The Effect of Different Types of Strength Training on Concentric Strength in Women

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ABSTRACT

The effects of 4 types of resistance strength training on concentric strength and thigh girth in young women were compared. The 4 treatment groups were concentric-only (Conc, n = 12), eccentric-only (Ecc, n = 10), conventional (Conv, n = 8), and supramaximal eccentric training (SmET, n = 8). Another group of subjects did not train and served as controls (n = 10). Subjects trained on a knee extension Schnell machine twice weekly for 8 weeks, performing 3 sets of 10 reps with a starting load of 65% of 1-RM. The load was increased by 5% every 2 weeks. ANCOVA indicated that SmET and Conv improved significantly (p < 0.05) in relative (1-RM/body weight) dynamic strength when compared with initial strength levels. Similar though not statistically significant trends were observed for Conc and Ecc. However, none of the differences among the 4 training groups were significant. There was no change in thigh girth in any of the training groups.

Key Words: eccentric, supramaximal, girth, knee extension, sample size

Introduction

The characteristics of eccentric muscle work in comparison with concentric muscle work have been well documented. Differences include the generation of greater maximal muscular force in eccentric than in concentric contractions at comparable velocities (1, 19, 22). This peculiarity has directed some investigators to explore the potential benefits of eccentric exercise as an alternative for strength training.

Based on the findings that greater maximal tension can be developed during eccentric than during concentric contractions (1, 19, 22), a concept of supramaximal eccentric training (SmET) may be suggested. It refers to training with loads greater than 1-RM, that is, execution of eccentric muscle contractions against resistance higher than can be overcome by a concentric contraction, thus producing a more intense stimulus.

Johnson et al. (20, 21) were the first to introduce this training method. They recommended that SmET be performed with loads not higher than 130% of 1-RM. Such loads were subsequently employed by Hakkinen et al. (11, 12, 13, 15) in a series of studies using combined concentric and eccentric muscle training. However, no study has been found in which the effectiveness of SmET was concurrently compared with conventional training, with only eccentric training, or with only concentric training. Such comparisons are needed to quantify the possible relative advantage of training with SmET.

The purpose of this study was to evaluate the effect of strength training with 4 types of muscle contractions on the knee extensor muscles in women: conventional (Conv), supramaximal eccentric (SmET), only concentric (Conc), and only eccentric (Ecc). A secondary purpose was to evaluate the effects of training on thigh girth in women.

Methods

Subjects

Sixty female physical education students with a mean age of 21.1 yrs (SD = 1.7 yrs, range 18–25) took part in this study. Consent for participation was obtained from all subjects after they were informed of the purpose and nature of the study. None of the students had any previous experience with heavy resistance training. Twelve subjects were randomly assigned to each of the 4 experimental groups and to a control group. Subject characteristics are specified in Table 1. During the experiment 12 subjects dropped out, 4 from the SmET group, 4 from the Conv group, 2 from the Ecc group, and 2 from the control group. None of the dropouts were related to the treatment. The means of the pretest measurements of the dropouts did not differ significantly from those of the other subjects.

Treatments

The experimental groups trained the knee extensors in the upright sitting position through a range of motion from 90° of flexion to full extension. Training sessions were conducted twice a week for 8 weeks according to the following protocols:

