Effects of Strength Training on Throwing Velocity and Shoulder Muscle Performance in Teenage Baseball Players

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For over 20 years, the literature has demonstrated widespread use of isokinetics, both for measurement of strength (1, 5-7, 15, 17, 19, 22, 24) and for exercise to improve torque production of various muscle groups (3, 10, 11, 22, 24). Isokinetic (IKN) exercise, in which the speed is constant, is thought to be totally accommodating to the individual because the resistance varies at each point in the range of motion (ROM) to match the force applied (2, 16). The major advantage of this fixed-speed, variable resistance exercise is that maximum resistance can be applied throughout the ROM, provided the effort is maximum (2, 14). Other advantages are that IKN exercise accommodates to pain and fatigue and that speeds can be increased or decreased depending on clinical needs (2).

Isokinetic exercise has been shown to be an effective means of increasing "strength" or torque output. Lesme et al (11) studied the effects of short (6-second) and long (30-second) burst exercise at 180°/sec on the knee extensors of both limbs in healthy males. After 7 weeks of training, both limbs improved significantly in peak torque, work output, and endurance. In a controlled study of the knee extensors of 16 healthy females, Peterson et al (22) found increases in concentric and eccentric torque production after 6 weeks of IKN training. Klingenstierna et al (10) studied the effects of multiple speed IKN training on the knee flexor and extensor muscles of eight adult, below-knee unilateral amputees. Significant increases in torque production were...
noted at most speeds in the amputated and uninvolved limbs. Smith and Melton (24) compared the effects of low- and high-speed IKN exercise to variable resistance isotonic (ITN) exercise (using Nautilus equipment) on quadriceps and hamstrings strength as well as various functional tasks: vertical jump, standing broad jump, and the 40-yard dash. In the 12 adolescent boys studied, all groups improved in strength measured isokinetically, while the high-speed IKN group had the greatest improvements in all functional tests. In a study of 32 collegiate tennis players, Ellenbecker et al (3) compared the effects of concentric IKN versus eccentric IKN exercise on rotator cuff strength and power and on tennis serve velocity measured by video analysis. After 6 weeks of training, both groups improved significantly in concentric strength. However, only the concentric training group improved in both eccentric strength and serve velocity.

Ironically, the advantage of fixed velocity may also be somewhat of a disadvantage when using IKN training to improve functional activities or athletic performance. Despite the successes reported in previous literature (3, 24), most IKN devices allow maximum velocities of 500°/sec, well below those required for most activities (12). For example, the shoulder joint must accelerate to an angular velocity of more than 6,000°/sec when throwing a baseball (18). The high angular velocities that occur with throwing pose a question as to whether training isokinetically inhibits limb acceleration and, possibly, optimum improvement in torque production and performance.

A recent advance in resistive exercise is offered by the Musculoskeletal Evaluation Rehabilitation and Conditioning (MERAC, Universal Equipment Co., Cedar Rapids, IA) dynamometer. In addition to isokinetics, the MERAC also provides the option of accommodative ITN exercise. This individualized, dynamic, variable resistance (IDVR) mode works as follows: from a series of maximum effort isokinetic contractions, the MERAC computer averages the data into a motor performance curve (MPC) as shown in Figure 1. The system is then programmed for exercise to provide resistance based on a selected percentage of the torque recorded at every point in the ROM on the curve. Maximum resistance is provided by programming 100 percent of the MPC. This resistance is ITN since it is no longer speed-constant; however, it is accommodative since the resistance changes constantly to match the MPC. With no preset speed, the limb can accelerate against the resistance according to the effort of the individual.

One week after completion of training, the pretest protocols were repeated.

The authors' clinical experience with IDVR strength training on a variety of patients has been positive, but no known published, controlled studies demonstrating its efficacy exist. The purpose of this study was to determine whether IKN or IDVR training would be more effective in increasing rotator cuff muscle torque production and power, as well as improving the velocity of throwing a baseball.

METHODS

Subjects were 27 volunteers, ages 14–17 (mean 15.5 ± .97), who were junior and senior high school baseball players of various positions. Average weight was 155.2 lbs (± 26.0). Twenty-five were right-handed and one was left-handed. In the previous 6 months, no one reported a history of upper extremity injury or pain that rendered him unable to compete or that required examination by a physician. Prior to participation, testing and training procedures were explained, and informed consent was obtained from the subjects' parents. Subjects were screened with shoulder, elbow, and wrist ROM tests in all planes and with shoulder locking and quadrant tests.

