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1989 21 pags. 84-89 / Graves JE, Pollock ML, Jones AE, Colvin AB, Leggett SH / Specificity of limited range of motion variable resistance training

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Specificity of limited range of motion variable resistance training

JAMES E. GRAVES, MICHAEL L. POLLOCK, ARTHUR E. JONES, ANDREA B. COLVIN, and SCOTT H. LEGGETT

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ABSTRACT

GRAVES, J. E., M. L. POLLOCK, A. E. JONES, A. B. COLVIN, and S. H. LEGGETT. Specificity of limited range of motion variable resistance training. Med. Sci. Sports Exerc., Vol. 21, No. 1, pp. 84–89, 1989. The present study evaluated the effect of limited range of motion (ROM) variable resistance training on full ROM strength development. Twenty-eight men and 31 women were randomly assigned to one of the three training groups (A, B, AB) or a control group (C). A, B, and AB performed variable resistance bilateral knee extension exercise 2 (N = 25) or 3 (N = 19) d·wk⁻¹ for 10 wk with an amount of weight that allowed one set of 7–10 repetitions. Group A trained in a ROM limited to 120° to 60° of knee flexion. Group B trained in a ROM limited to 60° to 0° of knee flexion. Group AB trained full ROM. Prior to and immediately following training, isometric knee extension strength was evaluated at 9°, 20°, 35°, 50°, 65°, 80°, 95°, and 110° of knee flexion with a Nautilus knee extension tensiometer. Reliability coefficients for repeated measurements of isometric strength at multiple joint angles were high (r = 0.95–0.98, P < 0.01; SEE = 23.1–37.2 N·m). Compared to the control group, all training groups increased isometric strength (P < 0.01) at each angle tested except for group A at 9° and 20° of knee flexion and group B at 95° of flexion. Isometric strength gains for the limited ROM trained groups were greater in the trained ROM than in the untrained ROM (P < 0.01). These data indicate that angular-specific training effects occur for limited ROM dynamic resistance training.

STRENGTH, ISOMETRIC EXERCISE, DYNAMIC EXERCISE, KNEE EXTENSION, SPECIFICITY OF TRAINING

Exercise is often performed within a specific, restricted joint range. This is especially true following orthopedic injury or surgery, when pain, joint stiffness, and muscle weakness can limit range of motion (ROM) (13). To minimize the risk of reinjury, rehabilitation programs typically begin with limited ROM exercise and progress to full ROM as the condition allows.

Knapik et al. (6) showed that isometric exercise training at one specific joint angle can increase muscular strength 20° from the angle at which training is performed. Other studies have demonstrated that, at joint angles greater than 20° from the training angle, little transfer of isometric training occurs (2,11,12). Thus, an angular-specific training response has been identified for isometric exercise.

Rehabilitation and strength programs generally employ dynamic modes of exercise training. There is a paucity of data in the scientific literature on the specificity of limited ROM dynamic exercise. Many studies that have used isometric exercise tests to evaluate changes in muscular strength have employed only one to three angles of measurement and have not described full ROM effects (1,2,6,11–14). The purpose of the present study was to evaluate the effect of limited ROM, dynamic resistance training on full ROM strength development. Eight angles of isometric measurement were employed to evaluate full ROM strength. Our goals were to determine whether an angular-specific training response would occur following limited ROM dynamic resistance training and to describe the full ROM response to variable resistance training.

METHODS

Subjects. Twenty-eight men (age = 26.8 ± 4.8 yr, height = 178.3 ± 5.3 cm; weight = 76.5 ± 11.5 kg) and 31 women (age = 26.5 ± 5.1 yr, height = 171.2 ± 8.6 cm, weight = 67.6 ± 12.9 kg) volunteered to participate in this study. All subjects were healthy sedentary individuals who had not participated in a regular exercise program for at least 1 yr prior to the investigation and who had no musculoskeletal dysfunction or other contraindications to exercise. Each subject read and signed an informed consent document in accordance with the University policy for the protection of human subjects.

Pre-training strength testing. Prior to training, subjects completed four isometric strength tests. For each
test, maximal voluntary isometric strength of the knee extensors was measured at 9°, 20°, 35°, 50°, 65°, 80°, 95°, and 110° of knee flexion using a Nautilus knee extension tensiometer. Joint angles were set using an internal electric goniometer interfaced to an IBM microcomputer. The force transducer and the electric goniometer of the tensiometer were calibrated daily using a software controlled system supplied with the tensiometer.