Conventional group (Conv) subjects performed 3 sets of 10 reps using both legs simultaneously with a
Table 1
Descriptive Statistics of Experimental Variables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Treatment</th>
<th>Conv n=8</th>
<th>SmET n=8</th>
<th>Conc n=12</th>
<th>Eccn n=10</th>
<th>Contr. n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>M</td>
<td>162.3</td>
<td>164.4</td>
<td>166.3</td>
<td>166.7</td>
<td>164.8</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>4.0</td>
<td>6.7</td>
<td>5.7</td>
<td>3.3</td>
<td>5.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>Pre M</td>
<td>57.10</td>
<td>58.13</td>
<td>57.52</td>
<td>60.60</td>
<td>63.47</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>7.73</td>
<td>6.62</td>
<td>5.90</td>
<td>4.31</td>
<td>6.77</td>
</tr>
<tr>
<td></td>
<td>Post M</td>
<td>55.20</td>
<td>58.38</td>
<td>56.79</td>
<td>58.97</td>
<td>63.03</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>7.66</td>
<td>6.35</td>
<td>5.46</td>
<td>4.50</td>
<td>6.76</td>
</tr>
<tr>
<td>Girth (cm)</td>
<td>Pre M</td>
<td>51.00</td>
<td>50.94</td>
<td>50.08</td>
<td>52.75</td>
<td>54.00</td>
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<tr>
<td></td>
<td>SD</td>
<td>3.73</td>
<td>3.04</td>
<td>2.88</td>
<td>2.96</td>
<td>3.35</td>
</tr>
<tr>
<td></td>
<td>Post M</td>
<td>50.81</td>
<td>51.19</td>
<td>49.71</td>
<td>52.50</td>
<td>53.50</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>3.34</td>
<td>2.00</td>
<td>2.63</td>
<td>2.92</td>
<td>2.31</td>
</tr>
<tr>
<td>1-RM/BW</td>
<td>Pre M</td>
<td>1.037</td>
<td>1.050</td>
<td>1.011</td>
<td>1.019</td>
<td>0.966</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.178</td>
<td>0.187</td>
<td>0.178</td>
<td>0.141</td>
<td>0.173</td>
</tr>
<tr>
<td></td>
<td>Post M</td>
<td>1.234</td>
<td>1.291</td>
<td>1.153</td>
<td>1.186</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.108</td>
<td>0.210</td>
<td>0.217</td>
<td>0.156</td>
<td>0.162</td>
</tr>
</tbody>
</table>

Resistance of 65% of their individual 1-RM. The training load was rounded to the nearest 1.25 kg. A single repetition consisted of a concentric contraction followed by an eccentric one as in conventional weight training. The subjects were taught to perform the eccentric phase in a controlled manner that lasted 3 to 4 sec.

Supramaximal eccentric training group (SmET) subjects exercised in a manner similar to the Conv group except that they lowered the weight (eccentric phase) with one leg only, alternating between right and left on successive repetitions. Thus each leg performed only 5 eccentric contractions per set but with twice the resistance of the Conv group, that is, 130% of 1-RM. The total amount of work was thus equivalent for both the Conv and SmET groups: 650% of 1-RM per knee per set (10 × 65% in the Conv and 5 × 130% in the SmET during the eccentric phase).

Concentric-only (Conc) subjects performed only the concentric phase, with both legs, as in the conventional group. The weights were lowered down back to the initial position by external assistance. Then the subjects lowered the legs without any external load. Therefore those in this group performed only half of the total work compared to subjects in the Conv group (i.e., the concentric half).

Eccentric-only (Eccn) subjects trained with only the eccentric phase of the movement as in the Conv group, using both legs. Thus only the eccentric half of the work was performed when compared to the Conv group. The resistance was lifted by external assistance for the next repetition.

A training load of 65% of 1-RM was selected for the current study. Usually a higher percentage of 1-RM is recommended for maximal strength effects. The rationale for this selection was that the subjects had no previous experience with resistance training. A pilot study indicated that many of the women were unable to complete the training regimen with loads higher than 65% of 1-RM. This initial load thus served the purpose of gradual adaptation to the new training requirement and guaranteed that all subjects could complete the training regimen with minimal risk of injury. Loads were subsequently increased by 5% every 2 weeks throughout the experiment. This value was decided based on the range of values of strength increments reported in the literature (2, 3, 6, 11, 19, 21, 26).

The control group did not engage in any heavy resistance training during this study. They were tested with the experimental groups both at the beginning and at the end of the study.

Testing and Measurements
A Schnell (Peutenhausen, Germany) knee extensor training machine was employed for both training and testing. Knee extension was done in a sitting position with the subjects applying force on a lever arm through a cushion positioned anteriorly at ankle level. The resistance was placed on a separate lever arm that was rotating in synchronization with the former. It was adjusted to provide maximal resistance when the subject’s knee was at 120°; full extension was defined as 180°.

