Isotonic preload versus isokinetic knee extension resistance training

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ABSTRACT

KOVALESKI, J. E., R. H. HEITMAN, T. L. TRUNDLE, and W. F. GILLEY. Isotonic preload versus isokinetic knee extension resistance training. *Med. Sci. Sports Exerc.*, Vol. 27, No. 6, pp. 895–899, 1995. To examine training (3 d·wk^{-1} for 6 wk) differences using active robotic isotonic and isokinetic concentric knee extension resistance on full range of motion (ROM) (90° to 0° of flexion) strength development and power, 22 men and 10 women were randomly assigned to either an isotonic, isokinetic, or control group. The isotonic group exercised using a preload resistance that was initially set at 25% of peak isometric torque and then increased 5 N·m each week. The isokinetic group exercised at 120, 150, 180, and 210°·s^{-1} using a velocity spectrum protocol. Before and after training, isotonic power (W), isokinetic power (W) at speeds of 120°·s^{-1}, 150°·s^{-1}, 180°·s^{-1}, and 210°·s^{-1}, and isometric torques (N·m) at 10°, 30°, 50°, 70°, and 90° of knee flexion were measured. Analysis of variance using repeated measures showed: 1) isotonic is superior to isokinetic resistance training in terms of increasing muscle strength ($P < 0.05$) and power ($P < 0.05$); 2) isotonic preload knee extension resistance training elicits full ROM strength development ($P < 0.05$); and 3) power ($P < 0.05$) increases are specific to isotonic training despite the testing mode.

MUSCULAR STRENGTH, MUSCULAR POWER, ISOMETRIC TORQUE, CONCENTRIC MUSCLE CONTRACTION

Isotonic and isokinetic resistance training are two effective methods for improving muscular power (1,2,16,22,27) and strength (4,12,16,17,22,24). Performance of an isotonic muscle contraction occurs through a range of motion with a constant load or resistance. The external force produced during isotonic loading is affected by the angle of pull, muscle length at any given time in the range of motion (ROM), and muscle shortening velocity. This creates maximal external loading at a specific point in the ROM, while the rest of the ROM is worked at less than maximal capacity (15). In contrast, performance of isokinetic training under conditions of constant angular velocity involves maximally loading the muscle at every point in the range of motion. An increase or decrease in the applied force results in a corresponding increase or decrease in the resistance (18). Strength increases after isokinetic training are attributed to the nature of the accommodating resistance and to greater work performed in the same time as compared to the work done during constant resistance exercise (7,18).

Isokinetic and isotonic exercise concepts are applied to resistance training methods and technology in an attempt to improve muscular strength and power. One such application incorporates using the dynamometer to provide either constant or accommodating muscle loading. With the use of active robotics, it is possible to evaluate and exercise the muscle using either isokinetic (where the individual's effort determines the load) or isotonic (constant) resistance. With an isotonic contraction, the velocity is variable while the load is controlled using a preloaded resistance that is initially set as a percentage of isometric strength. Preload is the amount of force or torque that the limb must overcome before the actuator arm will initiate movement. Therefore, the limb must overcome the preload resistance to accelerate through the ROM. Any increase in applied force by the subject will be absorbed by the dynamometer and returned as a directly proportional increase in velocity. As compared to conventional isokinetic movement, training with isotonic preload movement could provide a means for increasing muscular strength and power that reflects contraction conditions similar to natural strength-requiring movements. The purpose of this study was to compare the effects of isotonic preload and isokinetic concentric knee extension loading on ROM strength development and peak power following 6 wk of training.

