EFFECTS OF VOLUME AND EXERCISE COMPLEXITY ON NEURAL
ADAPTATIONS, STRENGTH GAINS AND LEAN BODY MASS
IN UNTRAINED ADULTS

A MANUSCRIPT STYLE THESIS PRESENTED
TO
THE GRADUATE FACULTY
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MASTER OF SCIENCE DEGREE

BY
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ABSTRACT


This study was designed to examine the effects of a 12-week resistance-training program using single vs. multiple sets of a complex vs. simple exercise. Twenty-eight untrained men (n=15) and women (n=13) (mean age 21.6 ± 2.5) performed several resistance exercises twice per week: a complex movement, the leg press (LP), and a simple movement, the biceps curl (BC). Group one (S-1, n=9) performed one set of each exercise, group two (M-6, n=9) performed six sets of the same exercises, and group three (control, n=10) was the control group. One-repetition maximums and EMG were measured in the LP and BC during pre-, mid-, and post-training. Lean body mass of the legs and arms were measured pre- and post-training by dual energy x-ray absorptiometry (DEXA). Results of the study indicated that both S-1 and M-6 groups significantly increased percentage strength pre- to post-training in both the LP and BC (S-1 pre-post LP=41.2% ± 23.7%, BC=8.5% ± 6.71%), (M-6 pre-post LP=52.6% ± 12.6%, BC=22.8% ± 15.6%). However, compared to S-1, M-6 showed a significantly greater increase in percentage strength in the BC (p=0.05) from pre- to post-testing. Results also showed that M-6 produced a significant increase in biceps (single-joint) muscle EMG adaptations pre- to mid-testing (p=0.05) compared to S-1. There were no significant differences found in lean muscle mass percent increases for the legs or arms in either training group (p  0.05). The data from this study suggest that multiple sets produce greater increases in percentage strength gains for simple exercises in untrained adults. It is possible that neural mechanisms are responsible for the observed differences.
Candidate: John B. Blaak

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Human Performance

The candidate has successfully completed the thesis final oral defense.

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Department: ___________________________  Date: ___________________________

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Director of University Graduate Studies  Date: ___________________________
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INTRODUCTION

The effective amount of resistance training volume for optimal strength gains continues to be debated in the strength and conditioning and fitness professions. In addition, the relationship between volume and exercise complexity has not been addressed in past research. The predominant recommendation has been to perform multiple sets (MS), 3 sets or more of a resistance exercise rather than one single set (SS), to effectively increase one’s training adaptations (2,7,10,11,12,16,17). These adaptations include increases in muscular hypertrophy, strength and endurance. One SS to failure resistance training has been suggested by some researchers to be as effective as MS (3,6,18,19,20). Carpinelli et al. (3) have interpreted from a review of literature that there are no significant differences in strength and hypertrophy gains using either training volume (SS or MS). Therefore, the belief that MS protocols are superior to SS may not be scientifically conclusive.

Single Set Effectiveness. A study by Hass et al. (9) examined the effects of SS vs. MS sets in recreation weightlifters with 4-6 years of weight training experience. Each participant was assigned to a training group and completed a corresponding circuit-training program. SS subjects performed a SS of each exercise. MS subjects went through the entire circuit, rested 3 minutes, and repeat the circuit again twice, each time with a 3-minute rest between each circuit. Results of this study suggest that no significant differences between the
groups existed and that even after a year of training, one SS is still effective. However, the fact that the MS group did not perform multiple sets of the same exercises consecutively questions the validity of the multiple set group results. A study by Starkey et al. (18) also concluded one set to failure to be as effective as three sets in increasing muscle thickness, knee extension and knee flexion isometric torque. Several other studies have also shown no significant differences between the effectiveness of using a SS to failure or MS training programs (3,6,19,20).

_Multiple Set Effectiveness._ Although almost any type of resistance training can increase strength in untrained persons, MS have been shown to produce superior strength gains over a SS to failure over a longer period of time (2,7,10,11,16,17). Kraemer et al. (11) compared the effectiveness of one SS versus MS on 1RM back squat. Subjects were randomly divided up into one of three training programs. The SS group performed one set of 8-12 repetitions to failure, while the MS group performed three sets of 10 repetitions, and the multiple set varied (MSV) group performed a varied multiple set/repetition training protocol. There were no significant differences found in body composition or body mass changes. However, there was a significant increase in squat 1RM, with the MS and MSV groups producing approximately 50% greater gains in strength over the SS during the 14 weeks of the study. Therefore, this finding suggests that training using MS produces a superior rate of strength gains over one set to failure. A study by Gotshalk et al. (7) examined the differences in
resistance volume (SS vs. MS) on growth hormone, testosterone, cortisol, and whole blood lactate levels. It was found that the MS training programs caused a significant increase in post-workout circulating growth hormone levels, suggesting that a higher volume of training may produce greater increases in training adaptations.

*Exercise Complexity.* Single vs. multiple joint exercises have been shown to affect the time course of neuromuscular adaptations. A study completed by Chilibeck et al. (5) examined the effects of complexity of the exercise task on muscular hypertrophy and rate of nervous system adaptations. Results of this study showed there was a greater initial rate in neuromuscular adaptation followed by a quicker muscle hypertrophy adaptation when performing a simple exercise, namely, the biceps curl (BC). However, when performing a complex movement, the leg press (LP), this caused a greater delayed rate in neuromuscular adaptations which correlated to a delayed increase in muscular hypertrophy. This study appears to suggest that both volume and complexity may have a combined effect on the neuromuscular rate of adaptation, causing muscular hypertrophy and muscular strength gains. Rutherford and Jones (13) have suggested that with an increase in the complexity of a movement, multi-joint vs. single joint, there is a delay in the motor learning and coordination ability of the muscles during a complex exercise – especially in the early stages of training.
The purpose of this study was to examine the effects of exercise volume and complexity on the rate of neuromuscular adaptations, strength gains and lean body mass changes in untrained adults. A limited amount of research is available on the interaction of training volume and exercise complexity on neuromuscular adaptations. Single set vs. multiple set studies have been previously completed, but additional data is still required to better determine the best amount of training volume for optimal strength gains.

