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Constant vs variable resistance knee extension training

RENATA J. MANNING, JAMES E. GRAVES, DAVID M. CARPENTER, SCOTT H. LEGGETT, and MICHAEL L. POLLOCK

Center for Exercise Science,
College of Medicine, and
College of Health and Human Performance,
University of Florida,
Gainesville, FL 32611

ABSTRACT

MANNING, R. J., J. E. GRAVES, D. M. CARPENTER, S. H. LEGGETT, and M. L. POLLOCK. Constant vs variable resistance knee extension training. *Med. Sci. Sports Exerc.*, Vol. 22, No. 3, pp. 397–401, 1990. To compare the effect of constant resistance (CR) and variable resistance (VR) training on full range-of-motion (ROM) strength development, 22 men and 27 women (age = 26 ± 5 yr) were randomly assigned to either a CR training group (N = 17), a VR training group (N = 17), or a control group (N = 15) that did not train. The CR and VR groups trained 2 to 3 d · wk^{-1} for 10 wk. Subjects completed one set of full ROM (120 to 0° of flexion) bilateral knee extensions with an amount of weight that allowed 8 to 12 repetitions during each training session. For the VR group, resistance was varied with a cam supplied by the manufacturer (Nautilus®). For the CR group, the cam was removed and replaced with a round sprocket. Prior to and after training, maximal voluntary isometric torque was measured at 9, 20, 35, 50, 65, 80, 95, and 110° of knee flexion. Analysis of covariance indicated that the VR and CR groups gained strength at all angles ($P \leq 0.05$) when compared to the control.

	Angle (degrees of flexion)							
Group	9	20	35	50	65	80	95	110
Control	100.1	208.0	273.7	322.0	323.9	277.0	238.0	238.0
CR	200.6*	247.3*	330.8*	392.0*	382.3*	322.8*	264.1*	258.8*
VR	182.8*	246.4*	317.9*	380.8*	386.8*	317.3*	269.8*	253.4*

Values are adjusted mean torques (N · m).
* $P \leq 0.05$ vs control.

There was no difference ($P > 0.05$) between the CR and VR groups at any angle, and the magnitude of strength gained was similar ($P > 0.05$) among angles for both groups. These data indicate that both CR and VR knee extension training elicit full ROM strength development.

CONSTANT RESISTANCE, VARIABLE RESISTANCE, ISOMETRIC TORQUE, RESISTANCE TRAINING, KNEE EXTENSION, MUSCULAR STRENGTH

Resistance training is an effective method of attaining and maintaining muscular strength (2,9) and is widely used in conditioning, general fitness, and rehabilitation programs. In recent years, new ideas have been applied to resistance training techniques in an attempt to produce greater and more efficient improvements in strength. Due to the biomechanical arrangement of muscles with the bony levers of the skeletal system, the magnitude of muscular strength is dependent on the joint configuration (joint angle) at the time of measurement and varies throughout the range of motion (ROM) (14). It is with this concept in mind that variable resistance strength training machines have been developed. These machines attempt to accommodate the muscle's changing level of force output throughout the ROM by varying the resistance produced by the machine. As stated by Kulig et al. (14), strength gains resulting from overloading the muscle at all points throughout the ROM are thought to be superior to strength gains resulting from a constant resistance that overloads the muscle only at a specific critical joint configuration (i.e., the "sticking point" in the ROM).

Data presented by Graves et al. (10) support the effectiveness of variable resistance training. Their study showed that full ROM variable resistance training resulted in uniform strength increases throughout the full ROM while limited ROM variable resistance training produced only limited strength benefits in the unworked ROM. Although previous literature provides evidence that both constant (1,4–6,8,17,19–22) and variable resistance training (1,6,8,10,11,17,19,20) produce significant improvements in muscular strength, the influence of constant resistance training on full ROM strength has not been reported. The purpose of the present study was to evaluate and compare the effect of constant resistance and variable resistance training on full ROM strength development.

METHODS

Subjects. Twenty-two men (age = 27.0 ± 6.2 yr; height = 178.9 ± 7.0 cm; weight = 75.6 ± 10.7 kg) and 27 women (age = 25.6 ± 5.6 yr; height = 165.8 ± 5.6

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cm; weight = 61.3 ± 9.4 kg) volunteered to participate in this study. They were healthy, active individuals who had not participated in a regular weight training program for at least 1 yr prior to the present investigation. None of the subjects had musculoskeletal dysfunction or other medical conditions that would contraindicate exercise, and they were required not to change their normal daily activities during the course of the study. All subjects read and signed an informed consent document in accordance with the University of Florida's Institutional Review Board and the American College of Sports Medicine's policy for the protection of human subjects.

