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Isokinetic versus isotonic variable-resistance training*

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ABSTRACT

A study of isokinetic exercise and isotonic variable-resistance training divided 12 individuals into four groups: 1) control; 2) isotonic variable-resistance training; 3) low-speed isokinetic (5, 10, and 15 rpm); and 4) high-speed isokinetic training (30, 40, and 50 rpm). All exercised groups showed good gains in strength when tested isometrically, isotonically, and isokinetically. However, when the individuals were tested for motor performance, the high-speed isokinetic group dominated (5.38% gain in the vertical jump versus 3.87% for the slow isokinetic, and 1.57% for the isotonic variable resistance; 9.14% gain in the standing broadjump versus 0.42% and 0.28%; and 10.11% gain in the 40-yard dash versus 1.12% and 1.35%).

Training should be specific in all training and rehabilitation programs, with the athlete/patient training in the manner most similar to his athletic event or performance.

The spectrum of strength is varied and is a major component of any sport participation. A method of strength training for each athletic event ideally would be the optimum way of improving that athletic performance. The major modes of strength training are isometric, isotonic, and isokinetic exercise. It is important to understand the difference in each of these forms of exercise.

Isometric contraction occurs when resistance of sufficient magnitude prevents motion. This allows maximum loading, but only in one point in the range of joint motion. Past reports have shown little effect on motor performance tests.[1]

Isotonic contraction results from exercise done through a range of joint motion with a set resistance. Because of the physiologic skeletal lever, neither the force on the system nor the resistance is constant during the range of motion. Therefore, loading occurs at the weakest point in the system, while the rest of the system is working at less than capacity. This is not efficient. The variable-resistance concept (of which Nautilus equipment (Nautilus Sports/Medical Industries, DeLand, FL) is an example) eliminates some of these disdavantages by using a cam effect. Others use friction, hydraulics, or levers and pulleys. Peterson,[2] in 1975, tested individuals at the US Military Academy and reported results as high as 58% improvement on a leg press. These individuals were tested on the same devices on which they trained. Pipes and Wilmore[3] did a study on variable-resistance exercise procedures which showed an increase in muscular strength, but values were not as high as in the Peterson[2] study (27% in the leg press versus 58%).

Isokinetic exercise is not doing an isotonic exercise at a fast speed. Isokinetic exercise is entirely different from the other modes. It controls the speed of exercise (a fixed speed) and varies the resistance. This variable-resistance exercise totally accommodates fatigue and pain. It maximally loads the muscle at every point in the range of motion. The increased strength associated with isokinetic exercise has been attributed to the fact that an accommodating contraction enables one to do more work in the same period of time than is possible in either constant resistance or variable resistance.

The studies by Pipes and Wilmore[3] have shown the superiority of isokinetics over isotonic exercise when functional tests are compared. To date, no study has compared isokinetic (accomodating resistance) with the variable-resistance modes (e.g., Nautilus). This study was designed to investigate the ability of these modes to effect changes in the muscular strength of the quadriceps (knee extensors) and hamstrings (knee flexor) muscles in adolescent males. Both isokinetic slow and fast speeds were examined.

MATERIALS AND METHODS

Twelve adolescent males between the ages of 16 and 18 voluntarily participated in a six-week training program. They were randomly assigned to four categories: control, variable resistance (Nautilus), isokinetic low speed, and isokinetic high speed. This study was performed in the spring, when none of the individuals was participating in or in training for any specific athletic team or performance. Eight had played high school football the previous fall. Four classified themselves as nonathletes and only participated in recreational sports.

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All groups trained three times per week. The training program for the variable-resistance group consisted of a Nautilus program where the individuals initially exercised at 80% of their maximum effort for 10 repetitions in three sets. They then progressed along a Nautilus protocol at a Nautilus facility under the supervision of a Nautilus instructor. They exercised on the leg curl machine, which exercises the knee flexors, and the quadriceps machine, which exercises the knee extensors. Use of the hip and leg extension machine was not allowed because this involves the hip extensor muscle as well.