METHODS

Subjects

This study involved twenty-eight untrained men (n=15) and women (n=13) (mean age 21.6 ± 2.5) who performed several resistance exercises twice per week. Untrained subjects had not participated in a structured weight-training program for at least six months prior to the subject selection date. Each subject was required to fill out a medical history/exercise history questionnaire. A physician and an exercise specialist screened the questionnaires. The information attained was used to determine if there were any individuals with limitations for participating, and, if so, they were excluded from the investigation. Approval by the Institutional Review Board for the protection of human subjects of the University of Wisconsin-La Crosse was obtained before the investigation. All subjects were informed of any risks associated with participation in the study and signed an informed consent (Appendix A) prior to participating in any of the testing and/or training. Table 1. describes the subjects' characteristics.
Table 1. General Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>9</td>
<td>22.09 ± 3.43</td>
<td>172.83 ±10.47</td>
<td>83.74 ± 29.44</td>
</tr>
<tr>
<td>M-6</td>
<td>9</td>
<td>20.04 ± 1.22</td>
<td>169.44 ±11.79</td>
<td>70.68 ± 23.03</td>
</tr>
<tr>
<td>Control</td>
<td>10</td>
<td>22.43 ± 1.89</td>
<td>171.30 ± 7.21</td>
<td>70.55 ± 7.77</td>
</tr>
</tbody>
</table>

Study Design

This longitudinal study was designed to examine the effects of a 12-week resistance-training program using SS vs. MS of a complex vs. simple exercise. One exercise consisted of a complex movement (leg press, (LP)) and the second one of a simple movement (biceps curl, (BC)). Subjects were randomly assigned to one of three groups: S-1, M-6 or control. The first group (S-1, n=9) completed single sets of the selected exercises using 10RM on day 1 and 6RM on day 2 as their training intensity. The second, group (M-6, n=9) completed multiple sets (six and three sets) using 10RM and 6RM as their training intensity. The control group (control, n=10) was only pre- and post-tested. A study by Chestnut and Docherty (4) suggested that 4RM and 10RM training intensity with an equal training volume produced similar neuromuscular adaptations over 10 weeks. However, this present study compared unequal training volumes when using 10RM and 6RM. Two testing periods were completed initially before training began (Day 1 and Day 2). Day 1 consisted of both body composition and bone
mineral density analysis. Day 2 consisted of 1RM testing for the LP and BC. During the 1RM LP electromyography (EMG) was collected from the right vastus medialis (VM) and vastus lateralis (VL). During the 1RM BC EMG was collected from the right biceps brachii (BB). Before completing 1RM testing subjects were allowed to ride a stationary bike for 5 to 10 minutes.

**Training Protocol**

The training program consisted of the following exercises in the following order: leg press, biceps barbell curls, chest flye, abdominal sit-ups and lower back hyperextensions. The LP and BC training intensities for both groups were 10RM on day 1 and 6RM on day 2. Exceptions for both training groups was made for abdominal sit-ups and lower back extensions in which 15RM was completed per number of set(s) for each group. The S-1 group performed one single set of each exercise with 2 to 3 minutes of rest between exercises. The M-6 group performed six sets of LP and BC. The remaining exercises (chest flye, abdominal sit-up, and hyperextension) were completed performing 3 sets of each. The M-6 group two was allowed 2 to 3 minutes of rest between each set of exercise and 2 to 3 minutes of rest between each of the exercises. Both groups performed each set(s) to the required intensity RM. Each training day subjects had their exercise weight and number of completed sets and reps recorded. Subjects were instructed not to perform any additional resistance exercises during the training period. Each subject was asked to keep a weekly record of
aerobic training and was not allowed to perform more than one aerobic workout per week.

**One Repetition Maximum Testing (1RM)**

One repetition maximum (1RM) was used to measure dynamic muscular strength of the legs and biceps. A number of warm-up trials were given in the 1RM test protocol using 30% (8-10 repetitions), 50% (4-6 repetitions), 70% (2-4 repetitions), and 90% (1 repetition) of an estimated 1RM from the subject's recommendations. At this point the weights were increased to a point where the individual reached his/her 1RM weight (UW-L, Musculoskeletal Research Center, Reliability Data, ICC (interclass correlation coefficient) = 0.998, %TEM (technical error of measure percentage) = 1.66). Subjects were required to lower the leg press so that the angle of the knee was at a minimum of 90 degrees, which was marked by adjustable spotters on the leg press machine. Subjects were required to curl the barbell with proper form (upper back against a wall to prevent assistance from the lower back). Adequate amount of recovery time was permitted between 1RM trials (3-5 minutes).

**Electromyography**

Electromyography was utilized during the 1 RM leg press and bicep barbell curl. A bipolar silver/silver chloride EMG surface electrode (Myotronics-noromed, Tukwila, WA) was attached over the belly of the vastus medialis and vastus lateralis muscle distal to the motor points for the LP 1RM. For the BC, the electrode was attached over the belly of the biceps brachii muscles distal to the
motor point. Each module contained two active electrodes and one reference electrode equidistant at two centimeters. All modules were appropriately applied to the target muscle with active electrodes aligned parallel to the muscle fibers. Electrode placement was carefully measured and marked to ensure placement in the exact same position for pre, mid and post testing. The amplified myoelectric signal (MEGA Electronics, Finland) was recorded using a computer and analog-to-digital card and processed using Peak Motus 6.0 (Peak Performance Technologies, Englewood, CO) and Data Pack 2000 2.0 (Run Technologies, Laguna Hills, CA) for analysis.