Strength measurements. All subjects completed four tests of bilateral knee extension strength prior to the start of training. These tests were separated by a minimum of 48 h. For each strength test, maximal voluntary isometric torque was measured during bilateral knee extension at 9°, 20°, 35°, 50°, 60°, 80°, 95°, and 110° of knee flexion with a Nautilus® (Dallas, TX) knee extension tensiometer. Joint angles were set using an internal electric goniometer (potentiometer) interfaced to an IBM microcomputer. The force transducer and electric goniometer of the tensiometer were calibrated daily using a software controlled system supplied by the manufacturer.

The subjects were seated 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 subjects' position could be standardized for the remaining testing and training sessions. Subjects were instructed to extend their legs against the pad on the lever arm of the tensiometer by slowly building tension to a maximal effort over a 2–3 s period. A 10 s rest period was provided between each isometric contraction. Subjects were given verbal encouragement and concurrent visual feedback of their performance on a video display screen during each isometric contraction.

The first two strength tests were considered practice to allow the subject to become familiar with the equipment and testing procedure. Strength measurements obtained during the third and fourth test sessions were used to calculate criterion measures of pre-training strength. To help offset any muscular fatigue associated with performing repeated isometric contractions, the third and fourth strength tests were conducted in two different orders. For order 1, the joint angles were set beginning with 110° of flexion and progressed to 9° of flexion. For order 2, the angles were set beginning with 9° of flexion and progressed to 110° of flexion. The reliability for this method of testing is high and has been reported in detail previously (10). The order of testing was randomly assigned and balanced over subjects and days.

Training. After completing the four pre-training strength tests, subjects were randomly assigned to one of three groups. One group trained using a variable resistance (VR), a second group trained using a constant resistance (CR), and a third group served as a control and did not train. The characteristics of the subjects in each of these groups are presented in Table 1.

Training was conducted on the same Nautilus® knee extension machine that was used for the isometric strength testing. For the VR group, resistance was varied by the use of a cam supplied with the machine. After the VR group completed training, the cam was taken off of the machine and replaced with a round sprocket to create a constant resistance throughout the full ROM for the CR group. In this respect, the same machine was used for training by both the VR and CR groups and only the pattern of resistance offered by the machine was changed. Machine resistive torque curves for both training groups are illustrated in Figure 1.

Subjects trained 2 or 3 d · wk^{-1} for 10 wk (CR: 3 d · wk^{-1} $N = 9$, 2 d · wk^{-1} $N = 8$; VR: 3 d · wk^{-1} $N = 9$, 2 d · wk^{-1} $N = 8$). For each training session, subjects completed one set of full ROM bilateral knee extensions using an amount of weight that allowed 8 to 12 repetitions, with failure due to muscular fatigue occurring during the last repetition. Each repetition was performed in a slow controlled manner, with a 2 s count required for the positive portion of the lift (raising the

TABLE 1. Group characteristics ($N = 49$).

	Group		
	Control	Constant Resistance	Variable Resistance
Men			
N	6	8	8
Age (yr)	26.3 ± 5.2 (20 - 34)	28.4 ± 8.7 (20 - 46)	26.0 ± 4.2 (21 - 35)
Height (cm)	176.8 ± 3.5) (172.1 - 181.0)	180.0 ± 7.8 (168.4 - 192.2)	179.5 ± 8.5 (161.3 - 189.9
Weight (kg)	68.4 ± 4.0 (62.5 - 74.4)	76.3 ± 7.7 (62.7 - 86.4)	80.3 ± 14.3[b] (59.7 - 99.9)
Strength (N · m)[a]	335.4 ± 24.2 (297.8 - 366.1)	371.1 ± 67.9[c] (248.4 - 460.6)	293.3 ± 49.6 (186.7 - 343.8)
Women			
N	9	9	9
Age (yr)	27.4 ± 4.8 (21 - 33)	23.8 ± 6.3 (17 - 38)	25.7 ± 5.5 (18 - 34)
Height (cm)	166.0 ± 5.1 (155.6 - 174.6)	167.5 ± 4.9 (159.3 - 175.8)	164.0 ± 6.6 (151.8 - 172.1)
Weight (kg)	61.0 ± 7.3 (54.3 - 75.8)	62.7 ± 11.0 (48.3 - 85.9)	60.0 ± 10.5 (48.5 - 79.1)
Strength (N · m)[a]	189.5 ± 38.6 (127.8 - 239.4)	243.5 ± 44.5[d] (185.4 - 326.5)	187.5 ± 51.9 (86.3 - 241.6)