The low-speed isokinetic group exercised on a Cybex II isokinetic dynamometer (Lumex, Inc., Ronkonkoma, NY) at 5, 10, and 15 rpm until 50% fatigue was shown on the graph readings. Fifty percent fatigue was calculated at one-half of the initial peak torque during the training session (Fig. 1). The high-speed isokinetic group trained on the Cybex II at limb movement rates of 30, 40, and 50 rpm. These also were trained until 50% fatigue was recorded on the graph. It should be noted that this rate for fast speeds is much faster than in previous studies (e.g. that of Moffroid and Whipple[4]). This was done because most athletic performances occur at limb speeds greater than 30 rpm (180°/second).

The control group had no training. They were tested at the beginning and at the end of the study. No participant in any group was allowed to do any running or training during this time outside of the training program. Any other form of training, such as weight lifting, was also prohibited.

Both the isokinetic and isotonic variable-resistance group exercised for three sets, three times per week. This was done to try to equalize the amount of work performed by all groups, since the amount of work performed can be a critical question, and not the number of sets. Ideally, a computerized work integrator would need to be hooked up to both the Nautilus machine and the isokinetic machine to compare the total work performed by the various exercise groups.

Because of the concept of specificity of training, each individual was tested in varying areas. Isometric strength was measured for the knee extensors at 65° of flexion, and the knee flexors were measured at 45° of flexion. This was done because of the noted difference in strength variation at different range-of-motion points. At these points, the knee extensors and flexors are most efficient.

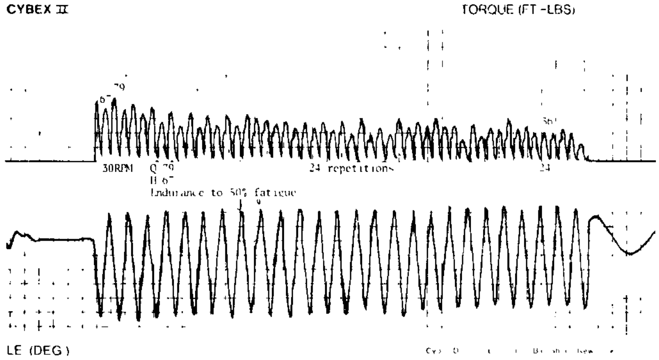

Figure 1. Fifty percent fatigue was calculated at one-half of the initial peak torque during the training session.

TABLE 1
Quadriceps strength changes with selected exercise protocols (six weeks)

	Test speeds		
	Isometric (0°/sec)	60°/sec	240°/sec
Control group			
Initial	147.5[a]	109.17	53.67
Final	153.0	110.17	52.0
Change (absolute)	+5.5	+1.0	−1.67
Change (%)	+3.73	+0.92	−3.11
Variable resistance			
Initial	195.83	169.67	74.33
Final	224.5	175.00	76.00
Change (absolute)	+28.67	+5.33	+1.67
Change (%)	+14.64	+3.14	+2.25
Isokinetic (slow)			
Initial	130.50	98.5	43.83
Final	131.16	119.5	54.67
Change (absolute)	+0.66	+21.0	+10.84
Change (%)	+0.51	+21.32	+24.73
Isokinetic (fast)			
Inital	135.17	98.83	32.83
Final	144.17	102.17	52.83
Change (absolute)	+9.00	+3.34	+20.00
Change (%)	+6.66	+3.38	+60.92

[a] Values are averages of right and left quadriceps expressed in foot-pounds of torque.

TABLE 2
Hamstring strength changes with selected exercise protocols (six weeks)

	Test speeds		
	Isometric (0°/sec)	60°/sec	240°/sec
Control group			
Initial	95.83[a]	79.00	46.17
Final	98.83	75.67	45.5
Change (absolute)	+3.0	−3.33	−0.67
Change (%)	+3.13	−4.22	−1.45
Variable resistance			
Initial	111.5	96.5	55.17
Final	123.67	110.5	62.67
Change (absolute)	+12.17	+14.0	+7.5
Change (%)	+10.91	+14.51	+13.60
Isokinetic (slow)			
Initial	91.17	72.00	35.67
Final	105.33	84.5	39.33
Change (absolute)	+14.16	+12.5	+3.66
Change (%)	+15.53	+17.36	+10.26
Isokinetic (fast)			
Initial	84.67	67.5	31.17
Final	92.33	73.33	47.17
Change (absolute)	+7.66	+5.83	+16.0
Change (%)	+9.05	+8.64	+51.33

[a] Values are averages of right and left hamstrings expressed in foot-pounds of torque.

