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Concentric versus eccentric isokinetic strengthening of the rotator cuff

Objective data versus functional test*

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ABSTRACT

Twenty-two male and female college varsity tennis players trained for 6 weeks, one group using eccentric isokinetic internal and external shoulder rotation, and the second group using concentric isokinetic internal and external shoulder rotation. Subjects pretested and posttested both concentrically and eccentrically, so that training overflow and specificity could be examined. Three maximally hit tennis serves made before and after training, which were analyzed by high speed cinematography to obtain ball velocity, served as a functional performance measurement. Statistical analysis of peak torque (newton meters) and peak torque to body weight ratio have revealed significant concentric strength gains ($P < 0.005$) in the concentric as well as the eccentric training groups. Eccentric strength gains were demonstrated by the concentric training group at selected speeds ($P < 0.05$ and $P < 0.005$) but were not generated in the eccentric group at the $P < 0.05$ significance level. Functional test analysis shows an increase in maximal serve velocity at a significance level of $P < 0.005$ in the concentric training group, with no significant ($P > 0.01$) increases in the eccentric group.

The relatively unique characteristics of eccentric contractions have been well documented in the literature.[1,7-9] Eccentric contractions show the lowest energy consumption per unit of tension exerted and the highest maximum muscle tension.[7] Examination of force-velocity relationships shows that muscle tension at the same velocity is always greater in eccentric work, and this difference becomes greater as a function of increase in contraction velocity.[8] During an eccentric contraction, the muscle is lengthening as it contracts, which stretches the noncontractile tissue.[1] Therefore, the increased internal muscle tension and force production are products of the noncontractile and contractile tissues working together during eccentric work. The presence of increased muscle soreness with the eccentric contraction may be regarded as indirect evidence for the extremely high connective tissue loading occurring during maximum conditions of eccentric work.[8]

Eccentric muscular contractions play a role in functional activities and athletics that is equally significant to concentric muscular contractions. The rotator cuff, specifically the infraspinatus and teres minor of the shoulder, are prime examples. During the follow-through phase of the tennis serve or throwing motion, these muscles must undergo high decelerative eccentric contractions to preserve healthy joint arthrokinematics.[4] The role of the rotator cuff is essential in preventing overhead overuse injuries. The dynamic caudal glide executed by the infraspinatus and teres minor posteriorly and the subscapularis anteriorly prevent the suprahumeral structures from becoming impinged on the coracoacromial arch.

Most published literature on comparative training and analysis between concentric and eccentric muscle contractions has focused on using the isotonic form of exercise.[6,7] Isotonic exercise is characterized by a variable speed and fixed weight or resistance, which differs from the fixed speed and accomodative resistance characteristic of isokinetic exercise.[2]

A study conducted by Komi and Buskirk[7] consisted of 7 weeks of either isotonic eccentric or concentric training.

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Pretesting and posttesting performed by both groups in concentric and eccentric isotonics and isometrics showed the eccentric group to increase maximal muscle tension in all three of the measured forces ($P < 0.01$). The concentric training group showed gains in tension eccentrically ($P < 0.05$) and concentrically ($P < 0.01$). It appears that when using isotonic training, an overflow of training to strength gains from concentric to eccentric, and vice versa, does exist. There is little information about the behavior of eccentric isokinetic overflow with isokinetic training.

The purpose of this study was to determine whether eccentric or concentric isokinetic training of the rotator cuff is more efficient in increasing power, as well as determining which would produce greater improvement in a functional test. The training overflow from eccentric training to concentric strength gains, and vice versa, were also of importance in this study.

MATERIALS AND METHODS

Twenty-two male and female college varsity tennis players volunteered for the 6 week training study. Informed consent forms were signed by all participants. Participants had no recent injury to the upper extremity or spine. A functional pretest was conducted using high speed cinematography, and an indoor lighting set-up. After a standard warmup, each subject was instructed to hit three serves at his or her maximum capability, within a specified service box. A film speed of 100 frames per second, with a filming distance of 40 feet was used (Fig. 1). The fastest serve landing in the specified service box was later used for digital analysis to obtain ball speed. This served as a functional performance measurement.

