Manipulating Exercise Order Affects Muscular Performance During a Resistance Exercise Training Session

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Reference Data

ABSTRACT
This investigation looked at the effects of exercise order on performance of isotonic muscle contractions. Subjects, 17 trained men between the ages of 18 and 29, were strength tested using 6 standard lifts. Each then completed 2 sessions consisting of 4 sets of 8 contractions (or until muscle failure), for each exercise with 2 min rest between sets. The order for one trial was squat, leg extension, leg flexion, bench press, military press, and triceps pushdown; for the other trial it was leg flexion, leg extension, squat, triceps pushdown, military press, and bench press. When the triceps pushdown and military press preceded the bench press, the bench press total force (TF) was significantly reduced. The TF for squats, leg extensions, and triceps pushdown were all significantly greater when done first in the first exercise sequence. Cumulative TF was greater when structural exercises (multijointed) were done first. Fatigue rate and TF for the bench press were substantially decreased when single-jointed exercises preceded structural ones.

Key Words: strength training, isotonic contractions

Introduction
Common sense and weight-room lore dictate that exercises done during a workout should proceed from those involving large muscles to those involving small muscles. A fatigued small muscle group such as the triceps, which contributes to a gross movement (e.g., bench press), could limit the training stimuli experienced by larger muscle groups (e.g., pectoralis). Thus it is usually recommended that structural exercises, those involving movement at 2 or more joints, precede exercises that isolate movement at a single joint (13).

Preexhaustion training, a term coined about 10 years ago, is a technique that advocates performing selected body-part exercises for large muscle groups prior to structural exercise (7). The logic is that small muscles will fatigue during structural exercises, resulting in submaximal stimulation to larger muscle groups. Therefore advocates of preexhaustion training might advise doing leg extensions (body part exercise) prior to squats (a structural exercise) to optimize quadriceps training.

In designing weight training programs, there are empirically derived reports to help one select the number of sets (2, 6), repetitions (4), length of rest periods (11, 15), and appropriate load (1). In spite of considerable anecdotal information, to our knowledge there are no systematic studies of the effect of exercise order on muscle performance and ultimate training effectiveness. Such information would be useful in making informed decisions on how to organize weight training sessions. Accordingly, the purpose of this study was to examine the effect on muscle performance of varying the order of exercise—structural first versus body part first—during resistance training.

Methods

Subjects
Subjects were 17 men, ages 18 to 29 yrs, with an average of nearly 5 yrs of weight training experience. The use of experienced individuals would be expected to minimize the between-trial variability associated with executing skills effectively. Each subject gave written informed consent before participating in the study. Subject characteristics were as follows:

- Age: 20.18 ± 2.5 yrs; range 18–29
- Weight: 86.53 ± 12.6 kg; range 68–118
- Height: 180.03 ± 6.48 cm; range 167–193
- Training exper.: 4.82 ± 3.7 yrs; range 0.92–15

Procedures
Strength Testing. The men were tested for 8 repetition maximum (8-RM) strength on 3 upper and 3 lower body exercises. The order was, parallel back squat (thighs parallel to floor), bench press, leg extension, seated military press, leg flexion, and triceps pushdown. These exercises were chosen because they are popular among weight lifters of all calibers. Each lift was ex-
executed in standard fashion (3). Attention was devoted to consistency in range of motion for each lift (e.g., squats were taken to parallel on each repetition). Form and technique were continuously monitored and a 3-min recovery was allowed between 8-RM tests for different exercises.

For each 8-RM test the men performed 2 warm-up sets (6 to 10 reps) using about 70% of their estimated 8-RM. After a 2-min rest they were tested for 8-RM. They completed as many reps as possible, but no more than 9. If an accurate load was not determined on the first attempt, a second attempt was completed following a 3-min rest. If 8-RM was still not determined, a load was estimated from a chart of predicted percentage loads (9). This technique was used in about half the load assignments. The load, as determined for all exercises, was held constant during the 2 subsequent weight training sessions. A recovery period of 48 to 72 hrs preceded the first training session.

Weight Training Sessions. Each subject completed 2 weight training sessions. The order of exercises progressed from structural to body part in 1 session (i.e., squat, leg extension, leg flexion, bench press, military press, triceps pushdown) and vice versa in the other session (i.e., leg flexion, leg extension, squat, triceps pushdown, military press, bench press). The order of the sessions was counterbalanced among subjects to minimize any potential order effect. Exercises for the lower body were always done first, however.