Subjects reported for testing and sat in the tensiometer chair, and a back rest was positioned so that the axis of rotation about the knee extended approximately 5 cm beyond the edge of the chair. The back rest was fixed at a 110° angle. The subjects were secured in place with a seat belt placed around the pelvis, and the position of the back rest was recorded so that the subject’s position could be standardized for subsequent tests and training. Subjects were instructed to continuously build tension during contraction and achieve a maximum effort in 3–5 s. A 10 s rest interval was provided between each isometric contraction while the next angle of measurement was set. During the contractions, visual feedback was provided on a video display screen and subjects were verbally encouraged to give a maximum effort.

The isometric strength tests were separated by a minimum of 48 h. The first two tests were considered practice sessions to familiarize the subjects with the testing equipment and measurement procedure. The isometric strength measurements made during the third and fourth strength tests were used to calculate criterion measures of pre-training strength. To help offset fatigue that may be associated with performing repeated isometric contractions, angles of measurement for the criterion tests were set in two different orders. For order 1, joint angles were set beginning with 110° of flexion and progressed to 9° of flexion. For order 2, joint angles were set beginning at 9° of flexion and progressed to 110° of flexion. The two orders of testing were randomly assigned and balanced over subjects and days.

Training. Following completion of the pre-training strength tests, subjects were rank ordered according to peak isometric strength and randomly stratified to one of four groups. One group (A) trained the knee extensors in a ROM limited to 120° to 60° of flexion. A second group (B) trained the knee extensors in a ROM limited to 60° to 0° of flexion. A third group (AB) trained using full range knee extensions (120° to 0° of flexion). The fourth group was a control group (C) that did not train. Training was conducted on a variable resistance knee extension machine (Nautilus). A range limiting device designed to sit on top of the weight stack, allowing only 120° to 60° of flexion, was used during the knee extensions performed by group A. The weight stack was double-pinned to allow only 60° to 0° of flexion for the knee extensions performed by group B.

Subjects trained 2 (N = 25; 13 male, 12 female) or 3 (N = 19; 9 male, 10 female) d wk⁻¹ for a period of 10 sk. During each training session, subjects completed one set of knee extensions with an amount of weight that allowed 7–10 repetitions until failure to complete an additional repetition. Repetitions were performed in a slow, controlled manner, with 2 s required for positive work (raising the weight) and 4 s required for negative work (lowering the weight). When subjects could perform more than 10 repetitions with a given amount of weight, weight was increased by 4.5 kg.

Post-training testing. Following the 10 wk of training, each subject completed two post-training isometric strength tests. The procedure used for these tests was identical to the procedure used during the third and fourth pre-training strength tests.

Treatment of the data. Isometric strength measures were expressed in units of torque (N·m). Reliability coefficients for repeated measurements of isometric strength at multiple joint angles were calculated using Pearson product-moment correlations. Total error and standard error of the estimate were calculated for each joint angle. Orders of testing were evaluated for the pre- and post-training data using analysis of variance (ANOVA) with repeated measures. Order 1 and order 2 tests were averaged to obtain criterion measures of pre-training and post-training isometric strength. Isometric strength changes at each angle of measurement and changes in training weight were analyzed for group effects using an analysis of covariance, with post-training strength measures used as the dependent variable and pre-training strength used as the covariate. ANOVAs were performed using the SAS (17) general linear models procedure. Statistical significance was accepted at P ≤ 0.05. If an F-value was significant, single degree of freedom comparisons were made using a post hoc Tukey’s (19) test.

RESULTS

Pre-training group characteristics are presented in Table 1. Groups did not differ (P > 0.05) with respect to initial age, height, weight, and isometric strength. Pre-training order 1 and order 2 isometric strength tests are illustrated in Figure 1. For both pre- and post-training isometric strength tests a significant (P < 0.01) order by angle interaction was noted.

Reliability coefficients (r), total errors (E), and standard errors of the regression estimate (SEE) for each angle of measurement are presented in Table 2. Reliability coefficients at all angles of measurement were high (r = 0.86–0.95). SEEs were moderate, ranging from 23.1 to 37.2 N·m. Total errors were considerably greater than the SEEs at several angles (9°, 20°, 35°, 50°, and 110° of flexion).
observed, and, therefore, data for subjects training 2 and 3 d·wk⁻¹ were pooled to analyze ROM effects.