The subjects' isotonic strength was measured on a variable-resistance machine which was totally different from their training machine. A Universal leg press exercise machine (Universal Athletic Sales Co., Fresno, CA) was used. Each individual was then tested isokinetically at 0, 5, 10, 15, 20, 30, 40, and 50 rpm of limb speed on a Cybex II. Because all subjects were tested before and after the exercise program on the Cybex II isokinetic dynamometer, they had some familiarity with the isokinetic equipment.

More importantly, functional motor performance tests were administered. These included the standing broad jump, the standing vertical jump, and the 40-yard dash. These tests were chosen because they have been shown to use the same type of mechanical motion that is needed in many athletic events. These activities are also influenced by the knee extensors and flexors which were trained specifically in the study.

TABLE 3
Motor performance changes with selected exercise protocols (Six weeks)

	Control	Variable resistance		
		Isotonic	Low-speed isokinetic	High-speed isokinetic
Leg press (lbs)				
Initial	336.67	426.69	288.33	271.69
Final	353.33	471.67	316.67	290.00
Change (absolute)	+16.66	+44.98	+28.34	+18.31
Change (%)	+4.95	+10.54	+9.83	+6.74
Vertical jump (inches)				
Initial	23.42	21.0	17.33	16.92
Final	21.33	21.33	18.00	17.83
Change (absolute)	−2.09	+0.33	+0.67	+0.91
Change (%)	−8.92	+1.57	+3.87	+5.38
Standing broad jump (inches)				
Initial	89.67	90.33	79.00	80.33
Final	89.5	90.58	79.33	87.67
Change (absolute)	−0.17	+0.25	+0.33	+7.34
Change (%)	−0.19	+0.28	+0.42	+9.14
Forty-yard dash (seconds)				
Initial	5.27	5.17	5.37	6.23
Final	5.17	5.10	5.43	5.60
Change (absolute)	−0.10	−0.07	+0.06	−0.63
Change (%)	−1.89	−1.35	+1.12	−10.11

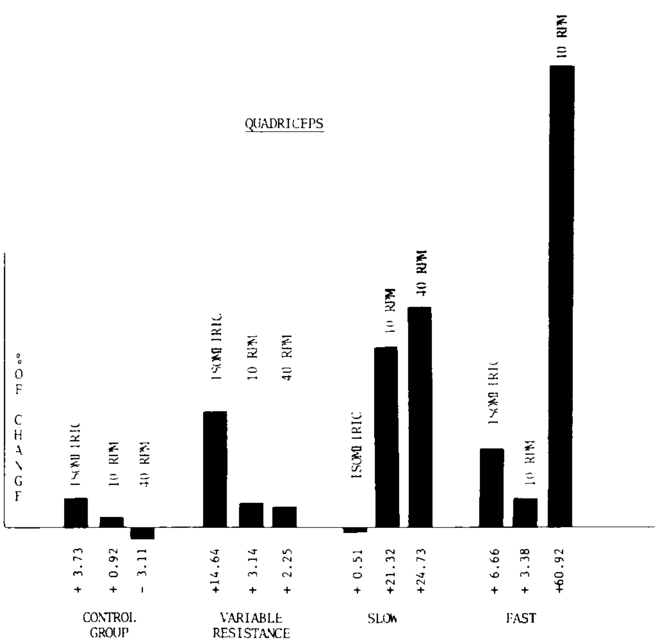

Figure 2. Percent change in quadriceps strength.