The following pretraining and posttraining measures were collected on each subject: (a) 1-RM—maximal weight lifted with concentric extension of both knees in a sitting position from 90 to 180° (full extension). The smallest increment unit was 1.25 kg. At least 3 min of rest was allowed between any two successive trials. Testing ended when the subject failed to overcome a given resistance in 2 successive trials. (b) Thigh girth was measured at the midpoint between the greater trochanter and the lateral femoral condyle. The midpoint was marked with the subject in a standing position. She was subsequently seated with the knee fully extended. Girth was then measured at the marked point with a tape measure to the nearest millimeter. Two girth measurements were taken by the same tester. In case of discrepancy, a third measurement was added to determine the exact girth. (c) Body weight was measured to the nearest half kilogram with the subject in shorts and a T-shirt. Height was determined to the nearest centimeter with the subject standing barefoot. All tests were completed in a single session over a period of approximately 2 hrs. The same sequence of tests was employed for all subjects.

Data Analysis
The main statistical procedure was a one-way analysis of covariance in which the 5 groups were compared on their posttraining tests with the pretraining scores serving as covariates. The unweighted-means solution was employed to treat the problem of unequal group size. Post hoc comparisons among adjusted means were computed using Tukey's HSD procedure (35).
The scores of the strength tests were indexed relative to body weight, dividing the raw strength scores by the subject’s pretraining body weight (1-RM/BW). This procedure was selected in order to account for the covariance between body weight and strength measures (17).

Results

Descriptive statistics of all experimental variables are presented in Table 1. The correlation coefficient between body weight and 1-RM was $r = 0.56$, thus justifying the use of a relative rather than an absolute strength index. Using the ratio between the two parameters helps eliminate error variance that could be explained by a difference in physique.

The results of the analyses of covariance are presented in Tables 2 and 3. Significant differences were found in relative dynamic strength. All the experimental groups improved significantly in comparison with their starting level. No improvement was noted in the control group. The post hoc comparisons further reveal that the Conv and SmET groups were significantly superior to the control group. All other pairwise comparisons of group means were not statistically significant. No significant differences among groups were detected either in thigh girth or body weight. The mean percentage increases in strength for each group are presented in Figure 1.

Discussion

The results of the present study support the well-documented potential of eccentric training (8, 20, 22, 23, 28, 29, 31) and of combined eccentric and concentric training (13, 15, 18) to elicit improvement in strength. Contrasting the benefits of eccentric and supramaximal eccentric training with conventional and concentric-only training, the average weekly gains in mean 1-RM were, Conc 1.8%, Eccn 2.1%, Conv 2.4%, and SmET 2.9%. These results are within the range of values reported in the literature. Mean weekly gains of 1.7 to 6.5% have been reported for knee extension (2, 3, 6, 10, 11, 19, 21, 26, 33) and gains of 1.3 to 6% for squats (7, 11, 13, 15).

The differences among the treatment means were not found to be statistically significant. Nevertheless, from a practical point of view, differences of such magnitude bear notice especially when considering the cumulating effects over several weeks of training, as exemplified by Figure 1. The lack of statistical significance should not be considered as evidence for equivalence among the various treatments. Studies on strength training are frequently conducted with relatively small sample sizes. In the studies reviewed, with one exception (3), sample sizes did not exceed 18 subjects per experimental group, with most treatment groups ranging between 8 and 12 subjects.

The use of small treatment groups is often imposed by practical limitations. Small group sizes combined with relatively large intragroup variability of

<p>| Table 2 |
| ANCOVA Comparison on Posttreatment Measurements With Pretreatment Measures as Covariates |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Source of variance</th>
<th>Sum of squares</th>
<th>Deg. of freedom</th>
<th>Mean square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Treatment</td>
<td>18.352</td>
<td>4</td>
<td>4.588</td>
<td>1.32</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>146.030</td>
<td>42</td>
<td>3.477</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girth</td>
<td>Treatment</td>
<td>6.188</td>
<td>4</td>
<td>1.547</td>
<td>0.81</td>
<td>n.s.</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>80.712</td>
<td>42</td>
<td>1.922</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-RM/BW</td>
<td>Treatment</td>
<td>0.254</td>
<td>4</td>
<td>0.064</td>
<td>4.63</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>0.577</td>
<td>42</td>
<td>0.014</td>
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</tbody>
</table>

<p>| Table 3 |
| Post hoc Pairwise Comparisons Between Treatments on Rel. Dynamic Strength (1-RM/BW) |</p>
<table>
<thead>
<tr>
<th>Adjusted means</th>
<th>Contr.</th>
<th>Conc</th>
<th>Eccn</th>
<th>Conv</th>
<th>SmET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.03</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18*</td>
<td>0.23*</td>
</tr>
<tr>
<td>Conc</td>
<td>1.15</td>
<td>0.03</td>
<td>0.06</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Eccn</td>
<td>1.18</td>
<td>0.03</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conv</td>
<td>1.21</td>
<td>0.03</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SmET</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Least signif. diff. according to Tukey’s HSD = 0.16.