Training data are presented in Table 3. Initial weights used for training were similar among groups (P > 0.05). After 10 wk of strength training, group B trained with significantly more weight than groups A or AB (P < 0.01).

Adjusted post-training isometric strength values are illustrated for each group in Figure 2. Post hoc test comparisons among groups are presented in Table 4. All training groups (A, B, AB) showed a significant (P < 0.01) improvement in isometric strength at each angle of measurement when compared to the control except for group A at 9° and 20° of knee flexion and group B at 95° of knee flexion. Peak isometric strength improved to a similar extent (P > 0.05) in all training groups. Group AB showed a similar improvement in isometric strength at each angle throughout the ROM. Group A showed significantly greater (P ≤ 0.05) gains in isometric strength than group B at 80° and 95° of knee flexion. Group B showed significantly greater gains in isometric strength than group A at 20°, 35°, and 50° of flexion.

DISCUSSION

Measurements of isometric strength at different joint angles are often used to describe strength over a full ROM (5,10,18,20). Isometric knee extension strength curves in the present study were ascending-descending curves with maximal values noted between 65° and 50° of knee flexion. This pattern has been described by Kulig et al. (9) in a review of the literature on human strength curves as typical for knee extension.

Two factors were of concern to us initially in establishing our methodology as suitable for evaluating full ROM changes in muscular strength. These factors were 1) the reliability of repeated measurements of isometric strength made at different joint angles and 2) potential fatigue associated with performing repeated isometric contractions. The reliability of repeated measurements of isometric strength at single joint angles has been studied in detail, and reliability coefficients of r = 0.91-

TABLE 2. Reliability coefficients (r, total errors (E), and standard errors of estimate (SEE)) for repeated measurements of isometric knee extension strength at multiple joint angles (N = 59).

<table>
<thead>
<tr>
<th>Angle (Degrees of Flexion)</th>
<th>9°</th>
<th>20°</th>
<th>35°</th>
<th>50°</th>
<th>65°</th>
<th>80°</th>
<th>95°</th>
<th>110°</th>
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<tbody>
<tr>
<td>r</td>
<td>0.86</td>
<td>0.92</td>
<td>0.90</td>
<td>0.93</td>
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<tr>
<td>E</td>
<td>40.1</td>
<td>37.7</td>
<td>46.7</td>
<td>44.1</td>
<td>33.4</td>
<td>28.7</td>
<td>24.0</td>
<td>38.8</td>
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<tr>
<td>SEE</td>
<td>27.5</td>
<td>26.6</td>
<td>37.2</td>
<td>36.2</td>
<td>34.4</td>
<td>27.7</td>
<td>23.1</td>
<td>26.4</td>
</tr>
</tbody>
</table>

* r (57 df) > 0.334, P < 0.01.
† E = \( \sqrt{\sum_{i=1}^{N}(Y_i - \bar{Y})^2/N} \).
‡ SEE = \( \sqrt{1-r^2} \).
§ Values for E and SEE are N·m.

Post-training peak isometric strength values adjusted for pre-training strength were significantly greater (P ≤ 0.05) for subjects that trained 3 d·wk⁻¹ (411.5 N·m) than for subjects that trained 2 d·wk⁻¹ (394.5 N·m). No significant ROM by days per week interaction was
0.99 have been reported (7,8). However, few data are available on the reliability of repeated measurements made at multiple joint angles or on isometric knee extension measurements. Reliability coefficients observed in the present study were high ($r = 0.86-0.95$, $P \leq 0.01$), indicating that the repeated isometric exercise tests were consistent. When total errors were compared to SEEs, a small degree of systematic error was evident at both ends of the isometric knee extension strength curve. Observation of the data plotted in Figure 1 indicates that this systematic error was likely caused by fatigue associated with performing previous contractions during the isometric exercise test.

A small but statistically significant amount of fatigue was noted when order 1 and order 2 tests were compared. This fatigue resulted in a downward shift in the isometric strength curve toward the last angles of measurement. Because the present study was concerned with evaluating changes in full ROM strength, muscular fatigue occurring as a result of performing repeated isometric contractions could potentially bias the results if measurement angles were set in only one order. This would result in reduced isometric strength values observed in the ROM that was evaluated last. In anticipation of this fatigue factor, testing in the present study was conducted from flexion to extension (order 1) and from extension to flexion (order 2), and the results from the two orders of testing were averaged to obtain criterion measures for evaluation.