During weight training sessions the men completed 4 sets of each exercise for 8 reps, or until muscle failure, with the designated 8-RM load. Each subject was allowed 2 min rest between sets and 3 min rest between different exercises. The lower and upper body portions of the workout were separated by a 5-min rest. At least 48 but no more than 72 hrs of recovery time was allowed between training sessions. During the training sessions, total force (TF = resistance × reps) was recorded for each set of each exercise. The rate of force decline (fatigue) was also considered an important dependent variable and was computed for each exercise during the 2 exercise order conditions. Fatigue rate (FR), commonly defined as a drop in force or power output across time, was calculated as the percent difference in TF production between Sets 1 and 4 for each exercise.

\[
FR = \frac{TF_{\text{set } 1} - TF_{\text{set } 4}}{TF_{\text{set } 1}} \times 100\%.
\]

Statistical Analysis
Two-way (2 × 4; order × sets) ANOVAs with 2 repeated measures were used to assess changes in TF and FR. For significant interactions between order and sets, simple-effects ANOVAs were used to locate significant differences between orders and among sets. Tukey post hoc tests were used to follow up significant main effects for sets. A 2 × 2 (order × body region) ANOVA was used to examine the effects of exercise order on cumulative TF in the upper and lower body. Pearson's \( r \) was used to examine the relationship between selected dependent variables. For all analyses the alpha was 0.05.

Results
Figure 1 illustrates bench press performance across 4 sets for both training protocols. A significant interaction, \( F(3, 48) = 31.97 \) \((p < 0.001)\) verified a much greater rate of force decline (i.e., FR) over the 4 sets when the bench press was done before the military press and triceps pushdown. Table 1 shows that FR from Sets 1 through 4 changed from 58.2% using the structural-to-body-part order to only 12.9% when the exercise order was reversed. Also, follow-up analyses revealed that bench press TF was significantly greater at each set when executed first in the workout. When the exercise routine went from body part to structural exercise, this resulted in a 61.4% decline in cumulative bench press TF production across the 4 sets compared to the structural-to-body-part order.

Although interactions were not significant, the follow-up analyses to significant main effects for exercise order found that the squat (Figure 2) and triceps pushdown (Figure 3) were significantly better \((p < 0.001)\) when executed first in the workout. Completing squats or triceps pushdown at the beginning produced about 25% greater TF over the 4 sets compared to doing them later in the workout. Regardless of exercise order (Table 1), the FR for squats or triceps pushdown was about the same over the 4 sets, as indicated by a lack of significant interaction in the analysis for either exercise.

Results for leg extension were similar to those for bench press but not as pronounced (Figure 4). When leg extensions were done prior to squats rather than after...
Table 1

Muscular Performance Across Sessions & Sets

<table>
<thead>
<tr>
<th>Sessions</th>
<th>Set 1 (TF)</th>
<th>Set 4 (TF)</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench press</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sess. A</td>
<td>720 (±76)</td>
<td>301 (±90)</td>
<td>−58.2%</td>
</tr>
<tr>
<td>Sess. B</td>
<td>179 (±146)</td>
<td>156 (±116)</td>
<td>−12.9%</td>
</tr>
<tr>
<td>% TF change</td>
<td>−75.1%</td>
<td>−48.1%</td>
<td></td>
</tr>
<tr>
<td>Squat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sess. A</td>
<td>896 (±115)</td>
<td>486 (±248)</td>
<td>−45.8%</td>
</tr>
<tr>
<td>Sess. B</td>
<td>698 (±243)</td>
<td>349 (±263)</td>
<td>−50.0%</td>
</tr>
<tr>
<td>% TF change</td>
<td>−22.1%</td>
<td>−28.2%</td>
<td></td>
</tr>
<tr>
<td>Leg exten.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sess. A</td>
<td>470 (±105)</td>
<td>358 (±121)</td>
<td>−23.8%</td>
</tr>
<tr>
<td>Sess. B</td>
<td>505 (±79)</td>
<td>421 (±106)</td>
<td>−16.6%</td>
</tr>
<tr>
<td>% TF change</td>
<td>+7.5%</td>
<td>+17.6%</td>
<td></td>
</tr>
<tr>
<td>Triceps exten.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sess. A</td>
<td>208 (±89)</td>
<td>156 (±59)</td>
<td>−25.0%</td>
</tr>
<tr>
<td>Sess. B</td>
<td>289 (±20)</td>
<td>210 (±71)</td>
<td>−27.3%</td>
</tr>
<tr>
<td>% TF change</td>
<td>+38.9%</td>
<td>+34.6%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sess. A</td>
<td>5049</td>
<td>1301</td>
<td>−44.0%</td>
</tr>
<tr>
<td>Sess. B</td>
<td>3674</td>
<td>1137</td>
<td>−31.9%</td>
</tr>
<tr>
<td>% TF change</td>
<td>−27.2%</td>
<td>−12.6%</td>
<td></td>
</tr>
</tbody>
</table>