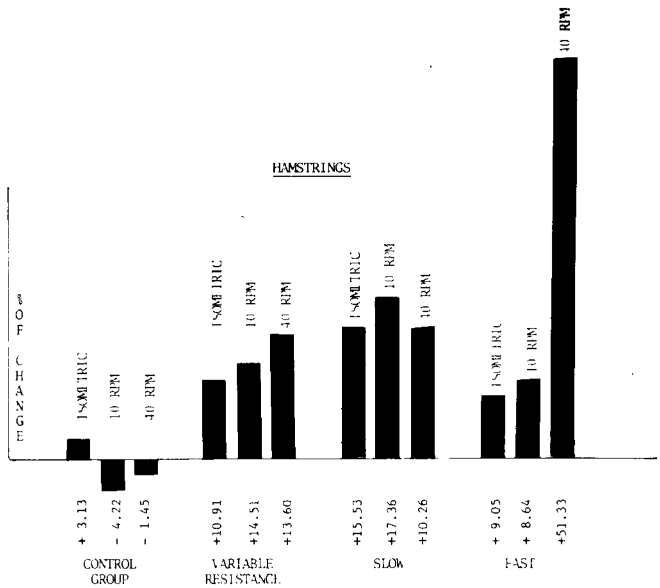

Figure 3. Percent change in hamstring strength.

RESULTS

Tables 1 to 3 contain the values of the test groups as shown on the graph of the quadriceps data (Fig. 2). The control group had no significant change in strength performance. The variable-resistance group had good increases in the isometric testing. However, when they were retested at high and low speeds on the isokinetic device, the strength gains were not as great. The slow isokinetic group had good strength gains, not only at the low speeds, but also at the higher speeds. The fast isokinetic group had strength gains in the isometric and low-speed testing and a remarkable increase in strength when tested at high speeds.

Our results differ from those of Pipes and Wilmore[5] in one important aspect. They reported strength gains uniformly in the isokinetic groups, no matter what speed of movement was used. In other words, their subjects who exercised at either low or high speeds gained when tested at both low and high speeds. In our subjects, this was not the case. Our low-speed isokinetic exercisers did exhibit gain in both low and high speeds. But our high-speed isokinetic group gained significantly only in the high speeds. This is probably because our high-speed group exercised at rates of limb movement much faster than those in the Pipes and Wilmore study. In fact, the present study is the first one, to date, to train and test individuals at rates of limb movement similar to most athletic performance speeds.

The hamstrings showed similar results (Fig. 3). There was no real change in the control group. The variable-resistance group had a good gain in strength across the board. The slow isokinetic group also had changes uniformly across the board, and these were comparable to the variable-resistance exercise group. The high-speed exercise group again showed the most marked improvement when tested at the high speeds.

Figure 4 shows that the largest gain in isotonic strength

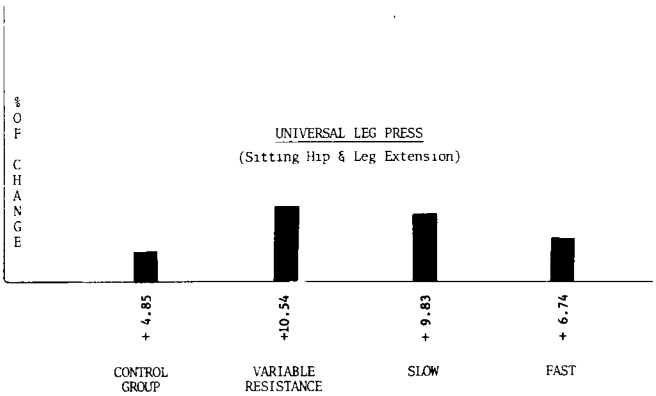

Figure 4. Percent change in exercise modes when tested on a Universal leg press.