Figure 1. Percent increase in dynamic strength after 8 weeks of strength training (means and standard errors).
treatment effects reduce the statistical power and increase the probability of Type II error. For example, the least significant difference between the posttraining-adjusted means of any two groups that could be detected with the current sample size was 0.16 1-RM/BW (Table 2), while the actual improvements in the means of these groups ranged between 0.142 and 0.241 (Table 1). Thus true differences could probably not be detected unless these differences were substantially large. Therefore, when comparing different training effects on the basis of small sample sizes, an absence of statistical significance should be evaluated beyond the scope of a single experiment.

Furthermore, when comparing training effects, the type of muscle contraction should not be the only variable taken into account. The effect of load and volume should be considered as well. In the current study the supramaximal and conventional training protocols produced equivalent training volume in terms of relative work (650% of 1-RM per set). However, the initial load for the concentric phase was selected at moderate intensity (65%) to match the subjects' limited ability. Higher loads are often recommended for optimal strength development in trained or better conditioned subjects. The eccentric phase, on the other hand, was set at the recommended load for optimal strength development (130%), as subjects had no difficulty with such loads.

While these protocols were found appropriate for the investigated population, that is, young women with no previous exposure to resistance training, they may not be optimal for other populations. Thus caution should be employed if the patterns of the current comparisons are to be generalized to conventional protocols that include higher loads and lower numbers of repetitions.

**Eccentric vs. Concentric Training**

Eccentric and concentric training were compared in previous studies. In most of them (19-24), eccentric training tended to produce greater improvement than concentric training when tested concentrically or isometrically. However, these trends were often found to be statistically insignificant. The only statistically significant results to indicate an advantage of eccentric over concentric training were reported by Komi and Buskirk (22). This advantage was limited to the specific effect of improvement in eccentric strength.

In the current study the differences between Conc and Eccn in strength improvement were relatively small and statistically insignificant, but with a trend similar to that reported in most previous studies. Several other studies do not support these trends. Urbanik and Uubukata (32) reported no differential effects for the two treatments, while Ellenbecker et al. (9) and Duncan et al. (8) reported certain advantages for concentric over eccentric training.

In the present study, strength testing consisted of a concentric contraction (1-RM). According to the principle of training specificity, subjects who train with concentric phases are expected to have an advantage in this type of test (31). The lack of significant differences between the Conc and Eccn groups, as well as between the Conv and SmET groups, with trends in the opposite direction, suggests that the effects of the eccentric phase in training are transferable to concentric strength and that this type of training is at least as effective as concentric training. It cannot be deduced that a similar transfer occurs from concentric training to eccentric strength gain, since such a contraction was not included in the testing protocol.

**Supramaximal Eccentric vs. Conventional Training**

Few studies have been reported on the effects of training with supramaximal eccentric contractions, either as a sole mode of training (21) or in conjunction with conventional weight training (11, 12, 13, 15). The only one in which SmET was contrasted with Conv is that of Hakkinnen and Komi (11). Generally, subjects who combined supramaximal eccentric routines with conventional routines in their training improved more than those who used only conventional routines. These observations are not supported by the results of the current study, in which SmET and Conv were not found to differ significantly.

Several explanations may be proposed for this disagreement: (a) While Hakkinnen and Komi (11) trained competitive and noncompetitive male weightlifters, non-weight-training women served as subjects in the current study. It is possible that experienced lifters adapt more specifically to a particular type of training and that adaptation in untrained subjects is more general, with similar responses to all types of training. (b) In the current study the amount of relative work in each training session was equivalent for both groups. It is not clear whether such equality was employed by Hakkinnen and Komi (11). (c) In the current study training lasted 8 weeks, at a frequency of 2 sessions a week for a total of 16 sessions. Hakkinnen and Komi (11) trained their subjects for 12 weeks at 3 to 4 sessions a week for a total of more than twice as many sessions. They pointed out that differential training effects among treatments were not evident during the first 4 weeks but instead developed at later stages of the training period. (d) The subjects in the current study were concurrently involved in other physical activities. Although nonspecific in nature, these activities might have interacted with the strength training effects in a manner that obscured differences between training modes.