**Body Composition and Bone Density**

Total and regional body composition and bone mineral density (BMD) was measured by dual energy x-ray absorptiometry (DEXA) (Prodigy™, Lunar Corporation, Madison, WI). Images were analyzed using the Lunar Prodigy™ software (v. 2.05) for calculation of BMD (g/cm²) and % body fat and actual body fat (g). The regions included were the arms, legs, trunk, rib, pelvis, and spine for the BMD measures, and the arms, legs, trunk, and unilateral arms, legs, and trunk (right and left separately) for the body fat measures.

**Statistical Analyses**

A general linear model (GLM)-repeated measures analysis with Bonferroni post-hoc tests were used to determine within and between group differences. A one-way analysis of variance was used to determine significant differences between the groups in percentage change. The criterion alpha level was set at
\[ p \leq 0.05. \] All statistical analyses were performed through the use of a statistical software package (SPSS, Version 10.0, SPSS Inc., IL, USA).

RESULTS

Strength Changes

The 1RM biceps curl and leg press results are presented in Tables 2 and 3. Both S-1 and M-6 significantly increased in percentage strength pre-post training in both the BC (Figure 1) and LP (Figure 2) exercises (S-1 \text{ pre/post LP} = 41.2\% \pm 23.7\%, BC = 8.5\% \pm 6.71\%), (M-6 \text{ pre/post LP} = 52.6\% \pm 12.6\%, BC = 22.8\% \pm 15.6\%). However, compared to S-1, M-6 showed a significantly greater increase in percentage strength in the BC (Figure 1, \( p=0.05 \)) from pre- to post-testing. There were no significant differences between groups in percentage strength in the LP (Figure 2). No significant changes in strength were observed in the control group.

Table 2. 1RM Testing of the Biceps Barbell Curl (kg)

<table>
<thead>
<tr>
<th>Group</th>
<th>Biceps Curl Pretest</th>
<th>Biceps Curl Midtest</th>
<th>Biceps Curl Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>33.84 ± 12.57</td>
<td>36.36 ± 14.60</td>
<td>37.12 ± 15.12†</td>
</tr>
<tr>
<td>M-6</td>
<td>29.55 ± 10.29</td>
<td>32.32 ± 10.21</td>
<td>35.61 ± 10.84†</td>
</tr>
<tr>
<td>Control</td>
<td>30.23 ± 11.19</td>
<td></td>
<td>30.23 ± 11.24</td>
</tr>
</tbody>
</table>

† Indicates significant change \( (p<.05) \) from pretest.
Table 3. 1RM Testing of the Leg Press (kg)

<table>
<thead>
<tr>
<th>Group</th>
<th>Leg Press Pretest</th>
<th>Leg Press Midtest</th>
<th>Leg Press Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>242.93 ± 139.56</td>
<td>292.63 ± 149.12</td>
<td>324.24 ± 166.38†</td>
</tr>
<tr>
<td>M-6</td>
<td>191.16 ± 76.75</td>
<td>248.48 ± 116.91</td>
<td>293.43 ± 126.19†</td>
</tr>
<tr>
<td>Control</td>
<td>198.18 ± 52.10</td>
<td></td>
<td>208.41 ± 61.70</td>
</tr>
</tbody>
</table>

†Indicates significant change (p<.05) from pretest.

Figure 1. Percentage change in maximum biceps curl strength (1RM) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater percentage strength increase compared to SS group (p ≤ 0.05).
Figure 2. Percentage change in maximum leg press strength (1RM) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater percentage strength increase compared to SS group (p ≤ 0.05).

**Electromyography (EMG) Changes**

A significant difference was found within M-6 in pre and mid testing of biceps brachii maximum EMG (p=0.003) and biceps brachii average EMG (p=0.001). There were no significant differences found in quadriceps muscle (vastus medialis and vastus lateralis) EMG's within and between groups (see Figures 3, 4, 5, 6, 7 and 8).
Figure 3. Change in maximum biceps electromyogram (EMG) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater maximum EMG increase compared to the SS group (p ≤ 0.05).

Figure 4. Change in average biceps electromyogram (EMG) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater average EMG increase compared to SS group (p ≤ 0.05).
Figure 5. Change in maximum vastus medialis electromyogram (EMG) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater maximum EMG increase compared to SS group (p ≤ 0.05).

Figure 6. Change in average vastus medialis electromyogram (EMG) from before (Pre) to midway (Mid), Mid to after (Post) and Pre to Post training. * = significantly greater average EMG increase compared to SS group (p ≤ 0.05).
Figure 7. Change in maximum vastus lateralis electromyogram (EMG) from before (Pre) to midway (Mid), mid to after (Post) and Pre to Post training. * = significantly greater maximum EMG increase compared to SS group (p ≤ 0.05).

Figure 8. Change in average vastus lateralis electromyogram (EMG) from before (Pre) to midway (Mid), mid to after (Post) and Pre to Post training. * = significantly greater average EMG increase compared to SS group (p ≤ 0.05).
Lean Mass Changes

Results of lean mass measurements are presented in Tables 4 (arms) and 5 (legs). There were no significant differences in lean muscle mass gains for either the arms (Figure 9) or legs (Figure 10) within and between groups S-1, M-6 and Control (p≤0.05).