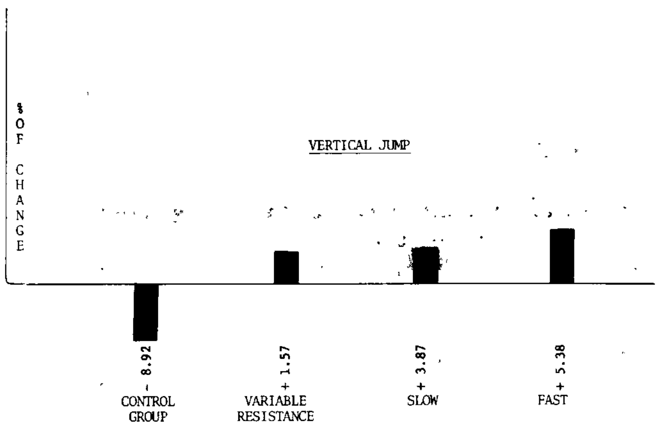

Figure 5. Percent change in exercise modes when tested by a standing vertical jump.

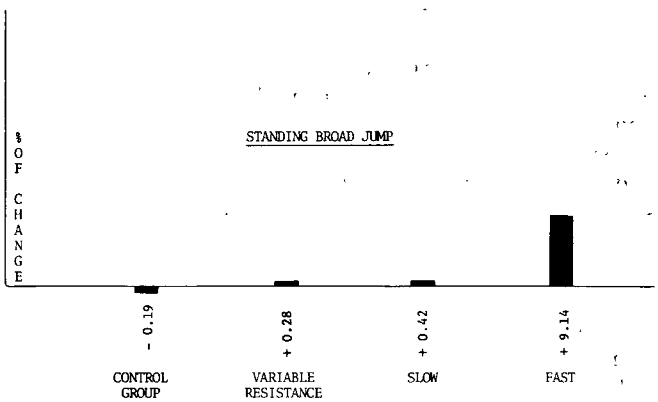

Figure 6. Percent change in exercise modes when tested in the standing broad jump.

when tested on the Universal leg press was accomplished by the variable-resistance group, with the slow-isokinetic group being a close second. This is due to the fact that the testing modality most resembles the training activity. In other words, in both the slow-isokinetic and the variable-resistance exercise program, the subjects were given a relatively long period of time to maximally contract their muscles.

The motor performance tests, however, required quick acceleration (contraction over a short period of time). It is with this testing that the most important changes occurred.

In the standing vertical jump (Fig. 5), the fast-isokinetic group improved 39% more than the slow isokinetic group and gained 243% over the variable-resistance group. The standing broad jump was even more dramatic (Fig. 6). The variable-resistance and the low-speed isokinetic groups had similar results. The high-speed isokinetic group had an almost tenfold increase when compared with the other exercise groups. The 40-yard dash group had similar results (Fig. 7).

DISCUSSION

Although this study had a small subject population, certain tendencies in athletic training and rehabilitation can be noted. In order to completely understand these results, we must consider the muscle itself, with its different fiber types and their importance to motor performance. There are two basic muscle fiber types, the slow-twitch and the fast-twitch fibers (so named for their contraction times).[5, 6]

The slow-twitch fibers contract approximately every 120 milliseconds. Their relaxation time is also slow. They have a high fatigue resistance and high mitochondrial density. They are called red fibers by some because of the high mitochondrial content and a higher capillary density. Slow-twitch fibers use oxidation to produce energy.

The fast-twitch fibers are called white fibers because they

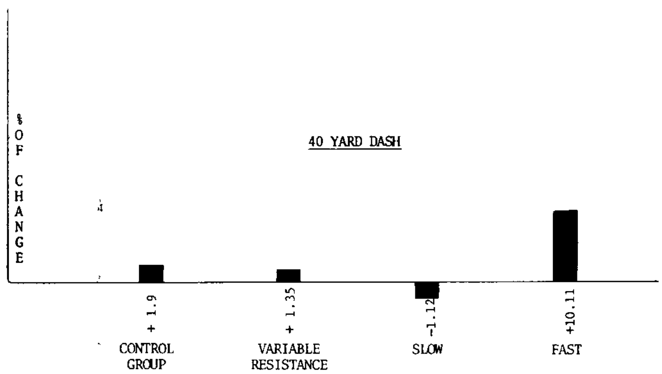

Figure 7. Percent change in exercise modes when tested in the 40-yard dash.