Values are means ± SD. Ranges are in parentheses.
[a] Strength is the mean pre-training isometric torque measured at 9, 20, 35, 50, 65, 80, 95, and 110° of knee flexion.
[b] Variable > Control; $P < 0.05$.
[c] Constant > Variable; $P < 0.01$.
[d] Constant > Control, Variable; $P < 0.01$.

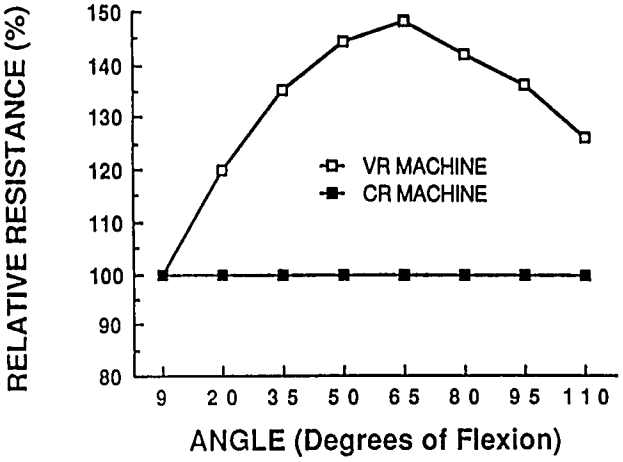

Figure 1—Relative resistance offered by the variable resistance (VR) and constant resistance (CR) training machines. Resistance is expressed as a percentage of the lowest resistance noted within the tested range of motion.

weight) and a 4 s count required for the negative portion of the lift (lowering the weight). When subjects were able to complete 12 or more repetitions with good form, the weight was increased by 2.27 kg. All training sessions were monitored by experienced laboratory personnel. The number of repetitions completed and the weight load lifted during each training session were recorded.

Post-training testing. After completing the 10 wk of training, subjects were given two post-training isometric strength tests. The procedure used for the post-training testing was identical to that of the third and fourth pre-training strength tests.

Treatment of the data. Isometric strength was measured in units of torque (N · m). The torque values at each angle of measurement were averaged over the order 1 and order 2 pre- and post-tests to obtain criterion measures of pre-training and post-training strength. Means and standard deviations were calculated for each joint angle measured. Changes in isometric knee extension strength were evaluated within groups using a two-way analysis of variance with repeated measures. Main effects were Time and Angle, and the Time by Angle interaction was used to determine whether the shape of the strength curve changed as a result of training. Because pre-training torque values differed among groups, strength training responses among groups were compared using an analysis of covariance. Pre-training isometric torque values were used as the covariate. The Group by Angle interaction for the adjusted post-training means was used to determine whether the shape of the strength curve differed among groups after training. Training weights were also compared for the CR and VR groups using an analysis of covariance. The initial training weight used was the covariate. An alpha level of $P \leq 0.05$ was required for statistical significance.

RESULTS

Isometric torque values before and after training are illustrated for each group in Figure 2. Both the CR and VR groups showed significant improvements ($P \leq 0.05$) in isometric knee extension strength at each angle of measurement following the training period. The control group did not change significantly ($P > 0.05$) at any angle following the 10 wk control period. No significant Time by Angle interactions were noted for the CR and VR groups, indicating that the training responses within these groups were similar throughout the ROM.

The adjusted post-training isometric torque values for each group are plotted in Figure 3. The CR and VR groups had significantly greater isometric torque values ($P \leq 0.05$) at each angle of measurement when compared to the control group. No significant differences ($P > 0.05$) existed between the adjusted post-training

