition schemes while squat improvement only occurred for the group performing 3×9-10 RM. Comparable studies in which multiple-joint, velocity-spectrum assessments were made have not been reported at this time.

Numerous studies involving the comparative effects of repetition manipulation during heavy-resistance training on DCER tests involving bench presses and/or squats have been reported. And, based upon the force-velocity relationship, it can be safely assumed that maximum strength in these situations encompassed only slow-velocity performance.17 18

Anderson and Kearney 19 used 43 young men to investigate the effects of three set- and repetition-schemes on the development of bench press strength consequent to 9 weeks of training (27 sessions). The group performing 3×6-8 RM made greater gains (p<0.05) in strength than other groups performing either 2×30-40 RM or 1×100-150 RM. Only one group in the current study appears to have had a comparable training exposure to what was used in the Anderson and Kearney study, although the highest number of repetitions performed 15 16 was still substantially less than for Anderson and Kearney’s second group. Consequently, very few meaningful comparisons between studies are possible.

The training protocols used in the present investigation were more similar to those used by Stone and Coulter,20 but subjects in their study were all female. Fifty young women were used to investigate the effects of three set and repetition schemes on the development of both bench press and squat strength. Following 9 weeks of training (27 sessions), no differences (p>0.05) were found in bench press or squat 1 RM strength for groups who had performed either 3×6-8 RM, 2×15-20 RM, or 1×30-40 RM. In the present investigation, young men who trained using 9-10 RM for squats and 3-4, 9-10, and 15-16 RM for bench presses improved maximum force output significantly more (p<0.05) than a control group but only at the slowest testing velocity. No differences (p > 0.05)
between the control group and any of the training groups were apparent for peak force at any testing velocities faster than for the slowest measured.

In the Anderson and Kearney study, the number of repetitions used by two out of three training groups was far greater than was used in the present investigation. For the Stone and Coulter study, the repetitions were more comparable, but the gender was different. In both of the previous investigations, a control group was lacking and velocity-spectrum testing was not performed.

In 1962, Berger looked at all possible combinations of one, two, and three sets using two, six, and 10 RM for college men training three times per week for 12 weeks on the bench press. After analyzing the data using analysis of covariance (pretest was the covariate), he reported that three sets were always superior (p<0.05) to one or two sets and that 6 RM elicited the greatest strength increases (p<0.05) as compared to 2 RM and 10 RM.

In 1963, Berger manipulated repetitions in a manner similar to that done in the present study. In his study, young men completed nine weeks (27 sessions) of heavy-resistance training consisting of either 6×2 RM, 3×6 RM, or 3×10 RM. Strength was assessed on the bench press using 1 RMs and data were analyzed using analysis of covariance with pretest performance serving as the covariate. He reported no significant differences (p>0.05) between training groups.

O’Shea conducted a six-week (18 sessions) training study similar to Berger’s 1963 study except the training lift was the squat instead of the bench press, his second group of college men performed sets of 5 RM instead of 6 RM, and each group performed 3 sets. The results corroborated Berger’s findings in that no differences (p>0.05) between training groups were found. Neither Berger nor O’Shea utilized control groups in their respective studies.

Withers also conducted a 9-week (18 sessions) study in which young men participated in one of the following training groups: 3×7 RM, 4×5 RM, or 5×3 RM. Strength (1 RM) was assessed for the arm curl, bench press, and deep squat. Results suggest no differences in post-test performance existed when expressed as a strength to body weight ratio. It is unclear what effect the variations in set number had on strength improvement.

Finally, Weiss, Coney and Clark used a single-joint isokinetic device to assess changes in peak torque of the knee extensors and flexors at 60 and 300°·sec⁻¹ subsequent to 7 weeks of heavy-resistance squat training (21 sessions) involving four sets of either 3-5 RM, 13-15 RM, or 23-25 RM. They reported significant increases (p<0.01) by all three training groups in knee extension peak torque at 60°·sec⁻¹ as well as in 1 RM squatting performance. In addition, squatting 1 RM was higher (p<0.05) in the group training with 3-5 RM than in the group using 23-25 RM. Vertical jump, fast velocity knee-extension performance, and knee flexion at either velocity were unaffected by any of the training programs. Although a control group was used in this study, the brief training phase may have been inadequate for some variables to discriminate between the respective training regimens since subjects were initially untrained. However, as in the present investigation, strength was only increased at slow velocities (knee extension peak torque at 60°·sec⁻¹ and 1 RM squat). It would appear, then, that at least over the short term with previously untrained subjects, that the traditional lifts (excluding Olympic lifts) have a positive impact primarily on slow-velocity strength.

Previous studies concerned with repetition manipulation during DCER training have not assessed changes in muscular power. Since success in many performances is dependent upon power, this absence of information needs to be addressed using both single- and multiple-joint models.

In the present study, the nature of power changes was noticeably different than what transpired for force. Significant (p<0.05) power improvements for bench presses and squats occurred over the entire velocity spectrum for groups performing 10 or less repetitions per set except for the fastest bench press test at which only the group training with 3-4 RM improved more than the controls. Clearly, when VR equipment is used over a 12-week (36 sessions) time span in a manner as described in this report, power improvements are diminished as repetitions exceed ten. Since power was apparently not assessed in previous studies in which DCER repetition numbers were manipulated, no comparable studies are presented.

Due to somewhat equivocal findings in the present investigation for force improvements consequent to the various repetition schemes, a definitive conclusion concerning repetition manipulation is unwarranted. Bench press results appear to corroborate most previous reports in that no distinctions between the
various repetition schemes made a difference in improvement of maximal force output. This is further supported in that DCER 1 RMs for bench presses are characteristically slow in nature and improvements in the present study occurred only at the slowest velocity tested. For squats, only the group performing 9-10 RM experienced improvements significantly greater than the control group. Other studies in which squat performance was assessed found no differences in strength changes as long as repetitions were held at 40 or below. As with the bench press, DCER 1 RMs for squats are characteristically slow in nature and the group experiencing an improvement did so at only the slowest test velocity.

Within the constraints of the present investigation, it appears that participation by novice lifters for three months in multiple-set maximal variable-resistance weight training elicits improvements only for slow-velocity tests. At the same time and under identical training conditions, mechanical power appears to increase across a velocity spectrum for squats and bench presses when 10 RM or less are performed per set. In the current study, the "sample size was small, all subjects were young men, and training was performed on VR equipment; therefore, subsequent research is needed concerning the effects of repetition manipulation on maximum muscular force and power to further clarify these phenomena.

References