The present study provided a 10 s rest interval between contractions. Previous studies that have described knee extension strength curves have reported intertrial rest intervals of 1 min (18) or a “short rest pause” (5) or have not reported their intertrial rest intervals (3,10,20). Providing rest intervals greater than 10 s could potentially minimize the amount of fatigue resulting from previous contractions and should be considered when it is imperative to obtain maximum isometric strength values at multiple joint angles. Because all groups in the present study were evaluated using both modes of testing before and after training, fatigue should not have influenced our group comparisons.

The present study used a variable resistance knee extension machine for training. In theory, a variable resistance enables the strongest positions in the ROM to work against the greatest resistance and the weakest positions in the ROM to work against less resistance. Group AB, which trained through a full ROM, showed a similar improvement in isometric strength at each angle measured. The actual resistance pattern offered by the training apparatus (machine resistive torque) is presented with the observed subject torque curve in Figure 3. The machine resistive torque curve is flatter and peaks earlier in the range of motion (flexion to

![Graph showing isometric strength values](image)

Figure 2—Adjusted post-training isometric strength values following 10 wk of dynamic strength training. Group A trained from 120° to 60° of knee flexion. Group B trained 60° to 0° of knee flexion. Group AB trained 120° to 0° of knee flexion. The control group did not train.

<table>
<thead>
<tr>
<th>Angle (Degrees of Flexion)</th>
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* Groups were compared using Tukey's (19) method for pairwise comparisons.
extension) than the pre-training knee extension torque curve. These data and previous research (4) suggest that the machine resistive torque of variable resistance exercise machines does not perfectly correspond to muscular torque capability. However, the present training data for group AB support the concept that some variable resistance training machines can provide a uniform training stimulus throughout a full ROM.

Angular specificity of isometric strength training has been identified by some (1,11,12) but not all (16) investigations. Knapik et al. (6) observed a significant transfer of isometric strength within 20° of the training angle. Other studies have demonstrated that, at 40° (12), 45° (11), and 70° (1) from the training angle, little transfer of isometric strength occurs. The primary focus of the present investigation was to examine the effect of limited ROM dynamic resistance training on full ROM strength. When compared to the control group, the limited ROM training groups improved in isometric strength at each angle measured except for group A at 9° and 20° of flexion and group B at 95° of flexion. The greatest improvements in isometric strength for the limited ROM groups, however, were noted in the ranges of training. Thus, angular specificity for limited ROM dynamic resistance training was identified.

It may be of interest to note that group B, the group that trained the quadriceps in the more contracted position, showed the greatest improvement in training weight. Peak isometric strength increases did not differ among the groups that trained. Raitsin (15) found that isometric strength training of the elbow flexors at 70° of flexion (flexed position) produced greater strength increases but less transfer of strength to untrained positions when compared with training at 150° of flexion (extended position). At present we are unable to explain why our training data are consistent with the findings of Raitsin (15) but the isometric data are not. Perhaps because our training program involved dynamic exercise through a limited ROM, as opposed to isometric training, there is a specificity of testing/training involved.

The findings of the present study have important clinical application. Exercise during rehabilitation from joint injury or surgery is often prescribed in a limited ROM. Range of movement may be limited due to pain, muscle and joint weakness, or for safety. The present data suggest that strength improvement over a full ROM may be obtained from limited ROM exercise, especially when joint range is limited to areas of maximal muscle shortening. Improvement from limited range exercise, however, is not as great at all angles as that obtained from full ROM exercise. Thus, as the condition permits, it is recommended that joint range be extended and exercise performed throughout a greater range of movement.

In conclusion, the present study showed that repeated measurements of isometric knee extension strength at different joint angles are highly reliable. A small but statistically significant amount of fatigue was noted for repeated trials of isometric contraction separated by 10 s rest intervals and resulted in an increased error of measurement. This fatigue factor may not be important when assessing changes in isometric strength among treatment groups but should be considered a limitation when maximal values must be obtained at each joint angle. Some full ROM benefits were obtained from limited ROM resistance exercise training performed through one half of the ROM (60°). Maximal isometric strength gains, however, were noted in the trained ROM. Thus, there is an angular specificity for limited ROM dynamic resistance training. The clinical implications of these findings are that limited ROM exercise can be performed to elicit some full ROM strength improvement. Range of movement should be progressed to a full ROM as the condition allows to attain maximum improvement in strength.

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