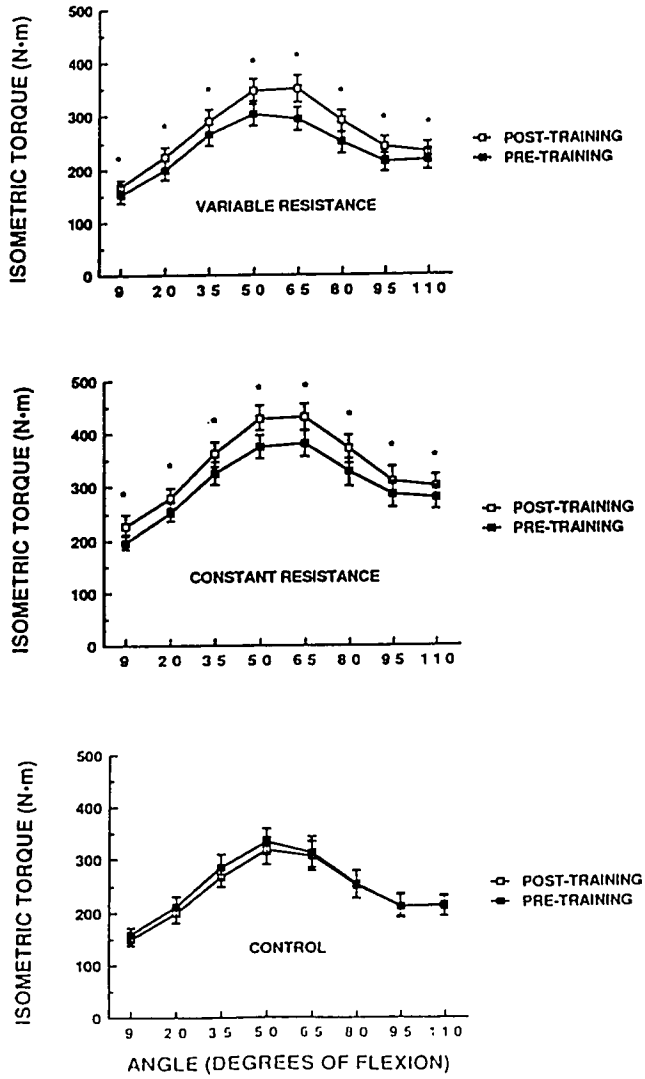

Figure 2—Pre- and post-training averaged torque values at each angle of measurement for the variable resistance, constant resistance, and control groups. *$P \leq 0.05$.

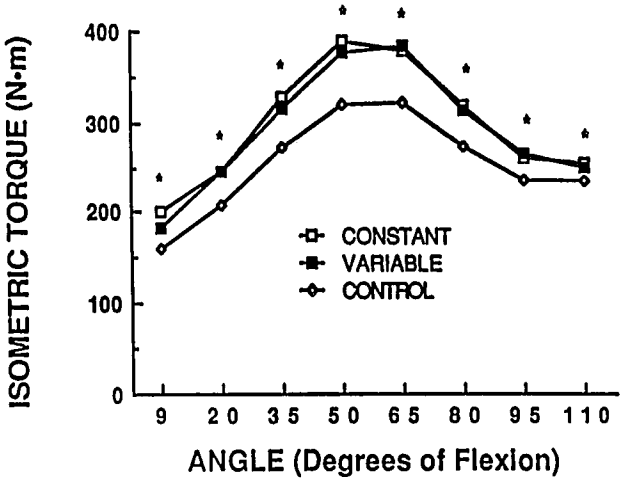

Figure 3—Adjusted post-training torque values at each angle of measurement for the variable resistance, constant resistance, and control groups. *Variable, constant > control ($P \leq 0.05$).

TABLE 2. Training data.

	Group	
	CR	VR
Pre-training weight (kg)[a]	60.3 ± 17.8	44.7 ± 12.7
Post-training weight (kg)[b]	73.8 ± 19.5	65.2 ± 20.0
Absolute change (kg)	13.5 ± 5.9	21.5 ± 9.8
Relative change (%)	23.7 ± 10.7	45.9 ± 19.3
Adjusted post-training weight (kg)[c]	64.6	74.4*

Values are means ± SD.
[a] Pre-training weight was the average weight used during the 1st wk of training.
[b] Post-training weight was the average weight used during the last week of training.
[c] Post-training weights adjusted by analysis of covariance. The pre-training weight was used as the covariate.
* $P \leq 0.01$.

torques for CR and VR, and there was no significant ($P > 0.05$) Group by Angle interaction.

Training weights are presented in Table 2. During the 1st wk of training, the CR group trained with significantly ($P \leq 0.01$) more weight than the VR group. Evaluation of the adjusted post-training and training weights revealed that the VR group increased their training weight to a greater extent ($P \leq 0.01$) than the CR group.

