Angular Specificity and Test Mode Specificity of Isometric and Isokinetic Strength Training*

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This study examined the angular specificity and test mode specificity of strength training. Six males and six females (X = 22.6 years) were assigned to groups which trained either isometrically (90°) or isokinetically (30°/second). They trained their left elbow extensors at 80% of their maximum voluntary contraction on a modified Cybex® apparatus for 10 weeks, three sessions per week, with 50 contractions per session. Before and after training, both groups were tested isometrically (70, 90, 110°) and isokinetically (30°/second). When tested isometrically, both groups improved equally, and strength was increased at all three test angles to about the same extent. When tested isokinetically, both groups improved, but the isokinetic group improved to a greater extent. In conclusion, no angular specificity of training was demonstrated within 20° of the training angle, and no test mode specificity was seen for isometric testing. However, isometric training showed less transfer to an isokinetic test.

The concepts of angular specificity of isometric strength training and specificity of training mode have been advanced by some educators.21 The hypothesis regarding angular specificity argues that isometric strength training at one joint angle will result in strength gains only at the angle trained. The hypothesis regarding training mode specificity argues that strength gained in one mode of training (i.e., isometric) will not transfer when tested in a second mode (i.e., isokinetic). Neither of these concepts is well defined in terms of how much transfer of training, if any, might be expected. It seems reasonable that training at one isometric angle might increase strength at a closely adjacent angle but not at an angle distant from the training angle. Some degree of transfer might also be expected from isometric training to a dynamic strength test, provided some of the same muscle fibers are included in both. A review of the literature provides studies which did and did not demonstrate specificity in reference to joint angle and type of contraction. Angular specificity was demonstrated in some situations but other investigations were not able to demonstrate this phenomena or had mixed results7,10,16,23 Likewise, in the area of test mode specificity some investigations showed no significant transfer,17,18 some degree of transfer,4,8,23 and even mixed results within the same study.11 The varied findings may be due not only to the different testing and training protocols used but also to failure to control the total number of contractions,4,8,18,19,23 different exercise intensities in different testing modes,4,8,19,23 and the fact that little consideration was given to controlling synergistic movement patterns or subject positioning.2,16,22

The purpose of the present study was to compare the effects of isometric training of the elbow flexors at a specific joint angle (90°) versus isokinetic training (30°/second) through a range of joint motion (45 to 135°) on isometric and isokinetic tests. Special attention was given to controlling the exercise intensity, total number of contractions, work/rest ratios, and total ex-
exercise time in both modes of testing. Mechanical immobilization devices were used in order to control subject positioning and synergistic movement patterns. Because of the varied findings in the literature, null hypotheses were adopted. They were as follows: 1) there will be no significant differences among the three isometric test angles after isometric or isokinetic training; 2) there will be no significant differences between the isometric training group and the isokinetic training group when tested isometrically; 3) there will be no significant differences between the isometric training group and the isokinetic training group when tested isokinetically.

**METHOD**

**Subjects**

Subjects were six male and six female volunteers assigned to the Army Security Agency at Fort Devens, MA. Their habitual level of physical activity was low, and they did not participate in any other physical training during the study. Subjects were assigned by random drawing to an isometric training (ISOM) group or an isokinetic training (ISOK) group so that three males and three females were in each group.

**Equipment**

Strength of the left elbow extensors was assessed using a Cybex® II isokinetic dynamometer (Cybex, Division of Lumex, Inc., Ronkonkoma, NY 11779) with a modified seating and arm coupling arrangement Fig. 1. These changes have been described previously and were designed to prevent synergistic movements that subjects commonly make in conjunction with elbow extension. The back rest of the chair was fixed at a 105° angle. Each subject was secured to the chair by straps over the pelvis.

Fig. 1. Subject positioning for isometric and isokinetic testing and training. (Note that in this figure the right arm is coupled to the device in order that the wedge-shaped block of wood on the left side can be seen. In both testing and training the left arm was coupled to the device in the manner shown).
and each thigh. A wedge-shaped piece of wood, which was attached to the left side of the back rest, served as an arm rest for the upper extremity being tested. The angle of the back rest (105°), complemented with the angle of the arm rest (15°), offered a 90° vertical support for the arm. Two metal sections, which were fitted with carved wooden blocks to conform to the contours of the shoulders, were secured to the back rest and used as restraints for the shoulders and upper trunk. The forearm was placed in a position midway between supination and pronation and coupled to the dynamometer via a wrist cuff applied to the distal end of the forearm. The lateral epicondyle was aligned with the axis of rotation of the dynamometer.