METHODS

Subjects

Thirty-two recreationally active college students volunteered to participate. Each was randomly assigned to

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either an isotonic (male = 8, female = 3; age = 23.0 ± 3.3 yr; weight = 81.8 ± 19.1 kg; height = 165.2 ± 3.5 cm), isokinetic (male = 7, female = 4; age = 22.5 ± 2.9 yr; weight = 71.6 ± 15.1 kg; height = 164.7 ± 4.6 cm), or control (male = 7, female = 3; age = 23.1 ± 1.5 yr; weight = 74.9 ± 14.0 kg; height = 166.1 ± 2.1 cm) group. No subject had participated in a regular weight training program for at least 9 months prior to the present investigation. Each participant refrained from participating in heavy resistance weight training or endurance training during the study. Usual recreational and daily living activities were allowed. According to institutional guidelines, before they gave their signed consent to participate, all subjects read and were informed of the nature, purpose, and possible risks involved in this study.

Instrumentation

Testing and training of the dominate knee extensor muscles were conducted using a LIDO Active Dynamometer (Loredan Biomedical, West Sacramento, CA). Each subject was seated and the dynamometer shaft aligned with the lateral epicondyle of the femur. The position of the back rest and LIDO actuator height were recorded so that each subject's position was standardized for the remaining testing and training sessions. The ipsilateral thigh was secured with a bolster while the contralateral leg was left unsecured and a large Velcro strap secured the pelvis and torso. Arms were at the side with hands grasping handles. The lever arm pad was positioned to place the inferior rim immediately superior to the medial malleolus. Additional detailed information concerning the positioning of subjects and the reliability and validity of this dynamometer have been reported previously (19).

Pretraining Testing

Each subject kicked a ball to determine leg dominance. On two separate days beginning 1 wk before testing, each subject observed and practiced the three muscle contraction tests to become familiar with the apparatus. Forty-eight hours separated the second familiarization session and the pretraining test.

The pretraining test required each subject perform three knee extension trials that consisted of isometric, isotonic, and isokinetic concentric muscle contractions. Testing was performed on two days and was separated by 24 h. Multiple angle isometric knee extension contractions were performed on the first testing day, while the isotonic and isokinetic knee extension contractions were performed on the second testing day. Isometric peak torque (N·m), isotonic peak power (W), and isokinetic peak power (W) at 120, 150, 180, and 210°·s^{-1} were recorded for data analysis.

The maximal voluntary isometric muscle contractions were performed at 10°, 30°, 50°, 70°, and 90° of knee flexion. Joint angles were set using an internal electric goniometer located in the LIDO actuator interfaced to a microcomputer. Subjects extended their leg against the lever arm pad by building tension to a maximal effort over 10-s. Thirty-second rest was provided between each isometric contraction. To help offset muscular fatigue associated with performing repeated isometric contractions, isometric testing was conducted using two different progression orders. For order 1, the joint angles were set beginning with 90° of flexion and progressed to 10° of flexion. For order 2, the angles were set beginning with 10° of flexion and progressed to 90° of flexion. The reliability of this method of testing is high and has been reported in detail (6). In addition, the order for isometric testing was randomly assigned and balanced over subjects and for the pre- and posttesting days.

The isotonic and isokinetic concentric muscle contractions were performed through a 90° ROM. Terminal extension was considered 0°. The isotonic preload test protocol consisted of each subject performing six submaximal and three near-maximal repetitions for warm-up followed by a 60-s rest. The subject then performed six maximal contractions while being encouraged to extend the knee against the preloaded resistance through the range of motion as hard and fast as possible. The preload resistance was determined and set at 25% of the peak isometric torque produced at 70° of knee flexion. This value was based upon the authors' clinical observations using different preload values and isometric angles that could be successfully completed during both the testing and training sessions.

The isokinetic test protocol consisted of performing six maximal effort repetitions, each at 120, 150, 180, and 210°·s^{-1}. The warm-up protocol was similar to the isotonic test warm-up, except the warm-up preceded each of the four testing speeds. A 60-s rest period was provided between each isokinetic testing speed. During the isokinetic testing, subjects were encouraged to extend the knee as hard and as fast as possible through the ROM (90° to 0° of knee flexion). A 5-min rest period separated the isotonic and isokinetic tests. The order of testing was randomly assigned and balanced between the pre and posttesting sessions.