Table 4. Average Lean Mass Measurements of the Arms (kg)

<table>
<thead>
<tr>
<th>Group</th>
<th>Arms Pretest</th>
<th>Arms Posttest</th>
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</thead>
<tbody>
<tr>
<td>S-1</td>
<td>6.60 ± 2.51</td>
<td>6.59 ± 2.53</td>
</tr>
<tr>
<td>M-6</td>
<td>5.95 ± 2.00</td>
<td>5.94 ± 1.90</td>
</tr>
<tr>
<td>Control</td>
<td>6.00 ± 1.87</td>
<td>5.79 ± 1.66</td>
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Table 5. Average Lean Mass Measurements of the Legs (kg)

<table>
<thead>
<tr>
<th>Group</th>
<th>Legs Pretest</th>
<th>Legs Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>19.60 ± 6.60</td>
<td>19.55 ± 6.27</td>
</tr>
<tr>
<td>M-6</td>
<td>16.78 ± 3.67</td>
<td>17.64 ± 4.66</td>
</tr>
<tr>
<td>Control</td>
<td>17.44 ± 34.88.01</td>
<td>17.45 ± 3.82</td>
</tr>
</tbody>
</table>
Figure 9. Percentage change in lean mass of the arms (kg) from before (Pre) to midway (Mid), mid to after (Post) and Pre to Post training. * = significantly greater lean mass increase compared to SS group (p ≤ 0.05).

Figure 10. Percentage change in lean mass of the legs (kg) from before (Pre) to midway (Mid), mid to after (Post) and Pre to Post training. * = significantly greater lean mass increase compared to SS group (p ≤ 0.05).
DISCUSSION

A greater training volume (M-6) promoted significantly greater percentage strength gains in the BC. This occurred in the single joint exercise most likely as a result of greater increases in maximum and average EMG in the M-6 group. It is unclear what mechanism allowed for greater gains in strength in the multi-joint exercise, since no differences in EMG changes or body composition were observed. A particularly interesting finding is that strength gains within the first six weeks were similar between the two groups with observed differences occurring primarily during the second six weeks of training.

Results of this study support research conducted by Chilibeck et al. (5) that showed there was a greater initial rate in neuromuscular adaptations with the BC (simple) exercise. However, in this case, only the MS group showed a significant increase in neuromuscular adaptations when comparing SS vs. MS of training. M-6 had a significant increase in both max EMG and average EMG pre and mid training. The physiological mechanisms involved in producing the strength gains in the BC would have to be neural changes as there were no significant increases in muscle mass in the biceps brachii. It is speculated that possible neural mechanisms could include an increase in motor unit recruitment and/or increased frequency of stimulation in the biceps brachii muscle (8,14). The increased recruitment of the biceps brachii may have involved an increase in the recruitment of higher force producing fast-glycolytic (type IIb) fibers.
On the other hand, the LP (complex) demonstrated no significant neuromuscular adaptations within or between groups. Increases in force output in larger muscles have been found to be a result of increases in motor unit recruitment (1). Rutherford and Jones (13) have suggested that multi-joint exercises require a longer rate of learning and coordination. This appears to be true in the current study as the biceps had a quicker rate of nervous system adaptations. Behm (1) has suggested that maximal resistance, low repetitions (less than 6), and long rest periods should be used to optimally promote neural adaptations. In this study, the training repetitions were set at 10RM day one and 6RM day two, and therefore, the lack of neural adaptations in the legs could have been a result of not training in the optimal neural adaptation zone. A study by Chestnut and Docherty (4) examined the effects of training with a 10RM vs. 4RM, and they found that both produce similar increases in neuromuscular adaptations, strength, and muscle hypertrophy. Regardless, the current data suggests that using a greater training volume promotes a faster rate of neural adaptations for a simple exercise.

Neither training volume, S-1 nor M-6, promoted a significant hypertrophy response in the arms or legs from pre to post training. Training frequency (twice vs. three times/week) and/or training study length (less than 12 weeks) may have influenced this outcome. Whether longer training would promote significant differences in lean mass changes when comparing multiple vs. single sets is yet to be determined. Research has shown that a training frequency of 2 days a
week promotes increases in muscle hypertrophy (15). Chilibeck et al. (5) reported similar findings when their study subjects used exercises that trained the same muscles. Therefore, for the present study, careful selection of exercises was taken into consideration to promote accurate lean muscle and EMG measurements. Subjects performed only the leg press (complex), biceps curl (simple) and alternated performing the chest flye and/or reverse flye plus one abdominal or lower back exercise every two weeks.

When comparing percentage gains made pre and mid testing, both groups increased in percentage strength nearly at the same rate in the LP (S-1: 26.56% vs. M-6: 27.73%). These results suggest that initially any type of training volume may promote similar percentage strength increases. Similar findings have previously been described by DeHoyos et al. (6) and Stowers et al. (19). However, it was observed that S-1 had a greater decrease in rate of percentage strength increase mid and post testing for the BC. Although not significantly different, there appears to be a larger drop in the rate of strength improvement using a SS training protocol in 6 weeks of training. Nevertheless, the decrease in SS effectiveness over time is where the current assertion favoring MS appears to be founded when comparing the effectiveness of SS vs. MS training.

Single set advocates suggest that performing a single set will produce nearly the same strength and/or hypertrophy gains as doing MS in less amount of training time. Stowers et al. (19) found that there were no significant differences when performing one vs. multiple sets of free weight exercises during
7 weeks of training. The pre to mid data from this study indicates that in 6 weeks of training there were almost identical percentage increases in LP strength between the two groups. In contrast, multiple set advocates believe that in order to promote long-term resistance training adaptations the principle of progressive overload needs to be applied (i.e., increasing the amount of training volume). The results from the present study support the suggestion that MS over time will produce significant increases in strength.