All of the subjects then underwent isokinetic pretesting, which consisted of concentric internal/external rotation with the glenohumeral joint abducted to 90° on the Cybex II isokinetic dynamometer (Lumex Corp., Ronkonkoma, NY) using the UBXT Cybex upper body testing table (Fig. 2). After a rest period, eccentric internal/external rotation with the glenohumeral joint at 90° of abduction was then tested on the Kin-Com dynamometer (Chattecx Corp., Chat-

Figure 1. All 22 subjects hit 3 maximal speed tennis serves before and after 6 weeks of isokinetic training. Data from high speed filming was used to determine functional test performance.

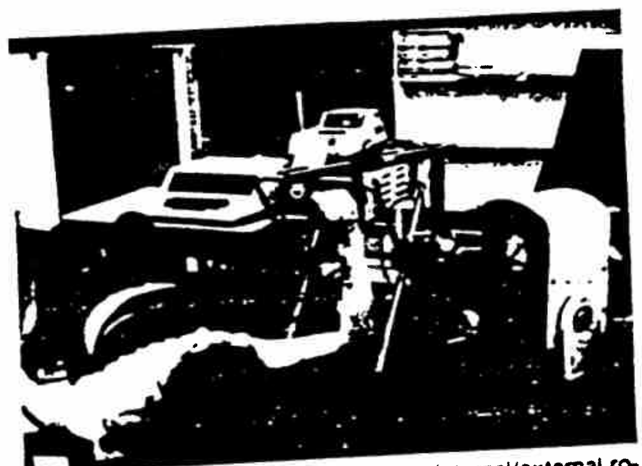

Figure 2. Concentric isokinetic shoulder internal/external rotation set-up.

Figure 3. Set-up used in eccentric isokinetic testing and training.

tanooga, TN) (Fig. 3). The isokinetic pretesting consisted of six maximal repetitions at speeds of 60, 180, and 210 deg/sec, with torque documentation in newton meters. Regardless of the training protocol the subject would later be placed in, all 22 subjects pretested eccentrically on the Kin-Com, and concentrically on the Cybex.

A standard 5 minute rest was allowed between the two pretests for all subjects. A range of 0° to 90° external, and 0° to 70° internal rotation was targeted on both machines. The order of isokinetic pretesting was randomly selected. All subjects were tested at similar times of day to prevent the addition of a diurnal variable. Only the dominant shoulder was tested and trained in this experiment. On the Cybex, subjects tested and trained using concentric internal and external rotation. On the Kin-Com, subjects tested and trained using eccentric internal and external rotation. The Cybex II isokinetic dynamometer was calibrated for torque and range of motion according to the Cybex II calibration and record card.[10] The Cybex Data Reduction computer (CDRC) was also calibrated according to standard Cybex protocol. The Kin-Com isokinetic system requires calibration each time the machine is turned on, and does so internally; therefore, calibration was completed daily whether testing or training.

Following isokinetic pretesting, the subjects were divided into two groups. A random stratified sampling method was used with emphasis on age, sex, number of years of tennis (high school and college varsity), playing experience, and previous shoulder or upper extremity injury being determinants of ranking order. The groups were randomly assigned, one group to train exclusively eccentrically on the Kin-Com, and the second group assigned to train exclusively concentrically on the Cybex.

The training phase consisted of 6 weeks of isokinetic exercise workouts, two times per week. Each individual workout consisted of six sets of ten repetitions using the velocity spectrum pyramidal ordering concept (60, 180, 210, 210, 180, and 60 deg/sec). After each training session, an ice pack was applied for 5 to 10 minutes to prevent any inflammatory reaction caused from the workout. A total of 12 workout sessions were completed by every subject in the allotted 6 week period.

Following the training phase, each subject participated in the functional posttest. Filming set-up and protocol for the posttest was identical to the pretest. The final phase of the study which each subject then completed was the isokinetic posttest. Prior to testing, both machines were calibrated in the same manner used prior to the pretest. Subjects from both groups posttested on the Cybex (concentric) and Kin-Com (eccentric), performing six maximal repetitions at speeds of 60, 180, and 210 deg/sec. The posttest protocols were identical to the pretest protocols and the subjects were randomly assigned to the order of testing.

Data was compiled using the CDRC and the computer output of the Kin-Com. Data compilation from the high speed filming was done using a Numonics 1224 digital analyzer (Numonics Corp., Lansdale, PA) to obtain the ball speed (in miles per hour) of the functional tests.

