Effects of Three Resistance Training Programs on Muscular Strength And Absolute and Relative Endurance

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The effects of three resistance training programs on muscular strength and on absolute and relative muscular endurance were investigated. Forty-three male college students were randomly assigned to the training protocols. The high resistance-low repetition group \( (n = 15) \) performed three sets of 6-8 RM (repetition maximum) per session. The medium resistance-medium repetition subjects \( (n = 16) \) trained by doing two sets of 30-40 RM per session, while the low resistance-high repetition group \( (n = 12) \) used a single set of 100-150 RM. All subjects trained with the bench press exercise three times per week for nine weeks. Tests of strength (1-RM), absolute and relative endurance were administered before and after training. Statistical analyses revealed that the 20% improvement in maximum strength by the high resistance-low repetition group was greater than the 8 and 5% gains reported for the medium resistance-medium repetition and low resistance-high repetition groups, respectively. Relative to absolute endurance, however, the 41 percent and 39 percent improvements registered by the low resistance-high repetition and medium resistance-medium repetition groups, respectively, were not significantly greater than the 28% gain reported for the high resistance-low repetition group. Results for the relative endurance test revealed that the high resistance-low repetition group's performance actually decreased by 7% after training, and was significantly poorer than the 22% and 28% improvements made by the other two groups. It was concluded that human skeletal muscle makes both general and specific adaptations to a training stimulus, and that the balance of these adaptations is to some extent dependent upon the intensity and duration of the training protocol used.

**Key Words:** muscular strength, muscular endurance, strength training, endurance training, specificity of training, training intensity, training duration.

It is well recognized that resistance training can enhance muscular performance. Many studies have demonstrated improvements in strength and/or muscular endurance following resistance training. The classic work in this area was done by DeLorme (1945), who maintained that high resistance-low repetition exercises build powerful muscles, whereas low resistance-high repetition exercises produce the quality of endurance, suggesting a functional and specific relationship between training stimulus and response. This contention has been supported from a performance standpoint by the work of Berger (1962), Berger and Hardage (1967), Penman (1969), and Petersen and others (1961). Berger demonstrated that three sets of 4-8 repetitions per set with as much resistance as could be handled produced optimal strength gains. Berger and Hardage (1967) showed that lifting maximum loads for each of ten repetitions produced greater gains in strength than performing ten repetitions with 10-RM. Penman (1969) measured acquisition of leg strength in subjects trained by dynamic leg extensions against a resistance allowing only 12 repetitions, maximal effort isometric leg extensions, and running up and down stadium bleachers. He found that the smallest gains in strength were made by those subjects trained by running bleachers. Petersen and others (1961) found that when subjects exercised at the same relative intensity, gains in muscular endurance paralleled the number of repetitions completed per training session.

The majority of studies which have assessed the biochemical adaptation to exercise have also supported the original observations of DeLorme (1945). The results have shown that low intensity-long duration training increases the activity of aerobic enzymes, whereas high intensity-short duration training increases the activity of anaerobic enzymes.

The observations of DeLorme have not gone unchallenged. DeLateur, Lehmann and Fordyce (1968) tested the DeLorme axiom with four groups of subjects, two of which were trained with a high resistance...
(25 kg), low repetition program, while the other two were trained with a low resistance (11.35 kg), high repetition program. The results revealed that those who were trained for strength gained as much endurance as those who were trained for endurance, and those who were trained for endurance gained as much strength as those who were trained for strength. The authors suggested that to produce both strength and endurance, choice of weights is not of prime importance as long as the repetitions are continued to the point of fatigue. Work by Clarke and Stull (1970) and Stull and Clarke (1970) comparing the effects of a high resistance-low repetition program and a low resistance-high repetition program has suggested that the primary effect of both programs was the enhancement of muscular strength.

In order to resolve this conflict, it was the purpose of the present study to directly test the hypothesis that adaptations in muscle performance are a function of the training protocol. More specifically, the purpose of the study was to determine the effects of three different resistance training programs: (1) high resistance-low repetition; (2) medium resistance-medium repetition, and (3) low resistance-high repetition on maximum strength as well as absolute and relative muscular endurance.