The data from this study suggests that MS training, or a greater volume of resistance exercise, produces more optimal gains in strength even for untrained persons. This means prescription of resistance exercise for general fitness should most likely include MS design philosophy. The relationship between volume and neural adaptations or body composition changes in single and multi-joint exercises, unfortunately, remains unclear at this time. This avenue of research must be pursued to allow for a better understanding of why additional volume in resistance exercise maximizes strength gains in both trained and untrained populations.
REFERENCES


APPENDIX A

INFORMED CONSENT
INFORMED CONSENT FOR THE EFFECTS OF VOLUME AND EXERCISE COMPLEXITY ON NEUROLOGICAL ADAPTATIONS, STRENGTH GAINS AND LEAN MASS GAINS IN UNTRAINED ADULTS
Principal Investigator: John Blaak

I, ____________________________, voluntarily consent to participate in a research study to compare the effects of the amount of exercise and complexity of exercise on the muscle. I have been informed that I will undergo a 16 week training program and will be randomly assigned to one of two weight training groups: 1) one single set and 2) multiple sets.

I have been informed that over the 16-week training period I will have to meet twice a week and undergo an exercise workout involving one exercise per specified body part with sets and repetitions designed to improve strength and muscle growth. The exercises for each specified body part are the following: Leg Press (Legs; Quadriceps, Hamstrings, Calves), Chest Fly (Chest; Pectoralis Major, Pectoralis Minor), Barbell Curl (Biceps; Biceps Brachii, Biceps Brachioradialis and Biceps Brachialis), Abdominal Crunch (Abdominals; Rectus Abdominus, Obliques), Back Hyperextensions (Erector Spinae). I have been informed that before testing begins I will be required to do a pretest, where I will undergo tests on strength and neuromuscular adaptations. Also I will have a body composition test and bone density scan. The pre, mid and posttest consists of isotonic one repetition maximum (1RM) testing using the leg press and barbell biceps curl to measure 1RM strength.

I have been informed that I will report to the Human Performance Laboratory in Mitchell Hall (room 25), at the University of Wisconsin-La Crosse for testing at the beginning, middle and the end of the study. Testing sessions will be approximately 20 minutes in length. I will be required to undergo a dual energy x-ray absorptiometry (Dexa) scan to determine my total and regional body composition. I have been informed that I will be asked to lie face up, on a padded table, for a total of 10 minutes while the scanner arm passes over me. The scanner will neither enclose nor touch me. I have been informed that I will be exposed to minimal radiation which is within acceptable range as defined by the Wisconsin Department of Health and Family Services (DHFS) (Chapter HSS 157.03 (1) (g)). The University of Wisconsin-La Crosse Institutional Review Board has approved this study for the Protection of Human Subjects.

Anytime an individual is exposed to radiation there is potential risk; however, the amount of radiation (1-4 microSieverts) that I will be exposed to is quite minimal. For example, I would receive 3 microSieverts on a flight from La Crosse to Chicago or 30 microSieverts from a typical chest X-ray.
I have been informed that the purpose of this study is to compare single vs. multiple sets of complex and simple exercises and the effects on neuromuscular adaptations. I agree to refrain from any additional weight training and aerobic activities during the course of this study. I have been informed that the possible benefits that I may receive are improved fitness and knowledge regarding strength and conditioning. I have been informed that the information used in this study is important for further research in the strength and conditioning field. I consent that the results of the study may be used in publication or presentation provided that my name is withheld for confidentiality purposes.

I have been informed of the scheduled times of the practice orientation session, pre, mid and posttests and all training sessions. I have been informed that the total time required is 25-30 hours and I am willing to dedicate my time to be involved in this study. All training and testing sessions have been scheduled and will be conducted by John B. Blaak (788-0544) in the Wittich Strength Center on the campus of the University of Wisconsin-La Crosse under the direction of Jeffrey McBride, Ph.D. (785-8167), Thesis Committee Chair Person and Travis McBride, Ph.D. (785-6546), Thesis Committee Member.

I have been informed that I may be exposed to the following risks or injuries but not limited to; muscle soreness, strains, sprains, fractures, muscle tears, spinal disc injuries, joint injuries and dislocations. The likelihood of any of these injuries occurring is minimal. In the event that an injury does occur, I will be responsible to report it immediately to the tester, John B. Blaak and I may be excused from the study. I have also been informed that I may withdraw from the study at any time and for any reason without penalty.

I have been informed that any information regarding my health history will be kept confidential. In addition, I have been informed that the individual results of my performance in the study will be kept between the tester and myself. To my knowledge, I have filled out all necessary forms and consider them to be correct. I am in good health and willing to participate in this study. I have been fully informed of the purpose and procedures involved in this study and have been informed and understand all the possible risks involved. Any concerns or questions may be directed towards John B. Blaak (Researcher) and Jeffrey McBride (Chair person). Questions regarding the protection of human subjects may be addressed to Dr. Dan Duquette, Chair, UW-La Crosse Institutional Review Board (608) 785-8161.