Note. Session A = structural to body part exercises; Session B = body part to structural exercises; TF = total force (kg) calculated as resistance × reps; FR = fatigue rate (%) calculated as change in TF from Sets 1 to 4.

Figure 2. Squat TF production across 4 sets during Session A (structural to body part) and Session B (body part to structural). *Significant main effect and TF was greater during Session A than Session B across all 4 sets.

Figure 3. Triceps pushdown TF production across 4 sets during Session A (structural to body part) and Session B (body part to structural). *Significant main effect and TF was greater during Session B than Session A across all 4 sets.

Figure 4. Leg extension TF production across 4 sets during Session A (structural to body part) and Session B (body part to structural). *Significant interaction and TF was greater during Session B than Session A at each set.

Squats, the FR, F(3, 48) = 3.82 (p = 0.016) and TF (p < 0.01) were significantly greater. Despite these significant analyses, only a 7.2% difference in FR and a 14% loss in TF across all sets were noted when leg extensions followed squats. These smaller percent-wise changes indicate that the order of exercise has less of an impact during lower body exercises than during upper body ones. No significant interactions were seen for either military press or leg curls. Main effects for exercise order on military press and leg curl were not statistically significant, although 17.2% and 6.5% more cumulative TF, respectively, were produced when these exercises were done earlier in the routine.

In the analysis of cumulative TF (4 sets of 3 exercises) by body region (upper and lower body), the in-
teraction term was not significant, but TF was 24.7% greater for upper body exercises and only 7.1% greater for lower body exercises when structural exercises were done first. A significant main effect (p < 0.05) made it clear that cumulative TF (4 sets of 6 exercises) was generally greater when structural exercises preceded body part exercises. For the whole workout, 13.6% greater TF—not a simple average of 24.7 and 7.1%, since greater TF was produced by the lower body—was generated using a structural-to-body-part workout compared to the opposite routine. As would be expected, the main effect (p < 0.001) of body region demonstrated that more force is produced during exercises involving the larger muscles of the lower body than during upper body exercises.

Discussion

Theoretically, performing large (structural) to small (body part) muscle group exercises should allow maximal workout stimulus to all of the involved muscles (9, 13). But this has never been empirically tested, and some have suggested that otherwise altering the order of exercise may be beneficial (5, 7). Results from the present study seem to support the structural-to-body-part order of training for maximizing muscular performance.

For a study of this kind, determining which variables to measure during a training session should be dictated by their practical importance. For many weight lifters this is defined by the gains in strength accrued with training. Therefore it makes sense to identify measurable variables in a workout that might be critical for strength development. An examination of the literature helps in systematically defining important stimuli for strength development. After considerable investigation, Goldberg and associates (10) concluded that tension development was the critical stimulus for muscle growth. Their conclusion is supported by studies showing that the use of near maximal resistance with a low number of repetitions, say, 5 to 6, is most effective at improving strength (2). In the present study, TF, determined as force × repetitions, was used to indicate tension development.

Recent work by Rooney et al. (12) gives compelling evidence that fatigue during an exercise session is also a key element in maximizing strength gains with training. These researchers speculated that greater fatigue is associated with greater motor unit recruitment, and ultimately with greater neural adaptations with training. In the present study the rate of fatigue (FR), determined as the drop in force production over time (i.e., the 4 sets), was used as an indicator of fatigue. In summary, as we look to elements of muscle performance that may be important during a training session, it seems appropriate to be concerned with TF and FR.

As for the volume of weight lifted over all exercises, it was determined that significantly more TF (13.6%) was produced during the structural-to-body-part routine as opposed to the reverse order. This exercise-order advantage was not equally distributed across the upper and lower body workouts. The cumulative TF was 24.7% and 7.1% greater for the upper and lower body exercises, respectively, when doing structural exercises first. Although TF was greater for both upper and lower body routines when structural exercises preceded body part exercises, the difference in magnitude between the upper and lower body effects merits further discussion.