Methods

Subjects

Forty-three normal, healthy, untrained subjects were voluntarily recruited from the undergraduate student population at the University of Kentucky. All subjects read and signed an informed consent form. For the purpose of the present study, subjects were considered untrained if their 1-RM in the bench press was less than 120% of their body weight. The mean and standard deviation for the physical characteristics of the subjects were as follows: age: 20.65 ± 1.79 years; height: 1.80 ± .13 meters; and weight: 75.08 ± 3.91 kilograms.

Criterion Variables

The bench press was the exercise selected for use in all testing and training procedures. This exercise was chosen because it was familiar to the subjects, easily administered, and has been shown to be a valid and reliable measure of muscular function (Berger, 1962). Prior to pre-testing, all subjects participated in a familiarization session to acquaint them with the specific testing and training procedures to be used.

Maximum strength was assessed by determining each subject's 1-RM bench press. Each subject attempted successive bench presses, starting at a weight agreed upon by both subject and investigator, and increasing or decreasing incrementally until two consecutive unsuccessful trials occurred. Strict form was required for all lifts, and three minutes were allowed for recovery between trials. Sixty percent of the subjects reached 1-RM in four trials, 30% required five trials, while the remaining 10% used six trials.

The maximum number of repetitions that each subject was able to perform, against a resistance equaling 40% of his own 1-RM, done at a rate of 40 repetitions per minute, served as the test of relative endurance. Absolute endurance was assessed similarly with all subjects being tested using 27.23 kilograms. The resistance used for assessment of relative endurance was adjusted to the new 1-RM at the post-test, whereas the absolute task was done using 27.23 kilograms at both test periods. These values were chosen in an attempt to have the number of repetitions completed in the tests be reasonably central along the repetition continuum (Clarke and Irving, 1960). Each subject underwent two pre-test sessions and was randomly assigned to complete the absolute endurance test (one session) or both the 1-RM and relative endurance tests (the other session). This same randomization procedure was used to assign subjects to their post-tests, which were administered one or two days following the final training session. The tests and procedures used in post-testing were identical to those used in pre-testing.

Training Procedures

The three training programs selected represented distinct positions along the resistance training continuum. The protocols selected were therefore variable relative to intensity-duration tradeoff, muscle tension requirements, fatigue rate, and ultimate degradation of the muscle's contractile ability. The high resistance-low repetition program consisted of three sets of 6-8 repetitions per training session (Berger, 1962). The resistance for each set was selected such that maximum performance was limited to 6-8 repetitions. Once a subject completed more than eight repetitions in a set, the resistance used in that set was incremented by five pounds (2.27 kg). The low resistance-high repetition training program consisted of one set of 100-150 bench presses performed at a rate of 40 per minute. The medium resistance-medium repetition regimen involved two sets of 30-40 repetitions per session. Repetitions were done at a rate of 40 per minute. In the case of the high resistance-low
repetitions and medium resistance-medium repetitions groups, two minutes were allowed between successive sets. With each of the protocols, the weight used in each session was selected such that maximum performance was limited to the desired number of repetitions; 6-8, 30-40, or 100-150. The resistance used was also progressively incremented (2.27 kg) each time a subject successfully completed more than the upper limit number of bench presses.

Subjects were randomly assigned to protocols high resistance-low repetitions (n = 15), medium resistance-medium repetitions (n = 16) and low resistance-high repetitions (n = 12), and trained three times per week for nine weeks. An attempt was made to have subjects maintain a schedule so that one rest day occurred between each two training sessions. In no cases were subjects permitted to train on three consecutive days.

Statistical Analysis

Mean, standard deviation, and standard error of the mean were calculated for subject characteristics and performance variables. To ascertain the overall effects of treatments a two-way (group x tests) ANOVA with repeated measures across tests was employed. To further elucidate the specific locations of significance, one-way ANOVAs and tests for the simple main effects were conducted. The Tukey w-procedure post hoc test was used to identify significantly different group means. An α = .05 probability level was used for all tests of statistical significance.