RESULTS

Analysis of data with repeated measures t-testing indicated several significant strength gains using the parameters peak torque and peak torque/body weight ratio in newton meters. Peak torque is the single highest point on the torque output graph, regardless of what point in the range of motion it occurs.[2] Significant concentric strength gains ($P < 0.005$) were seen by the concentric training group at all three speeds (Table 1). The eccentric training group also showed significant concentric strength gains ($P < 0.005$) at all three speeds in both internal and external rotation (Table 1). Eccentric training did result in significant concentric strength gains, indicating an overflow phenomenon of eccentric training to concentric strength gains.

Significant eccentric strength gains ($P < 0.005$) were demonstrated by the concentric trained group at 210 deg/sec in external rotation and 180 deg/sec in internal rotation. All other speeds were significant at the $P < 0.01$ level for internal and external rotation (Table 2). This demonstrates an overflow phenomenon of concentric strength training to eccentric strength gains. Eccentric strength gains by the eccentric training group were not significant at the ($P < 0.05$) level (Table 2).

Examination of eccentric/concentric peak torque ratios, achieved by taking each subject's eccentric values and dividing them by his or her respective concentric value, comply with the principle that a muscle can produce more torque while executing an eccentric contraction than while performing a concentric contraction. Results from this study show eccentric/concentric ratios of external rotation to have a mean of 1.68 before training and a mean of 1.41 after training. Internal rotation values were similar, with an overall mean of 1.65 at all three speeds before training, and of 1.35 after. This supports EMG work done by Doss and Karpovich,[4] which found that subjects exercised at a 36% greater mean muscle tension eccentrically than concentrically. The eccentric/concentric ratios in this study decreased with posttesting, demonstrating that greater overall strength gains occurred concentrically in both training groups, relative to eccentric gains.

The eccentric/concentric peak torque ratios from this study also comply with other peak torque eccentric/concentric isokinetic ratios. A study by DeNuccio[3] compared concentric and eccentric isokinetic peak torque and integrated EMG data using a standard fatigue protocol. Peak torque eccentric/concentric ratios of the quadriceps muscle at 180 deg/sec were found to have a mean of 1.87. Ratios found by Komi and Rusko[8] using the elbow flexors at 40 deg/sec were found to average 1.46. Similar work by Rodgers and Berger[11] using the elbow flexors found eccentric/concentric ratios of 1.67 at 72 deg/sec. These ratios show that as contractile velocity increases, eccentric performance is enhanced. A greater ratio is found in DeNuccio's study at 180 deg/sec.

TABLE 1
Concentric parameters—pre/post differences peak torque (in newton meters)

Speed (deg/sec)	External rotation $\bar{x} \pm$ SD (difference)	External rotation Significance ($P<$)	Internal rotation $\bar{x} \pm$ SD (difference)	Internal rotation Significance ($P<$)
Concentric trained group				
60	8.8 ± 4.7	0.005	8.0 ± 7.6	0.005
180	8.6 ± 4.0	0.005	10.4 ± 8.6	0.005
210	7.5 ± 4.8	0.005	8.2 ± 6.4	0.005
Eccentric trained group				
60	8.9 ± 3.6	0.005	5.8 ± 6.5	0.005
180	7.3 ± 3.0	0.005	4.7 ± 4.7	0.005
210	7.3 ± 4.6	0.005	7.2 ± 4.1	0.005

TABLE 2
Eccentric parameters—pre/post differences peak torque (in newton meters)

Speed (deg/sec)	External rotation $\bar{x} \pm$ SD (difference)	External rotation Significance ($P<$)	Internal rotation $\bar{x} \pm$ SD (difference)	Internal rotation Significance ($P<$)
Concentric trained group				
60	3.2 ± 6.9	0.10	4.7 ± 7.7	0.05
180	4.7 ± 8.4	0.10	8.3 ± 7.7	0.005
210	9.0 ± 5.4	0.005	5.3 ± 9.4	0.10
Eccentric trained group				
60	3.5 ± 9.5	NS	−3.6 ± 12.8	NS
180	1.8 ± 4.1	NS	−1.8 ± 15.1	NS
210	4.2 ± 7.2	0.05	−2.3 ± 12.0	NS

an with that of Rodgers and Berger, and Komi and Rusko, 72 and 40 deg/sec, respectively.