Training Program

After completing the pretraining testing, subjects were randomly assigned to one of three groups. One group trained using isokinetic resistance, a second group trained using isotonic preload resistance, and a third group served as a control and did not train. Training was conducted on the same LIDO dynamometer used for testing.

Subjects trained 3 d·wk^{-1} for 6 wk. For each training session, both the isokinetic and isotonic groups completed 12 sets of 10 repetitions of full ROM knee extensions. One minute separated each set of 10 repetitions.

TABLE 1. Isokinetic incremental velocity spectrum training protocol.

Velocity (°·s^{-1})	Repetitions
120	10
150	10
180	10
210	10
210	10
180	10
150	10
120	10
120	10
150	10
180	10
210	10

The isokinetic group exercised using a standard (13,14,21,26) incremental velocity spectrum training protocol (Table 1). The isotonic group exercised the first week at the same preload resistance used for the pretraining test. The preload was increased 5 N·m at the beginning of each week of training to provide a progressive resistance exercise effect. All training sessions were monitored.

Posttraining Testing

After completing the 6 wk of training, each subject performed the isometric, isotonic, and isokinetic tests. The procedures used for the posttraining testing were identical to those of the pretraining testing.

Statistical Analysis

The experimental design employed to examine the effects of isotonic and isokinetic training on strength was a 3 × 2 factorial design with repeated measures on the last factor. This design allowed manipulation of the independent variables, the two training methods (isotonic vs isokinetic) along with a control group, and the pre- and posttest measures taken on each subject. The dependent variables were isotonic peak power (W), isokinetic peak power (W) at speeds of 120°·s^{-1}, 150°·s^{-1}, 180°·s^{-1}, and 210°·s^{-1}, and isometric peak torque (Newton-meters) at 10°, 30°, 50°, 70°, and 90° of knee flexion. Three separate 3 × 2 ANOVA were computed, one for each dependent variable. Differences among means were analyzed using the Scheffé test ($P \leq 0.05$). All data are presented as means ± SE.

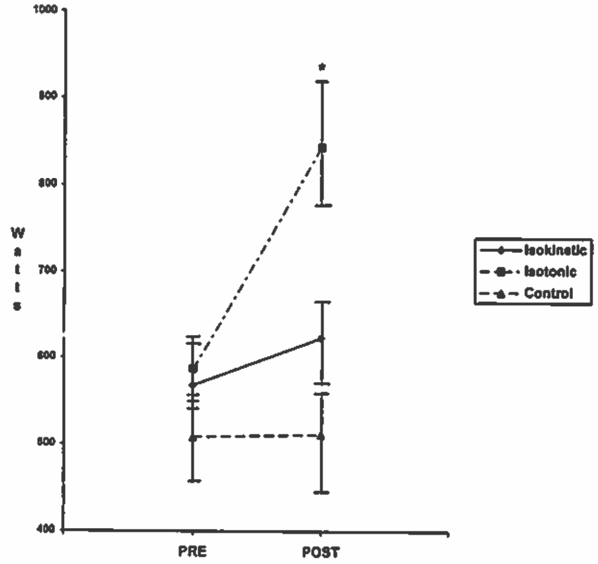

Figure 1—Group comparisons across pre and posttest isotonic power scores. (* isotonic > isokinetic and control; $P < 0.05$). Values are means ± SE.