Pretest

Throwing velocity was tested approximately 1 hour prior to muscle torque and power testing in all subjects to reduce the chance of fatigue influencing the muscle testing. The pretests were not randomized because the gym space and radar equipment needed for velocity testing were available for a limited time. In a method modified from Pawlowski et al (19), velocity was tested indoors to control for weather effects, using a standard pitching distance of 60 ft, 6 in. A pitcher's mound was not used. Subjects were instructed to use a wind-up motion and were allowed as many warm-up throws as they felt necessary for maximum effort throwing. Following a 2-minute rest, five maximum effort throws were measured in miles per hour (mph) with a calibrated Magnum X 6 radar gun (CMI Corporation, Owensburg, KY). The radar gun was mounted at a height of 36 in and positioned to the right of the catcher. The mean of the five throws was recorded. Reliability was insured by calculating percent of agreement for all throws in the pretest and posttest. Of the throws, 92.2 percent were within 2 mph of the means, and 98.9 percent were within 3 mph.

Dominant shoulder internal and external rotation torque (ft-lbs) and power (W) were tested isokinetically.
FIGURE 1. A) Isokinetic graph, internal and external rotation, tested at 500°/sec; B) Motor performance curve from the IDVR graph.

The individualized, dynamic, variable resistance training showed significant increases in throwing velocity.

The shoulder joint. The chair was then locked into place (Figure 2). Dynamometer height, resistance handle length, and chair position on the template were recorded for use in the training and posttest sessions.

Torque was calibrated to baseline prior to each test. Reliability and validity of the MERAC for torque measurement, angular velocity, and shoulder test-retest positioning have been established previously (5, 13). Stops were programmed into the computer to limit the arc of motion to 90°. As a warm-up, subjects performed seven submaximal effort contractions followed by three maximal effort contractions. After a 90-second rest, four maximal effort contractions were recorded. Data for
Training Sessions

Subjects were randomly assigned to IKN training, IDVR training, or a control group of no training. Sessions were held between the fall and spring baseball seasons at regular intervals, three times a week for 5 weeks, for a total of 15 sessions. Two subjects missed one session, all others completed 15. For training, the subjects were placed in the pretest position and the MERAC was programmed for either IKN or IDVR resistance. The IKN group exercised at 500°/sec. The IDVR group exercised at 100 percent of the variable resistance provided by the pretest MPC, with no preset velocity. In week 1, subjects completed six sets of 10 maximal effort repetitions with a 1-minute rest between sets. One set of 10 repetitions was added each week until 10 sets of 10 were performed in week five.

Posttest

One week after completion of training, the pretest protocols were repeated. Subjects were positioned and tested by the same investigators as in the pretest.

DATA ANALYSIS

In order to reduce the effect of size in torque output, peak torque values were normalized by expressing them as a percentage of body weight, providing PT:BW ratios (5, 6, 16, 23). To ensure that assignment to training groups had been well randomized, one-way analysis of variance (ANOVA) of the pretest means of velocity, PT:BW, and power was performed. After training, one-way ANOVA of the differences between the pretest and posttest means of each measure was used. Newman-Keuls post hoc multiple comparison tests were then performed to determine the effects of the IKN and IDVR training conditions. Minimum level of significance was established at \( p < .05 \).

RESULTS

Analysis of variance of the pretest measurements of throwing velocity, PT:BW, and power showed no significant differences among the IKN, IDVR, and control groups. Table 1 lists the effects of the type of training on the various measurement parameters.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Training Group</th>
<th>Change Mean (SD)</th>
<th>Overall F(2, 24)</th>
<th>Overall p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (MPH)</td>
<td>IDVR*</td>
<td>2.06 (1.07)</td>
<td>7.23</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>IKN**</td>
<td>0.86 (1.71)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>-0.34 (0.74)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT:BW internal rotation (ft-lbs/lbs)</td>
<td>IDVR</td>
<td>3.60 (6.35)</td>
<td>5.00</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>IKN</td>
<td>-3.60 (4.95)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>-1.57 (3.41)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT:BW external rotation (ft-lbs/lbs)</td>
<td>IDVR</td>
<td>5.50 (4.53)</td>
<td>6.92</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>IKN</td>
<td>1.90 (1.45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.14 (1.95)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power internal rotation (W)</td>
<td>IDVR</td>
<td>8.68 (18.18)</td>
<td>1.39</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>IKN</td>
<td>14.75 (26.55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>-1.61 (6.55)</td>
<td></td>
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</tr>
<tr>
<td>Power external rotation (W)</td>
<td>IDVR</td>
<td>10.71 (4.23)</td>
<td>9.81</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>IKN</td>
<td>8.62 (5.80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.57 (3.68)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* individualized, dynamic, variable resistance mode
** isokinetic mode
*** Peak torque to body weight ratio

Table 1. Effect of type of training on throwing velocity, shoulder rotator PT:BW, and power.
IDVR velocity increases to be significantly greater than the IKN ($p < .05$) and control ($p < .01$) groups. The IKN group was not significantly greater than the control.