**Muscle Mass**

Muscle hypertrophy is often reported as a concomitant consequence to intensive strength training. Hypertrophy, as reflected by cross-sectional area, has commonly
been evaluated by means of anthropometric measurements or through high tech procedures such as ultrasound (7) or computed axial tomography (6).

Hypertrophy has been found in the upper extremity (4, 6, 25, 34) as well as in the thigh (2, 5, 7, 11, 26, 30) in studies that employed conventional resistance, eccentric (22, 28), and combined eccentric and concentric training (11, 15, 18). Other investigators reported no significant hypertrophic effect on the thigh as a result of concentric (8) or conventional training (4, 6, 34).

The results of the present study do not support the existence of hypertrophic effects. Several explanations can be suggested for these observations: (a) Wilmore (34) stated that hypertrophy is not a necessary consequence of strength improvement. Studies in which subjects of both sexes were compared indicated that women developed less hypertrophy in the upper arm than men (6, 34). On the other hand, training of the lower extremity did not result in hypertrophy of the thigh musculature among women (4, 6, 34). The responses found in our subjects are congruent with the latter.

(b) In several studies that employed training of both upper and lower extremity, hypertrophic effects in the upper extremity were not accompanied by parallel effects on thigh girth (4, 6, 34). Cureton et al. (6) explain such results as stemming from the less trained status of the upper extremity. The physical education students in this study were relatively well trained, a fact that might have adversely affected their potential for hypertrophy.

(c) Hypertrophy was found to accompany strength development more at later than during earlier stages of training (15, 25). Moritani and DeVries (25) suggested that early strength improvement without hypertrophy signifies neurological adaptation and that hypertrophic enhancement of strength appears only after several weeks.

(d) Several other reports indicated an increase in cross-sectional area (2, 10, 16) as well as in the size of fast-twitch fibers (5, 30) in women as a result of strength training. The procedure employed in the current study is insufficient to reflect this type of change. On the other hand, Hakkinen et al. (14) suggested that isometric strength correlated significantly with thigh girth but did not correlate with mean fiber area of the vastus lateralis, thus supporting the relevancy of girth measures to the consequences of strength training. Our purpose in measuring thigh girth was mainly to address the issue of women's concerns with increased muscle bulk; the results reveal a lack of such effect. However, changes in cross-sectional area may not necessarily be manifested in proportional changes in muscle girth, especially if increased lean body mass is accompanied by locally reduced fat tissue. Since such indices were not included in the current study, it is possible that the lack of change in thigh girth was a result of inverse trends of lean and fat tissues.

Practical Applications

1. Supramaximal eccentric training is effective in increasing leg strength among novice women engaged in weight training. It provides significant gains in strength without notable side effects such as injuries or increased thigh girth. However, this type of training has not been demonstrated to be better than other types.

2. Eccentric training seems to be at least as effective as concentric training in eliciting strength gains in concentric contractions. Thus it can be part of the repertoire of training programs designed to improve strength in movements that are predominantly concentric in nature.

3. In the current study, conventional and supramaximal eccentric training were compared as training alternatives when initiating a training program. It is worthwhile to explore whether the latter have an advantage if introduced after a period of initial conditioning by conventional training. Advanced strength training subjects may well benefit more from this mode of exercise.

4. Physically active women should not be concerned with developing increased muscle mass in the legs from heavy resistance exercise at a frequency of twice a week, at least during the first few weeks, even with loads that are considered supramaximal. Longer term effects should be investigated further.

5. Caution is required when comparing training with different types of contraction. When sample sizes are small, a lack of significant statistical differences does not necessarily prove equality among treatments. If the magnitude of differences obtained under such circumstances is of practical benefit, further research should be conducted to verify the results before final rejection or acceptance of those differences. Furthermore, one should view results from small-group studies in relation to other observations reported in the literature. A meta-analysis may be required in order to summarize all the studies in this field.

References