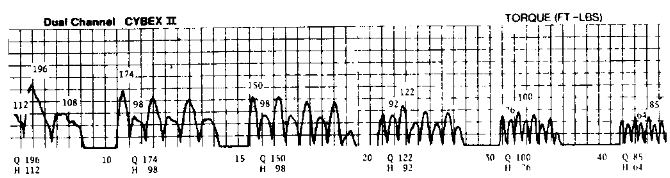

Figure 8. As the speed of contraction increases, the force production decreases.

have fewer mitochondria and a lower capillary density. They contract about every 40 milliseconds. Their relaxation time is also much faster. However, their resistance to fatigue is also much less than that of the slow-twitch fibers. They produce energy by the anaerobic pathway.[7]

Use of the different types of motor units varies with force demands. A specific motor nerve innervates only one fiber type[8] (slow or fast twitch). When drinking a glass of water, one uses only a low-force mechanism. Approximately 20% of the arm's maximal contraction capability is used. These are mostly slow-twitch fibers. This fine tuning of motor control lets one walk about the room without putting one's feet through the floor, which would occur if all the capabilities of the hip and leg extensor muscles were maximally recruited in walking.

As the speed of contraction increases, the ability to produce force decreases (Fig. 8). This is probably because the actin-myosin filaments are sliding by one another in muscle contraction and do not have time to produce the optimal tension needed for full force.

Because of this, during a high-speed, short-duration event, such as sprinting, it would be advantageous not only to have, but also be able to train, fast-twitch muscle fibers. Sprinters only have about 40 milliseconds to develop their power as their feet push off the ground. A study by Costill et al.,[9] using muscle biopsies, has confirmed this.

An athlete can train fast-twitch fibers for some increased endurance.[10] By training at high speeds, one can increase the levels of enzymes related to anaerobic metabolism and also develop mitochondria. Fast-twitch fibers respond better than slow-twitch fibers to weight training. This may account for the fact that some people do not "bulk up" with weights, and may be due to the preponderence of slow-twitch fibers in their muscles.

Now the concept of specific training becomes important. If one trains in a modality similar to the one in which he will be tested, he should have better results than someone training in modes different from the testing. This was verified by our results.

Specific training can also be important in postoperative rehabilitation. We are all familiar with the patient who has had a meniscectomy and a vigorous progressive-resistance program who can now lift 50 lb with his knee extensors and yet is unable to return to full activity. Unfortunately, there is nothing in the patient's athletic performance that requires him to lift one heavy weight through one range of motion for an indefinite amount of time unless he is a weight lifter. Most functional limb speeds exceed 90°/second, and some exceed 240°/second (15 to 40 rpm). Therefore, it would be prudent to train the athlete-patient in the manner most suited to his performance specifics and capabilities.

It must be emphasized that this study does not show that variable-resistance isotonic exercise (Nautilus) is an inferior method of training, because it is not. Excellent gains in strength were obtained with this type of training. However, this study does show that isokinetic exercises at high speeds produce much better results when the results tested are in the high-speed contraction velocities (e.g. 40-yard dash, standing broad jump). It should be noted that, although isokinetic high-speed exercise produced the best results when tested at high speeds, all modes tested produced excellent gains in strength. Gaining strength, however, is only one important aspect of training. A well-rounded training program can include any of the modes which produce strength, but one exercise modality, or one speed of training should not constitute the sole training or rehabilitation program. A complete training rehabilitation program should include exercises to increase strength and power (rate of strength development), and should attempt to increase the fatigue limit most comparable to the athletes' performance levels.

CONCLUSIONS

In this study, fast isokinetic exercise was shown to increase strength and performance levels more efficiently than low-speed isokinetic training or training with isotonic variable-resistance modes when the subjects were tested by quick acceleration.

The concept of training specificity should be used in all training and rehabilitation programs. The patient-athlete should be trained in the manner most similar to his actual athletic performance.

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