**Internal Rotation of PT:BW**

Analysis of variance of the change in mean PT:BW showed that a statistically significant difference between the groups existed [$F(2,24) = 5.00$, $p < .05$]. Post hoc tests demonstrated IDVR mean increases to be significantly greater than the IKN group ($p < .05$), but that neither the IDVR nor IKN groups were significantly greater than the control group.

**Internal Rotation Power**

Analysis of variance of the change in mean power showed no significant differences between any of the groups [$F(2,24) = 1.39$, $p > .05$].

**External Rotation PT:BW**

Analysis of variance of the change in mean PT:BW demonstrated that a statistically significant difference between groups existed [$F(2,24) = 6.92$, $p < .01$]. Post hoc tests showed changes in the IDVR group to be significantly greater than the IKN ($p < .05$) and control ($p < .01$) groups. The IKN group was not significantly greater than the control.

**External Rotation Power**

Analysis of variance of the change in mean power demonstrated that a statistically significant difference between groups existed [$F(2,24) = 9.81$, $p < .001$]. Post hoc tests showed that mean power increases for both the IDVR and IKN groups were significantly greater than the control group.

**DISCUSSION**

The results suggest that the IDVR training mode was more effective than IKN exercise for improving throwing velocity and external rotator PT:BW. These findings differ from those of Smith and Melton (24), who found IKN exercise to be more advantageous than ITN training on Nautilus equipment, which is at least partially accommodating. Both IDVR and IKN exercises were effective in increasing external rotator power. A surprising finding of this study was that internal rotator PT:BW and power did not improve significantly in either condition. This could have been due to the testing and training position of $90^\circ$ abduction and $30^\circ$ in the POS. Although the $90^\circ$ abduction component simulates throwing, previous studies have shown decreases in internal rotator torque output (6) and subscapularis electromyographic activity (21) with progressive degrees of shoulder abduction. Conversely, the POS component may have enhanced the mechanical advantage and length-tension relationship of the external rotators (4, 6, 21). Abduction of the shoulder in the POS does not fully simulate a throwing motion. However, the POS was used in the present study because of previous work by Greenfield et al (15) indicating that significantly greater external rotator torque was produced in the POS compared to the frontal plane. Internal rotator torque output was the same in both planes.

The IDVR training group showed significant increases in throwing velocity, which may have been due, in part, to improvements in external rotator PT:BW and power. Pedegana et al (20) reported a relationship between throwing velocity and strength of the external rotators, which are active concentrically in cocking the shoulder and eccentrically in controlling arm movement during the follow-through phase (8, 9). Increases in external rotator concentric torque production would seem also to have improved eccentric function, a concept supported by previous studies (3, 22). Similar to the findings in the present study, Pedegana et al found no significant relationship between internal rotator strength and throwing velocity (20). A more important factor in improvements seen in the IDVR groups seemed to be the ability to accelerate the arm freely, simulating the activity of throwing. The IKN group could not accelerate beyond $300^\circ$/sec far below the angular velocity required for throwing (18). Using IDVR, with no fixed speed, subjects were able to accelerate according to their abilities.

For future study, the authors recommend also testing isotonically and recording speeds of contraction to evaluate the speed factor. Narrowing the age group studied should be considered, since $13$- and $17$-year-old boys may respond differently to training effects.

**CONCLUSIONS**

Results suggest that the IDVR mode may be more effective than the IKN mode in improving throwing velocity and shoulder external rotator torque production. This may be the result of IDVR exercise allowing the arm to accelerate more freely during a maximal effort contraction. The lack of improvement of internal rotator torque production may have been due to the testing and training position used, which put the external rotators at more of a mechanical advantage. Clinicians should consider using IDVR protocols, but they should use different positions of shoulder abduction to attempt to involve all muscle groups.

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REFERENCES