Participant ___________________________ Date: _______________________
Researcher ___________________________ Date: _______________________

APPENDIX B

TESTING RECORD SHEET
### Name:

**Pre-test data**

**Date:**

**Weight:**

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<td>Trial #2</td>
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**Comments:**

**Biceps Barbell Curl**

| 1RM | Trial #1 | Trial #2 | Trial #3 | Trial #4 | 1 RM Wtg. | EMG |

**Comments:**

---

### Name:

**Mid-test data**

**Date:**

**Weight:**

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<td>Trial #1</td>
<td>Trial #2</td>
<td>Trial #3</td>
<td>Trial #4</td>
</tr>
</tbody>
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**Comments:**

**Biceps Barbell Curl**

| 1RM | Trial #1 | Trial #2 | Trial #3 | Trial #4 | 1 RM Wtg. | EMG |

**Comments:**

---

### Name:

**Post-test data**

**Date:**

**Weight:**

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<td>Trial #2</td>
<td>Trial #3</td>
<td>Trial #4</td>
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</tbody>
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**Comments:**

**Biceps Barbell Curl**

| 1RM | Trial #1 | Trial #2 | Trial #3 | Trial #4 | 1 RM Wtg. | EMG |

**Comments:**
APPENDIX C

RESISTANCE TRAINING PROTOCOL
RESISTANCE TRAINING PROTOCOL

Two training workouts were completed twice per week. Subjects were randomly assigned to one of two different training groups: S-1 (performed one single set of each exercise) and M-6 (performed six sets of leg press and biceps curl and three sets of the other exercises). The workout days were on Monday, Wednesday and Friday at the University of Wisconsin-La Crosse Wittich Strength Center. Subjects selected two training days from the available days to train on. Subjects were instructed as to which exercises they should perform and how many sets/repetitions to perform each day they trained. For safety an exercise specialist always supervised subjects. The exercise specialist recorded records of attendance, training weights, sets and repetitions for each subject/training day completed.

The single set training group (S-1) program consisted of the following:

Day 1: 1 set of 10 repetitions for the leg press, biceps barbell curl and chest flye exercises, and 1 set of 12-15 repetitions for the abdominal and lower back exercises. 2 minutes of rest was allowed between exercises.

Day 2: 1 set of 6 repetitions for the leg press, biceps barbell curl and chest flye exercises, and 1 set of 12-15 repetitions for the abdominal and lower back exercises. 3 minutes of rest was allowed between exercises.

The multiple set training group (M-6) program consisted of the following:

Day 1: 6 sets of 10 repetitions for the leg press, biceps barbell curl, 3 sets of 10 repetitions for the chest flye exercise, and 3 sets of 12-15 repetitions for the abdominal and lower back exercises. 2 minutes of rest was allowed between exercises.

Day 2: 6 sets of 6 repetitions for the leg press, biceps barbell curl, 3 sets of 6 repetitions for the chest flye exercise, and 3 sets of 12-15 repetitions for the abdominal and lower back exercises. 3 minutes of rest was allowed between exercises.

The training intensity for both groups was set at 10 repetitions maximum (10RM) for day one and 6 repetitions maximum (6RM) for day two. If 10RM and /or 6RM were easily reached, the subject's weight was increased. For S-1, weights were only increased for the next training identical training session (i.e. next same (RM) day). For the M-6 group weight was either increased for the next set and/or the next same training session.
APPENDIX D

SINGLE SET TRAINING JOURNAL
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**Training Journal**

**Week 1**

**Week 2**

**Week 3**

**Week 4**

**Week 5**

**Training Parameters**

**Workout Duration (minutes):**

- Week 1: 1.4
- Week 2: 1.4
- Week 3: 1.4
- Week 4: 1.4
- Week 5: 1.4

Name:
APPENDIX E

MULTIPLE SET TRAINING JOURNAL
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REVIEW OF RELATED LITERATURE

Introduction

The purpose of this study was to examine the effects of volume and exercise complexity on the developmental rate of neuromuscular adaptations, percentage strength gains and lean mass gains in untrained adults. This chapter provides a review of training volume, specifically, comparing the effectiveness of single vs. multiple sets of training. It will also review exercise complexity and neural adaptations with regard to resistance training.

Single Set Effectiveness

Single set (SS) advocates have suggested that single set training protocols are an effective training stimulus. SS advocates have argued for many years that SS training protocols will produce similar training adaptations as that of multiple set training protocols (MS) (5,9,15,28,30,31). They have suggested that SS training programs take less time, reduce the possibility of over-training, are cost efficient, and promote a higher workout compliance (10).

Several studies have examined the effectiveness of performing one vs. two sets of resistance training exercises. Pollock et al. (23) had subjects perform dynamic cervical extension for 12 weeks. Subjects were assigned to one of two training groups: SS or two sets (MS). Both groups completed the same number of repetitions per set (8-12). Results of the study indicated that both groups significantly increased dynamic strength (40.9 and 43.5% respectively). Both
training groups also significantly increased (at all eight angles) cervical isometric torque. No significant differences were found between groups for either dynamic strength or isometric torque. These results suggested that performing one additional set of exercise did not promote a greater rate of dynamic and/or isometric strength improvement over performing one set.

DeHoyos et al. (9) examined the effects of a SS to fatigue vs. three sets to fatigue. The majority of MS training protocols are not completed to failure therefore this study examined how training volume and intensity (training to failure) effected rate of strength development. Subjects were pre tested, completed 12 weeks (3 days a week) of the training protocol and then were post tested. Results of the study showed that there were no significant differences found in strength gains between SS to failure vs. three sets to failure.

Wescott and colleagues (31) completed a study in which subjects (54 men and 23 women) trained for ten weeks. Subjects trained three days a week performing a self selected training program consisting of: one, two or three sets of five, ten, or fifteen repetitions. Subjects were pre and post tested in total number of dips and chin ups utilizing their own body weight as the training resistance. Results of the study showed that although all three groups improved in mean dips and chin-ups, no significant differences were found between any groups in producing a more effective mean increase in number of repetitions performed. These studies all have suggested that performing a SS training protocol is just as effective as performing a MS training protocol.
SS advocates have also suggested that SS programs are just as effective when using a resistance-training program consisting of only free-weight exercises. Stowers et al. (30) examined the effectiveness of training using a SS to failure vs. three sets to failure or three sets periodized (varied number of repetitions). Eighty-four untrained male subjects were randomly placed in one of three training groups, and trained for seven weeks. Subjects were pre, mid and post tested in 1RM bench press and 1RM back squat. Results of the study showed that all groups significantly increased in 1RM bench press and back squat. There were not significant differences found between SS to failure, three sets to failure and/or three sets periodized.