The difference between upper and lower body sensitivity to exercise order may be due to the choice of exercises for the present study. While bench press performance is greatly affected by preexhausting the deltoids and triceps, squat performance is probably much less dependent on quadriceps and hamstrings, due to a relatively great reliance on muscles not tested in the present study (i.e., gluteal, lower back, abdominal muscles) (3, 8). This assumption is supported by the fact that bench press performance was 75% less in the first set when done after triceps pushdowns and military press, while squat performance was only 22% less when done last in the lower body routine (Table 1). Therefore, although squat performance suffered when the squat was executed later in the routine, it is not greatly affected by preexhausting quadriceps and hamstrings because these muscles are not exclusively responsible for limiting hip extension during the squat. Future studies might employ other exercises and examine the effect of exercise order on squat performance.

It is evident that the major muscles of the chest are not fatigued and perhaps not adequately overloaded when the bench press is executed after body part exercises such as triceps pushdowns. During the structural-to-body-part exercise session, the last set of bench presses may have been limited by the ability of the triceps to develop tension. This is suggested in light of the similarity between the resistance that could be applied during the last set of bench work (301 ± 90 kg) and the first set of triceps work during the body-part-to-structural session (289 ± 20 kg). The correlation between these sets was significant (p = 0.012) and moderately strong (r = 0.61). Also, when the bench press was done last in the routine, the average TF developed across all 4 sets (184 ± 135 kg) closely matched the TF of the fatigued triceps (210 ± 71 kg).

If similarity of force production indicates a limitation of one muscle upon another, then it seems necessary to have a well rested triceps muscle to appropriately overload the major muscles of the chest. Further examination of all variables that may describe this intermuscle relationship (e.g., controlling for movement pattern, fiber recruitment, speed of movement) are needed to more fully develop the argument of one muscle group limiting the performance of another.

While TF was generally improved (6 to 25%) for smaller muscle groups when these were exercised first,
FR for these muscles was virtually the same regardless of exercise order. This suggests that smaller muscles will be well challenged and overloaded during a heavy resistance training session whether done first or last. The same cannot be said for the larger muscles of the chest, where FR was nearly 50% greater and TF 64% higher when these muscles were worked first in the routine.

This was the first study to examine the immediate effects of altering exercise order on muscular performance. It has already been demonstrated that during intense, heavy resistance exercise of similar muscle groups, muscle function later in the workout may become impaired and this drop in performance may be related to metabolic events (e.g., increasing lactate levels and decreasing pH) (14). Whether metabolic changes during the exercise session can explain or partly account for the differences between exercise order seen in this study is not yet known.

The results indicate that training in the structural-to-body-part exercise order maximizes the stimulus exposure during a workout; however, the long-term effects of these training techniques remain unknown. There has yet to be a description of the muscular adaptations consequent to training with altered exercise order. And there are successful bodybuilders who employ preexhaustion techniques that emphasize body part before structural exercises. Given the potential for greater TF and FR during each training session, particularly for the muscles of the chest, a program emphasizing a structural-to-body-part order may maximize training adaptations. Because the present study focused on the immediate effects of manipulating exercise order, further speculation about the effects of chronic training are unwarranted. However, these data do provide a sound platform for a subsequent longitudinal investigation.

In summary, TF during an exercise session is greater when large muscle groups are exercised prior to small muscles. If tension development as represented by TF and fatigue as represented by FR are critical for strength development, then structural-to-body-part exercise order may be the best way to enhance strength, particularly for upper body routines. Both TF and FR are greatly enhanced when structural exercises such as the bench press are performed first, whereas TF is only slightly greater and FR is unaffected for body part exercises such as the triceps pushdown or hamstrings curl when they are completed first. In conclusion, during an exercise session TF and FR are considerably greater during the bench press when it is undertaken before the triceps and deltoids become fatigued, but this effect is not as pronounced for the squat when it follows quadriceps and hamstrings work.

**Practical Applications**

The implications of this study are relevant to designing exercise sessions for maximizing muscle force during a workout. If the objective is to maximize the stimulus exposure for a particular muscle group, the exercises for that group should be completed first. But if the objective for the training session is to generally overload most major muscle groups, then a structural-to-body-part order of exercises is recommended. Executing large-muscle-mass exercises prior to small-muscle-mass exercises will maximize the total resistance lifted during the training session. This is especially true for upper body routines where maximal overload of the pectoralis muscles is unlikely to occur if smaller body part exercises (e.g., triceps pushdown and military press) are done first.

**References**