This result is further illustrated in this study by exami- ıtion of average eccentric/concentric ratios at the three ntractile velocities. In pretesting external shoulder rota- ın, the average eccentric/concentric ratios were 1.58 at 60 g/sec, 1.75 at 180 deg/sec, and 1.71 at 210 deg/sec. Post- sting external rotation values show similar relationships, do eccentric/concentric peak torque to body weight ratios r external rotation (Table 3). Table 3 also illustrates the ternal shoulder rotation pretest and posttest eccentric/ ncentric ratios. As the velocity increases, the eccentric/ ncentric ratio becomes larger both in peak torque and ak torque to body weight ratio. This is consistent with the ce-velocity relationships mentioned earlier.

Concentric torque acceleration energy was determined ng the Cybex II Data Reduction computer. Torque accel- ıtion energy is the work occurring during the first 1/8 of a ond under the torque curve. This measurement attempts capture the explosiveness of the muscle being tested. ired difference t-testing was again used, showing signifi- ıt gains in both the concentric and eccentric training

TABLE 3
Eccentric/concentric rotation peak torque ratios*

	Pretest 60	Pretest 180	Pretest 210	Posttest 60	Posttest 180	Posttest 210
xternal rotation						
Mean	1.58	1.75	1.71	1.25	1.42	1.56
nternal rotation						
Mean	1.46	1.69	1.80	1.22	1.41	1.43

ll speeds are degrees per second.

groups, in both internal and external rotation ($P < 0.005$) (Table 4). Functional speeds of performance for upper extremity activities are shown in Table 5.

Statistical analysis of the functional tests show insignificant speed increases in the eccentric training group (Table 6). Half of the subjects who trained eccentrically actually demonstrated a decrease on the speed of the serve. A significant increase in ball speed was found in the concentric training group ($P < 0.005$) (Tables 7 and 8). All of the subjects in the concentric training group did show an increase in serving speed. Further analysis must be done before a positive correlation can be assumed between increases in muscle strength and faster serving speed. Several factors such as form, technique, and height are also important, and were not objectively analyzed in this study.

DISCUSSION

Eccentric isokinetic training produced the greatest increases in concentric strength. A hypothesis that attempts to explain this result is based on the work of Doss and Karpovich[4] mentioned earlier. In eccentric training, the involved musculature is usually contracting at a mean tension approximately 36% greater than that which could be achieved concentrically. As noted by Komi and Buskirk,[7] the "rate of strength development as measured by muscle tension is reportedly directly related to the tension produced in conditioning." By training for 6 weeks at a higher muscular tension, a greater training overflow is expected to exist between eccentric training and concentric strength gains. This finding is consistent with the isotonic training study of Komi and Buskirk , which also found eccentric training

TABLE 4
Torque acceleration energy (TAE)—pre/post differences peak TAE (in newton meters)

Speed (deg/sec)	External rotation		Internal rotation	
	$\bar{x} \pm SD$ (difference)	Significance ($P<$)	$\bar{x} \pm SD$ (difference)	Significance ($P<$)
Concentric trained group				
60	0.62 ± 0.58	0.005	0.73 ± 0.60	0.005
180	2.15 ± 0.98	0.005	2.62 ± 2.3	0.005
210	2.39 ± 1.8	0.005	2.47 ± 2.2	0.005
Eccentric trained group				
60	0.68 ± 0.29	0.005	0.33 ± 0.25	0.005
180	1.40 ± 0.77	0.005	1.43 ± 1.1	0.005
210	1.63 ± 2.2	0.025	2.10 ± 2.1	0.05

TABLE 5
Performance speeds

Joint	Activity	Velocities (deg/sec)	Reference
Shoulder	Throwing	5730	Gainor BJ et al.[7]
Shoulder internal rotation	Throwing	$\bar{x}$ 6180 peak 9198	Pappas AM et al.[12]
Shoulder	Swimming	250–300	Bartels R et al.[1]

TABLE 6
Eccentric trained group functional test values for each participant

	Pretest speed (mph)	Posttest speed (mph)	Difference (pre/post)
	122.5	122.0	−0.5
	85.2	75.0	−10.2
	106.4	110.5	4.1
	103.2	116.6	13.4
	65.0	74.8	9.8
	92.7	87.5	−5.2
	83.5	89.3	5.8
	83.9	93.3	9.4
	86.8	80.6	−6.2
	73.0	72.4	−0.6
	81.6	72.7	−8.9
	67.9	73.1	5.2
Mean	80.9	82.1	1.2
SD	27.9	29.0	7.2
Variance	778.1	838.9	51.6