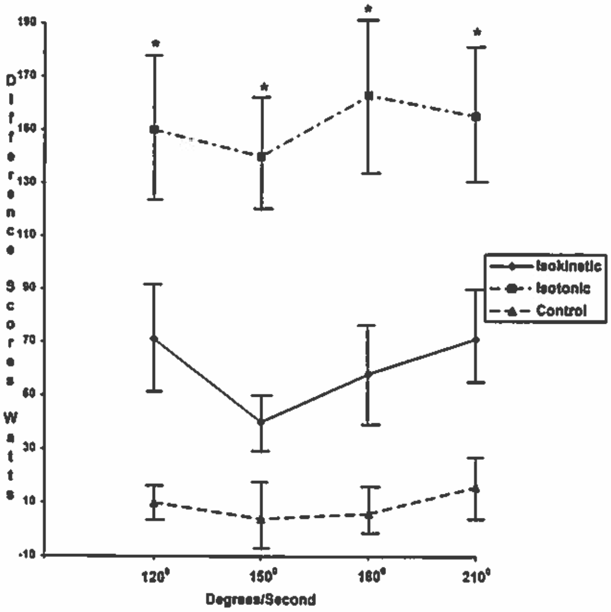

Figure 2—Group comparisons across isokinetic velocities. Values are means ± SE of pre to post differences in power (* isotonic > isokinetic and control; $P < 0.05$).

RESULTS

The isotonic group produced greater peak isotonic power than the isokinetic and control groups [F(2,29) = 34.97; P = 0.0001) (Fig. 1). The isotonic group also produced greater peak isokinetic power than the isokinetic and control groups at 120°·s^{-1} [F(2,29) = 12.78; P = 0.0001), 150°·s^{-1} [F(2,29) = 20.27; P = 0.0001), 180°·s^{-1} [F(2,29) = 14.17; P = 0.0001); and 210°·s^{-1} [F(2,29) = 10.65; P = 0.0003). No differences in isokinetic power were observed between the isokinetic and control groups ($P > 0.05$) (Fig. 2).

At 90° of knee flexion, the isotonic group produced greater peak isometric torque than the isokinetic and control groups [F(2,29) = 10.11; P = 0.0005). At the 70° angle, the isotonic group produced greater peak isometric torque than the isokinetic and control groups, and the isokinetic group produced greater peak isometric torque than the control [F(2,29) = 19.85; P = 0.0001). At the 50° [F(2,29) = 6.65; P = 0.004), 30° [F(2,29) = 7.32; P = 0.003), and 10° [F(2,29) = 3.59; P = 0.051) angles

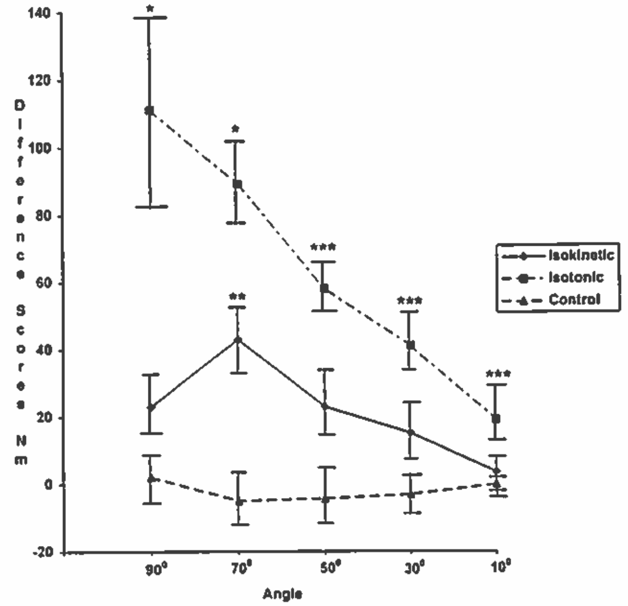

Figure 3—Group comparisons across isometric torque angles. Values are means ± SE of pre to post differences in peak torque. * isotonic > isokinetic and control, $P < 0.05$; ** isokinetic > control, $P < 0.05$; * isotonic > control, $P < 0.05$.**

the isotonic group produced greater isometric torque than the control group (Fig. 3).

DISCUSSION

Although previous reports present evidence that both isotonic and isokinetic resistance training produces improvements in muscular strength, the influence of preload isotonic training using active robotics on power and strength has not been reported. The present investigation demonstrated that greater increases in isometric strength and dynamic power are produced after isotonic resistance training than isokinetic training. This illustrates the importance of achieving maximal muscle activation using constant resistance and variable velocity during training.