A greater amount of training volume has been suspected to cause a greater increase in lean body mass. However, single set advocates have claimed that a SS is an effective stimulus to promote lean mass increases. A study by Starkey et al. (28) has addressed the idea that a SS to failure is just as effective in promoting lean mass increases as well as strength increases. Subjects in this study were divided up into one of two training groups and trained three days a week for fourteen weeks. Subjects were pre and post tested in: peak knee extension torque, peak knee flexion torque, and muscle thickness using ultrasound. Results of the study showed that there were no significant differences in muscle thickness, and peak knee extension and flexion torque between groups.
A key argument of multiple set advocates is that over time the body will adapt to a SS training stimulus. If this were true then after an extended amount of time a SS training program would no longer promote any additional benefits, causing a plateau in possible strength and lean mass gains. This issue was addressed in a research study completed by Hass et al. (45). They examined the effects of SS vs. MS sets in recreation weightlifters with 4-6 years of weight training experience. Participants were to complete a circuit-training workout program in which the SS group performed one set to failure of each exercise, while the second group performed MS of each exercise. MS subjects were to go through the entire circuit, rest three minutes, and repeat the circuit again twice, each time with a three-minute rest in between. Results of this study suggested that no significant differences between groups were found and that even after a year of training, one SS is still effective.

Finally, a review of literature by Carpinelli and Otto (5) which reviewed the effectiveness of a SS vs. MS of training appeared to be more of a review of support for a SS. The authors provided many detailed examples of the effectiveness of SS training however, the authors neglected to discuss many of the published MS studies. There remains insufficient research examining the effects of a SS on elite athletes.
Multiple Set Effectiveness

Although almost any type of resistance training stimulus can increase strength in untrained persons, MS have been shown over time to produce superior strength gains over a SS to failure. Multiple set advocates have suggested that due to the human body's ability to adapt to a constant stimulus (SS) over time, an additional stimulus (MS) needs to be added to further promote training adaptations. MS advocates have also suggested that MS programs are superior in promoting strength gains, lean mass gains, nervous system adaptations and endocrine adaptations (2,12,13,16,17,19,21,26,27).

Some of the first research, which examined the effects of training volume, was completed by Berger (2). In this study they divided up male subjects into 9 groups with approximately 20 males in each group. Each group was assigned a unique amount of sets/repetitions to perform. Subjects were to complete three training days, training for a total of 12 weeks. All subjects performed the same exercise: bench press exercise (BP). Subjects were pre and post tested in 1RM bench press strength. Results of the study found that training using three sets was superior over one and two sets. Berger (2) also found that three sets of six repetitions produced the greatest rate of strength increase. However, an additional study by Berger (3) did not support the proposal that three sets of six repetitions was the most effective training stimulus to increase strength. To this date Berger's studies have laid the foundation for the current development of research examining the effects of training volume on strength increases.
Several volume studies (SS vs. MS) completed in recent years have found that MS training protocols promote a greater increase in strength for both men and women. A recent study by Schulumberger et al. (27) compared the effects of SS vs. MS in women. Subjects were randomly placed into one of three groups: SS, MS and control. Subjects were trained for six weeks twice a week and performed a whole body resistance-training program. Subjects were tested pre and post training in the leg extension and seated bench press machine. Results of the study showed that although both groups significantly increased in strength in the leg extension. Only the MS group showed a significant increase in strength in the seated bench press machine. The author reported that after calculating effect sized and percentage gains the MS group had a higher increase in strength gains for both exercises.

Sanborn et al. (26) have completed a study examining the effects of using a SS to failure vs. MS not to failure training protocol. Subjects consisted of untrained college aged women who were randomly assigned to one of two training groups. The subjects were pre and post tested in 1RM parallel squat and countermovement vertical jump (CMJ). Subjects trained for eight weeks performing three workouts per week. Results of the study showed that both the SS and MS training groups significantly in 1RM parallel squat. Only the MS showed a significant increase in CMJ.

Kraemer et al. (17) compared the effectiveness of a SS versus MS on 1RM back squat. Subjects were randomly divided up into one of three training
programs. Group one, SS performed one set of 8-12 repetitions to failure, while the MS group performed three sets of 10 repetitions not to failure, and the MSV group performed a varied multiple set/repetitions not to failure training protocol. The 14-week training protocol involved performing seven free-weight exercises three times a week. Results showed that there were no significant differences found in body composition and/or body mass. However, there was found to be a significant increase in the squat exercise (complex exercise) 1RM, with the MS and MSV groups producing an approximate rate increase of 50% greater increase in strength over the SS during the 14 weeks of the study. Therefore, suggesting that training using MS produced a superior rate of strength gains over one set to failure.

Very little research examining the effectiveness of SS vs. MS amongst athletes has been conducted. Kraemer et al. (16) completed a study involving competitive women tennis players. Twenty-four subjects were divided up into one of three groups: SS performed one set of 8-10 repetitions maximum (RM), multiple set varied (MSV) performed 2-5 sets of 3-5RM, 8-10RM, and 12-15RM respectively and finally, the control group. Subjects performed the assigned training protocol three days a week, for nine months. Subjects were tested pre, 4 months, 6 months and post training in strength, and the Wingate anaerobic power test. Results of the study showed that after 4 months of training both training groups improved in strength in the bench press, military press, and leg press. However, only the MS training group was observed to significantly
improve in strength over time. The MS vs. SS group only showed significant increases in fat free mass increase and a significant decrease in body fat %. Finally, only the MS group showed a significant increase in anaerobic power increase. The authors concluded that over an extended period of time (> 6 months) MS training protocols promote greater resistance training adaptations over SS.