TABLE 7
Concentric trained group functional test values for each participant

	Pretest speed (mph)	Posttest speed (mph)	Difference (pre/post)
	89.7	100.9	11.2
	59.5	70.3	10.8
	61.6	66.8	5.2
	76.2	79.7	3.5
	75.9	86.9	11.0
	72.7	84.2	11.5
	90.2	100.6	10.4
	93.6	107.0	13.4
	70.3	76.9	6.6
	104.2	104.9	0.6
Mean	72.2	79.8	7.7
SD	26.3	28.5	4.5
Variance	693.8	813.9	20.2

TABLE 8
Functional pre/post test values (miles per hour)

	$\bar{x} \pm SD$ (difference)	t-value	Significance ($P<$)
Eccentric training group	1.34 ± 7.7	0.5944	0.10
Concentric training group	8.42 ± 4.2	6.37	0.005

with concentric strength overflow to be greater than concentric training with eccentric strength overflow.

Although greater tension can be generated with eccentric contractions as compared with concentric contractions, it is important to realize that the increased tension-generating capacity is not solely due to the contractile elements. One of the reasons the eccentric contraction generates more tension is the existence of the noncontractile tissues in the muscle. The series elastic components and sarcolemma provide mechanical kinetic energy creating much of the tension-generating capacity of the eccentric contraction: it is not necessarily from the actual contractile muscle fibers. Conversely, the concentric contraction tension is exclusively produced by the contractile unit. Therefore, if the specific training goal is to enhance (strengthen) the muscle fibers to provide rapid contractions (torque acceleration energy) or facilitate power generation, then the training mode to isolate the actual contractile muscle fibers is a concentric contraction.

A second finding of this study is the insignificant eccentric pretest/posttest results of the eccentric training group. Komi and Buskirk[7] found a latent strengthening phenomenon, especially in the first few weeks of eccentric training, which was due to an induced soreness that prohibited maximal tension gain. This latency may be a factor in the insignificant eccentric strength gains found in the eccentric training group. Increased muscle soreness from periods of eccentric training or work has been well documented in the literature in both isotonic and isokinetic forms.[1-3,7]

Both eccentric and concentric training groups showed significant increases in torque acceleration energy at all three testing/training speeds in the 6 week period. At this time torque acceleration energy is only available as a concentric parameter on the Cybex. This is of key importance in end-stage rehabilitation of an impaired joint for an activity of fast twitch nature, such as tennis. In 6 weeks of training there was a significant increase in the amount of concentric work during the first 1/8 of a second. Not only did the subjects in both training groups increase in internal/external rotation strength, but that strength was developing more rapidly following initial muscle contraction.

Although both experimental groups increased rotator cuff torque acceleration energy work, the transfer to functional skill improvement occurred only in the concentrically trained group.

The analysis of pretest and posttest serving speed shows a major difference between the two training groups in functional impact of training. Further statistical analysis must be done to correlate the increasing speed of serves to a specific increase in muscle strength. Regarding serve performance, training specificity could explain significant increases occurring only in the concentric training group. The speed of the serve or throwing motion depends partly on a rapid and forceful concentric internal rotation in the acceleration phase.[5] The concentric training group specifically performed this concentric motion for 6 weeks, while the eccentric training group was performing an opposite type of muscular contraction. The eccentric phase of training may specifically affect only the decelerative phase of the motion, while the concentric accelerative phase may be determining the trajectory and velocity components of the performance. This further reinforces the concept for specificity of training in sport-specific functional activities. Again, further analysis must be done to completely understand this result, but the significant increases in performance do suggest that strength gains documented with concentric isokinetic training do produce improvements in functional performance.

SUMMARY

Six weeks of isokinetic training of the rotator cuff have shown significant strength gains, using the parameters of peak torque, peak torque to body weight ratio, and torque acceleration energy. Comparative analysis between concentric and eccentric training groups has demonstrated significant overflow and specificity of training of power gains which comply with earlier isotonic studies. This study has clinically demonstrated that significant power gains, particularly at fast functional velocities, and increases in muscle explosiveness (torque acceleration energy) of the rotator cuff occur through concentric and eccentric isokinetic training. This muscle group is of key importance in preventive conditioning and rehabilitation of the patient with an overuse injury to the shoulder. Lastly, documented isokinetic strength gains by the concentric training group demonstrated significant increases in a functional sport activity (tennis serving speed), but there were no statistically significant improvements in the eccentric isokinetically trained group.

Consequently, when designing a preventive conditioning or rehabilitation program, the concept of specificity of muscular contraction appears to be important.

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