Results

The descriptive statistics presented in Table 1 reveal that all three groups improved in muscular strength and absolute endurance as a result of training. Gains in relative muscular endurance were also recorded for the medium resistance-medium repetition and low resistance-high repetition groups. The gains in maximum strength ranged from 13.70 kilograms, 20.22% for the high resistance-low repetitions group, to 3.22 kilograms, 4.92% for the low resistance-high repetitions group. In the case of absolute endurance these two groups responded conversely with the low resistance-high repetitions group improving 41.30% while the high resistance-low repetitions group gained 23.58%. Scores on the relative endurance task revealed that the low resistance-high repetition group improved the most. Initially they performed a mean of 37.50 repetitions, and after training completed 48.17. This gain is in contrast to the performance of the high resistance-low repetition group. This group performed a mean of 2.81 fewer repetitions, −6.99%, on the posttest than they had completed before training. The gains in muscular strength and absolute muscular endurance as a function of position on the resistance-repetition continuums are presented in Figure 1.

Table 1

Descriptive Statistics for Maximum Strength, Absolute Endurance, and Relative Endurance

<table>
<thead>
<tr>
<th>Training Regimen</th>
<th>Maximum Strength</th>
<th></th>
<th>Absolute Endurance</th>
<th></th>
<th>Relative Endurance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>% Change</td>
<td>Pre</td>
<td>Post</td>
<td>% Change</td>
</tr>
<tr>
<td>High resistance-low repetition</td>
<td>67.73</td>
<td>81.43</td>
<td>20.22</td>
<td>40.46</td>
<td>50.00</td>
<td>23.58</td>
</tr>
<tr>
<td>Low repetition</td>
<td>±4.30</td>
<td>±5.04</td>
<td></td>
<td>±11.88</td>
<td>±9.63</td>
<td></td>
</tr>
<tr>
<td>Medium resistance-medium repetition</td>
<td>65.96</td>
<td>71.38</td>
<td>8.22</td>
<td>36.81</td>
<td>51.25</td>
<td>39.23</td>
</tr>
<tr>
<td>Medium repetition</td>
<td>±5.18</td>
<td>±4.06</td>
<td></td>
<td>±8.71</td>
<td>±10.36</td>
<td></td>
</tr>
<tr>
<td>Low resistance-high repetition</td>
<td>65.44</td>
<td>68.66</td>
<td>4.92</td>
<td>35.33</td>
<td>49.92</td>
<td>41.30</td>
</tr>
<tr>
<td>High repetition</td>
<td>±5.03</td>
<td>±4.91</td>
<td></td>
<td>±12.08</td>
<td>±15.31</td>
<td></td>
</tr>
</tbody>
</table>

*Values reported as means and standard deviations. For maximum strength the statistics reported are in kilograms lifted; absolute and relative endurance values are reported in number of repetitions completed.
Figure 1—Responses of maximum strength and absolute muscular endurance as a function of position on the resistance-repetition continuums.

In order to elucidate the specific nature of relative effects of the three training regimens on muscular performance characteristics, a combination of analyses for the simple main effects and the Tukey w-procedure was applied.

As revealed in Table 2, each of the groups demonstrated significant tests for the simple main effect for strength gains with training. The variable nature of

<table>
<thead>
<tr>
<th>Variable and Level</th>
<th>Simple Main Effects, F</th>
<th>Group Means</th>
<th>Differences Between Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F Tests at HR-LR</td>
<td>104.78*</td>
<td>81.43</td>
<td>10.05**</td>
</tr>
<tr>
<td>F Tests at MR-MR</td>
<td>17.46*</td>
<td>71.38</td>
<td>2.72</td>
</tr>
<tr>
<td>F Tests at LR-HR</td>
<td>4.61*</td>
<td>68.66</td>
<td></td>
</tr>
<tr>
<td>Absolute Endurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F Tests at HR-LR</td>
<td>23.95*</td>
<td>50.00</td>
<td>1.25</td>
</tr>
<tr>
<td>F Tests at MR-MR</td>
<td>58.59*</td>
<td>51.25</td>
<td>1.33</td>
</tr>
<tr>
<td>F Tests at LR-MR</td>
<td>44.84*</td>
<td>49.92</td>
<td>.08</td>
</tr>
<tr>
<td>Relative Endurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F Tests at HR-LR</td>
<td>2.00</td>
<td>38.07</td>
<td>9.99**</td>
</tr>
<tr>
<td>F Tests at MR-MR</td>
<td>20.16*</td>
<td>48.06</td>
<td>.11</td>
</tr>
<tr>
<td>F Tests at LR-HR</td>
<td>22.16*</td>
<td>48.17</td>
<td>.11</td>
</tr>
</tbody>
</table>