The effectiveness of isotonic preload resistance training on strength development has not been reported. Our primary interest was to evaluate the training response using a 90° ROM. To accomplish this, multiple joint angle isometric torque and isotonic and isokinetic power were measured to illustrate dynamic changes in muscle function. If isotonic resistance optimally overloads a muscle only at a specific point in the ROM while the rest of the ROM is worked at less than optimal capacity, it would be expected that increases in strength from the isotonic resistance would be limited to this specific angle. In theory, if isokinetic resistance involves maximally loading the muscle at every point in the range of motion, strength increases would be expected to occur throughout the ROM. Our results do not support either contention. The amount of strength gained throughout the ROM for the isotonic group was greater than the isokinetic group (Fig. 3). In addition, the isotonic group produced greater isotonic (Fig. 1) and isokinetic (Fig. 2) power than both the isokinetic and control groups. We feel that isotonic power better reflects dynamic muscle function because velocity was variable throughout the ROM. This could help produce contraction conditions similar to natural strength requiring movements since movement is generally not performed at a constant velocity.

Specificity of training suggests that different modes of testing and training will influence the size of measured strength gains (4,9,24,25). However, Knapik et al. (10) compared the relationships among isometric, isotonic, and isokinetic strength measurements in knee flexion and extension and found a generally high correlation among torque measurements. They concluded that one method of testing may be an adequate predictor of maximal voluntary strength of other testing methods. Training responses for both the isotonic and isokinetic groups in the present study were evaluated using the same isometric test. Therefore, test specificity should not have influenced our comparison among groups.

Controversy exists concerning the physiological mechanisms responsible for increasing muscular strength and power during isokinetic exercise (1,2,16,20). Performing 6- or 30-s bouts of maximal isokinetic contractions resulted in similar gains in peak torque and changes in muscle fiber area after training (1,16). However, only the 30-s exercise program resulted in elevated glycolytic, ATP-CP and mitochondrial enzyme activities (1). Despite these changes, none of the parameters were related to the gains in either muscle strength or fatigability. Therefore, the stimulus responsible for increasing muscle enzyme activities appears related to the duration of each isokinetic exercise bout and not the quantity of work performed by the muscle. It is possible that isokinetic velocity spectrum training protocols that use specific sets and repetitions do not provide sufficient duration of contraction to promote skeletal muscle adaptations. This may partially explain the differences observed between the isokinetic and isotonic groups in the magnitude of strength and power gains despite the fact that both groups used the same number of sets and repetitions. Individuals who isokinetically exercise to improve muscular strength and power may need to use larger volumes of training as compared to those who train isotonically (20).

Another possible mechanism that explains the differences between isokinetic and isotonic contractions involves the adaptation of neurological control of muscle fiber recruitment. Isokinetic velocity spectrum advocates have claimed that both type I and type II muscle fibers are recruited by varying movement velocity during the exercise session (1,2,11,12,26). Practicing this method of training promotes an optimal neuromuscular response and is supported by current theory concerning velocity-specific resistance training (11,18,23).

Neural influences may also be responsible for variability in muscle torque production under differing activation conditions (3). The effects of voluntary vs involuntary activation (preload) on the relationship of isokinetic muscle torque to speed show greater effects of activation forces on concentric torque values as compared to eccentric torque values. In dynamometer training sufficient muscle activity has to be developed to recruit the high threshold motor units (5). In addition, training studies have shown both low and high threshold units to maintain regular firing intervals at lower rates than before training (8). This change could be interpreted as increasing the range of firing rates over which motor units can maintain tonic (as opposed to phasic or intermittent) firing. This would allow higher threshold units to fire continuously longer before they fire intermittently or cease to fire altogether. This could explain the greater torque and power produced by the isotonic group and help create a better understanding of differences in neural adaptation between isokinetic and isotonic resistance training.

One purpose of exercise and rehabilitation is to produce optimal strength and power. Dynamometer training using isotonic resistance allows for exercise with maximal increases in muscular strength and power more than isokinetic resistance.

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