A few MS studies have also suggested that MS training protocols produce significantly increases in hormonal and metabolic responses over SS. A study by Gotshalk et al. (13) which examined the effects of heavy resistance volume (SS vs. MS) on growth hormone (GH), testosterone (T), cortisol (C), and whole blood lactate (L) levels. They found that the MS training program caused a significant increase in post-workout circulating growth hormone levels. Mulligan et al. (21) also found that MS produced significantly greater hormonal and metabolic responses, suggesting that a higher volume of training is an essential factor in resistance training programs.

Finally, past research has not supported any clear amount of training volume with regards to elite athletes. The majority of volume studies reviewed has been done using untrained subjects. Additionally, there remains insufficient research examining the effects of SS vs. MS training volume over an extended length of time (ex. greater than a year) in untrained subjects and trained subjects (32). The need for long-term research is a definite subject matter which needs to be addressed in future research.
Exercise Complexity

Resistance training exercises have been divided up into two major groups. Group one is simple exercises which have been classified as single joint exercises involving movement around one joint such as the elbow. (i.e. biceps curl and/or triceps extension exercises). Group two are complex exercises which have been classified as multiple joint exercises involving movement around two or more joints such as the hips and knees. (i.e. leg press and/or back squat exercises). Single joint vs. multiple joint has been shown to effect the time development of neuromuscular adaptations, strength gains, and lean mass gains (6,7,8,10,29).

A study done by Chilibeck et al. (7) which examined the effects of resistance training on bone mass in young women found that different types of training exercises had significant differences in rate of increase in strength gains and lean mass gains. They observed from the results that the hypertrophy adaptation was delayed in the complex exercises (leg press and bench press) as opposed to the simple exercise (biceps curl). Similar results were also found by Calder et al. (4) which examined the effects of split-body resistance training programs.

Chilibeck et al. (6) examined the effects of complexity of the exercise task, its effects on muscular hypertrophy, and rate of nervous system adaptations. Results of this study showed there was a greater initial increase in neuromuscular adaptations with regards to performing the simple exercise,
namely, the biceps curl (BC). However, the complex movement, the leg press (LP) and bench press (BP) caused a greater delayed rate in neuromuscular adaptations as compared to slower increases in muscular hypertrophy. This study appears to have suggested that both volume and complexity may have a combined effect on the neuromuscular rate of adaptations; therefore causing a delayed increase in muscular hypertrophy and muscular strength gains.

Rutherford and Jones (24) have suggested that with an increase in the complexity of a movement, such as multi-joint exercises, as compared to simple single-joint exercises, there seems to be a delay in the motor learning and coordination ability of the muscles during a complex exercise – especially in the early stages of training. Several studies have examined the effects of performing simple exercises and found that in almost all cases there is a faster hypertrophy response when performing simple exercises (8,24). Studies which have examined the effects of using complex exercises, have found that there is an increase in strength but little or no increase in muscle hypertrophy. Cureton et al. (8) and Staron et al. (29) found that when females trained for 8-16 weeks using complex exercises such as the leg press and back squat. The subjects had significant improvements in leg strength but no changes in leg lean mass gains.

Similar findings have been found when using males vs. females who also performed complex exercises Dons et al. (10).
Neuromuscular Adaptations

The use of electromyography (EMG) instruments has made it possible to separate neuromuscular adaptations and hypertrophic adaptations in muscle (14). Specifically, changes in EMG such as: recruitment of motor units in the prime mover, rate coding (firing frequency) and impulse synchronization (the coincident timing of two or more motor units) have been defined as neural adaptations (1,25). Increases in strength without increases in muscle hypertrophy have been explained by an increase in neural drive, such as increases in motor unit recruitment and their firing frequency (1).

Possible mechanisms of neural adaptations have been found to be: increased activation of the prime movers in a specific movement and learning and coordination of the skill (25). It was reported by Chilibeck et al. (6) that single-joint vs. multi-joint exercises will have a faster rate of neural adaptations. It has been suggested that increases in force output in smaller muscles will predominantly be increases in rate coding. However, increases in force output in larger muscles have been suggested to be predominantly increases in motor unit recruitment (1). Behm (1) has suggested that to optimally promote neural adaptations maximal resistance, low reps (less than 6 reps) and long rest periods should be used.

Hakkinen (14) has suggested that in untrained subjects, the initial stages of resistance training adaptations are largely the result of neural factors. However, the latter adaptations are due to both neural and hypertrophy of the
muscle, with hypertrophy becoming the greater factor over the duration of training. Moritani et al. (20) found that the initial increases in strength were the result of neural adaptations specifically, an increase in maximal neural activation (IEMG). They examined the effects of an 8-week isotonic strength workout on seven young males and eight females. Results of the study showed that during the initial three weeks of the training, neural adaptations were responsible for increases in strength. However, it was observed after 3-5 weeks, that muscle hypertrophy became the overriding reason for increases in strength. Narici et al. (22) have also found similar results when examining the changes in force, muscle hypertrophy, and neural adaptations during strength training and detraining of the quadriceps muscle. They reported that after 60 days of training; hypertrophy accounted for 40%, and an increase in neural drive accounted for 60% of the strength increases observed.

It has also been suggested that although neural mechanisms may be the same, there is a difference in the rate of neuromuscular adaptations in trained vs. untrained individuals. In untrained subjects the predominate training adaptation is an increased in the neural activation of the muscles, followed by muscle hypertrophy taking a greater effect. However, in trained subjects the role of neuromuscular adaptations becomes increasing more complex and difficult to assess (14).

Further research needs to be completed examining the relationship between volume and exercise complexity and it effects on neural adaptations.
REFERENCES