| HR-LR—High resistance-low repetition |  | *Significant at α = .05. |
| MR-MR—Medium resistance-medium repetition |  | **Significant using Tukey's w-procedure, α = .05. |
| LR-HR—Low resistance-high repetition  |  |                          |

Figure 1—Responses of maximum strength and absolute muscular endurance as a function of position on the resistance-repetition continuums.
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this response, suggested by the significant groups by test interaction, is clarified by the application of the Tukey w-procedure to the post-test means. This analysis revealed that the high resistance-low repetition group was significantly stronger than the other two groups that were similar to each other.

Although the percentages of improvement in absolute endurance revealed by the three groups varied, the lack of a significant groups by test interaction, the similar F-ratios for the tests for the simple main effects, and the non-significant Tukey results suggest that these responses were essentially parallel in nature.

The three training groups responded differently in terms of relative endurance. The location of the significant groups X test interaction is demonstrated in Table 2. The high resistance-low repetition group did not improve significantly on relative endurance and was significantly different at the post-test than the other two groups that were similar at the post test, and did reveal significant simple main effects for gains in relative endurance.

Discussion

Although the results of the two-way ANOVA on maximum strength failed to reveal among group differences, consideration of the significant groups X test analysis, the tests of simple main effects and the application of the Tukey w-procedure leads to the conclusion that the groups responded differently to training. The high resistance-low repetition group that employed three sets of 6-8 RM as its training regimen made greater strength gains than either of the other groups. This finding supports the original contention of DeLorme (1945) and numerous more recent searches in strength development (Berger, 1962; Berger & Hardage, 1967; Petersen and others, 1961) and is graphically presented in the upper portion of Figure 1.

There appear to be a number of theoretical bases upon which these findings can be based. Muscle tension alone, with no influence from neural or blood flow factors, has been shown to increase the rate of incorporation of amino acids into proteins, and thus cause hypertrophy (Buresova, Gutman, and Klicpera, 1969; Schiaffino and Hanzlikova, 1970). Penman (1970) has demonstrated a "packing effect" of actin and myosin filaments with high-tension training. This ultrastructural change may improve the capability of the meromyosin cross bridges of developing force.

Another tentative explanation for the results would be to consider the recruitment patterns of the involved motor units. Since the maximum strength test was far more similar to the training load used by the high resistance-low repetition group, it is conceivable that the specific pattern and rate of neural discharge required to exert maximum strength was selectively trained by this group (Milner-Brown, Stein, & Yemm, 1973a,b; Ikai and Fukunaga, 1970).

Biochemically, strength of a muscle is dependent upon its ability to activate large amounts of ATP in a short period of time. The work of Thorstensson and others (1976), MacDougall and others (1977), and Costill and others (1979) has shown that high-intensity, short-duration training does indeed enhance the ability of a muscle to activate and resynthesize large amounts of ATP in a short period of time. Those motor units which are biochemically and ultrastructurally specialized for producing large amounts of tension (FT units) have been shown to increase in size with high-intensity, low-duty training (Thorstensson, Sjodin and Karlsson, 1975; Costill and others, 1979; Edstrom and Ekblom, 1972; Gollnick and others, 1972). It is feasible that all of these mechanisms could be activated by high-resistance, low-repetition resistance training such as that employed in this study.