DISCUSSION

The present investigation demonstrated that significant increases in isometric and dynamic strength are obtained from both variable and constant resistance training. These findings are in agreement with previously reported data (1,4–10,17,19–22). Our primary interest was to evaluate the training response through a full ROM. To accomplish this, isometric torque was measured at multiple joint angles. Specificity of training indicates that different modes of testing and training will influence the magnitude of measured strength gains (3,8,12,19,20). In general, changes in isometric strength are not as great as changes in dynamic strength following dynamic resistance training (3,10,12). However, because the responses for both the VR and CR groups trained in the present study were evaluated using the same isometric test, test specificity should not have influenced our comparison among groups.

No data exist comparing the effectiveness of constant and variable resistance training modes on full ROM strength development. If a constant resistance effectively overloaded a muscle only at a specific joint angle ("sticking point"), it would be expected that increases in strength from constant resistance training would be limited to this specific angle. Our results do not support this contention. In fact, the magnitude of strength gained was lowest at the weaker angles although, statistically, strength gains did not differ among angles for the CR group. In addition, the improvements in strength observed for the constant resistance training were similar to those observed for variable resistance training (Fig. 3). That is, both the CR and VR groups increased in isometric strength to a similar extent at each angle measured throughout the ROM following 10 wk of training.

Previous testing on the equipment used in the present study has shown that the knee extension strength curve is ascending-descending, with the weakest joint angles positioned at the beginning (flexion) and end (extension) of the ROM (10). Thus, it is the strength at these positions that will limit the amount of constant resistance used during training. Although the strength in the middle of the ROM (35 to 80° of flexion) is significantly greater than at either end, the resistance used during constant resistance leg extension exercise was found to be sufficient to elicit full ROM training benefits.

We are challenged to explain why the magnitude of strength gained from constant resistance training was similar throughout the ROM. One viable explanation may be that there is a significant carry-over of strength to the unworked areas associated with resistance training. Knapik et al. (12) have shown that, when a muscle is trained isometrically at a specific joint angle, strength increases will carry over to 20° on either side of that angle. Graves et al. (10) reported a similar carry-over effect using limited ROM variable resistance training. The greatest changes in strength noted by Graves et al. (10) occurred in the ROM that was trained. Although strength improvements were significantly reduced as little as 20° from the trained ROM, some full ROM strength improvement was noted in the unworked ROM. This was especially true for strength carry-over resulting from training in the latter half of the extended ROM (60 to 0° of knee flexion). In addition to the possibility of strength carry-over to unworked areas, it is possible that the submaximal training stimulus provided by a constant resistance at the strongest positions in the ROM is sufficient to elicit a significant training response.

An additional factor that may contribute to full ROM training responses for both constant and variable resistance exercise is the speed of the exercise completed during training. Slow, controlled movements were emphasized during training in the present study in an attempt to minimize the influence of momentum and to accentuate the eccentric portion of the lift. It has been suggested that exercise at slow speeds closely simulates isometric effort (18). Although we did not evaluate training at fast speeds, momentum resulting from fast speed training may reduce the training stimulus at the end of the ROM. The effectiveness of eccentric training has been demonstrated by Komi and Buskirk (13). Although other studies comparing concentric and eccentric training are equivocal (see Fleck and Kraemer (7) for review), Madsen and McLaughlin (15) and McLaughlin et al. (16) have found that stronger competitive weight lifters spend more time in the eccentric portion of the lift when compared to less skilled lifters. Thus, similarity in speed of movement and the accentuation of the eccentric portion of the training exercise may have minimized potential differences between constant and variable resistance training.

Although the changes in training weight (Table 2) suggest that variable resistance training may elicit greater improvements in dynamic strength when compared to constant resistance training, these data must be interpreted cautiously. Varying the resistance used for training may have offered the VR group a greater mechanical advantage during training. In addition, the CR group was stronger than the VR group prior to training. It is possible, therefore, that the VR group had a greater potential for strength gain.

In summary, the results of this investigation indicate that 10 wk of constant and variable resistance training induce significant improvements in both isometric and dynamic muscular strength. For the knee extension exercise studied, strength gains were similar at each angle measured for both types of training. It is concluded that the training stimulus from both constant and variable resistance knee extension exercise is sufficient to elicit full ROM training responses when the exercise is performed slowly and with an eccentric component.

Address for correspondence: James E. Graves, Ph.D., Center for Exercise Science, Room 27 Florida Gymnasium, University of Florida, Gainesville, FL 32611.

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