Using the same logic to consider the results of the analyses of changes in relative endurance reveals that the high resistance-low repetition protocol was significantly inferior to the two higher repetition programs. This finding supports the assertion that low weight, high repetition exercises produce the quality of endurance. It would seem that the mechanisms producing the enhancement of the activities of those enzymes associated with endurance are more dependent on the duration of the exercise than on maximal intensity. The work of Gordon, Kowalski and Fritts (1967), showing that forceful exercises increase myofibrillar protein and repetitive exercises increase the concentrations of energy-liberating enzymes, supports this idea, as does the work of many authors who agree that short, intense activities increase the anaerobic capacity of muscles, while longer and less intense activities increase the aerobic capacity of muscle.

Since the training protocol used by the medium resistance-medium repetition and low resistance-high repetition groups was very comparable to both the muscular endurance tests, a portion of the performance improvement observed may be attributed to

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1The 7% decline in relative endurance performance by the high resistance-low repetition group must be viewed in light of the fact that maximum strength increased by 20% and thus the load used for the relative endurance test was higher.
acquisition of appropriate neural coding. This assertion may be supported by the work of Milner-Brown, Stein and Yemm, 1973, and Ikai and Fukunaga, 1970.

The extent of fatigue induced by the different programs may also contribute to the different training effects. At the end of a set the subjects in the low resistance-high repetition group were fatigued to the point at which they could no longer lift a weight ranging from 11.5 to 20.5 kilograms. On the other hand, subjects in the high resistance-low repetition group were only fatigued to the point at which they could no longer lift weights ranging from 47.7 to 88.5 kilograms. Thus, one would suspect that the subjects in the first group had experienced a greater perturbation of the homeostatic state of the muscle.

Although there was not a significant difference among groups with respect to absolute endurance, the medium resistance-medium repetition and low resistance-high repetition groups did exhibit more improvement, 39.2% and 41.3%, respectively, than did the high resistance-low repetition group, 23.6%. It is also interesting to note the trend toward gains in both relative and absolute endurance, paralleling the number of repetitions per training session (Petersen and others, 1961) with the high resistance group (18-24 repetitions per session) showing the smallest gains (and actually decreasing in relative endurance), medium resistance-medium repetition group (60-80 repetitions per session) showing intermediate gains, and the low resistance-high repetition group (100-150 repetitions per session) showing the largest gains. These results further support the contention that those mechanisms which enhance endurance depend more on duration than on maximal intensity.

Although all training protocols employed in the present investigation elicited gains in both muscular strength and absolute muscular endurance, (refer to Figure 1), the results do not support the results of DeLateur, Lehmann, and Fordyce (1968), Clarke and Stull (1970), and Stull and Clarke (1970). These earlier studies each reported similar responses to varying training regimens. In the case of the DeLateur, Lehmann, and Fordyce study the resistances used for training the knee extensors were rather modest, 25 and 11.35 kg, and thus the training stimulus applied to the "strength" group and the "endurance" group may have been quite similar. Comparison with results of the works of Clarke and Stull (1970) and Stull and Clarke (1970) must acknowledge at least three major procedural differences: (1) the different training programs used for "strength" development, (2) the varying criterion tests, and (3) the fact that different muscle groups were trained. The high resistance-low repetition protocol employed in the Clarke and Stull investigation was three sets of 10-RM using progressive loads of 50, 75, and 100% of 10-RM. A regimen of this type may be less effective for eliciting the development of maximum strength than the protocol employed in the present work (Berger, 1962; and Berger & Hardage, 1967). The criterion test employed in the Clarke and Stull studies was a five-minute rhythmic isometric elbow flexion task.

**Summary**

In summary, the results of the current investigation support original assertions by DeLorme and in general the concept of specificity of training for acquisition of muscular strength and muscular endurance. The reader should note, however, that with the exception of the relative endurance task for the high resistance-low repetition group, all training protocols demonstrated significant improvements on each of the three criterion tests. Therefore, in designing a resistance training program one may adjust the resistance and repetitions used to optimize specific outcomes with confidence that concomitant gains will be made in muscular strength or muscular endurance.

**References**


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