The electrical signals from the Cybex recorder were fed simultaneously into a Grass Model 7 Polygraph (Grass Instrument Co., Quincy, MA 02169) recorder and into a meter relay (ARIEM Instrumentation, USARIEM, Natick, MA 01760). The meter relay was adjusted so that full scale was equal to each subject's maximal voluntary contraction (100%). A centralized signal generator (ARIEM Instrumentation, USARIEM, Natick, MA 01760) provided the cadence for the exercises.

Isometric exercises were performed by locking the dynamometer at the desired angle at 0°/second. Plastic, fixed goniometers were used to position the elbow at the desired angles. One was constructed for each of the elbow angles used in the study, and each one was aligned with the following landmarks: lateral epicondyle, styloid process, and acromion process.

The dynamometer was calibrated on each day of testing and training by locking the lever arm at 90° and applying two separate loads of 50 and 75 pounds each. The maximal torques were noted and adjustments were made on the polygraph recorder.

Testing Procedure

After a briefing in which informed consent was obtained from the subjects, they were familiarized with the equipment. The pretest included a medical examination, anthropometric evaluation, and an assessment of isometric and isokinetic strength of the left elbow extensors. The anthropometric evaluation involved measurement of height, weight, percent body fat, and lean body mass. Percent body fat was estimated from four skinfold thicknesses using the equations of Durnin and Womersley. Lean body mass was calculated from percent body fat and weight.

The isometric and isokinetic tests were counterbalanced. All subjects were allowed two or three submaximal isometric or isokinetic contractions prior to the first maximal test contraction. Isometric strength was assessed at joint angles of 70, 90, and 110°. Subjects were told to build up to their maximal force as rapidly as possible and to hold it until told to stop (4–5 seconds.) Maximal voluntary isometric strength (MVIS) was evaluated at the three angles during three maximal contractions at each angle. The MVIS for each subject was the average of these three contractions. Isokinetic strength was evaluated at 30°/second. Subjects were told to move the bar as hard and as fast as possible and to complete the entire range of motion. The peak torque achieved was recorded. Three maximal contractions were performed and the average of these contractions was each subject's maximal voluntary isokinetic strength (MVKS). Strength was reassessed every 2 weeks of the training period to establish a new MVIS for the ISOM group and a new MVKS for the ISOK group. The posttest was identical to the pretest described above except that the medical examination and height measurements were not performed.

Training Procedure

After the pretest, subjects returned to the test area within an hour of their initially scheduled appointment for subsequent testing and training periods. The subjects trained for 10 weeks, three sessions a week with, at least, 1 day between sessions. They performed 50 contractions during each session at a cadence of 3 seconds of contraction and 3 seconds of rest. The level of intensity of each contraction was about 80% of the maximal voluntary isometric or isokinetic contraction.

Attha noted the absence or paucity of studies on such variables as the muscle tension needed to secure maximal strength, the number of repetitions advantageous for increasing strength, optimal duration for a maximal stimulus, and the optimal duration of the interval between repetitions. The following studies or summaries of studies provide some support for the training procedures used in this study. Fox noted that a training program of 3 days per week will produce significant gains in strength without risking the possibility of chronic fatigue. He also indicated...
that as long as this frequency was used, significant strength gains may be expected to occur following a strength training program of 6 weeks or longer. McArdle et al.\textsuperscript{13} noted that a load that is equal to 60 to 80\% of a muscle's force-generating capacity is sufficient to increase strength. Atha\textsuperscript{7} further stated that the duration of a muscle contraction should exceed 2 seconds, and that repetitions as low as five or six have been considered to be appropriate. However, a higher number of repetitions have been recommended by others to achieve increased strength.\textsuperscript{6,16} When training the elbow flexors isometrically at 10\°, Meyers\textsuperscript{16} demonstrated that a transfer of strength to the 90\° angle only occurred when the number of repetitions was 20; there was no transfer with three repetitions. There has not been much attention paid to intervals between repetitions with durations of these ranging anywhere from 0 seconds to 2 minutes in studies where improvements in strength occurred.\textsuperscript{1} These studies supporting the training procedures used in this study were derived from isometric studies. Procedures to secure maximal strength gains during isokinetic training have not been very well investigated. Since it was desired to keep the ISOM and ISOK programs identical in terms of the various durations and intensities, suggestions from the isometric literature were adopted.

Instructions to the subjects regarding how to exert the muscular contractions during training were identical to those of the testing sessions. The centralized signal generator provided the cadence with 3 seconds of noise (a buzz) and 3 seconds of silence. The subjects were told to contract during noise and rest during the silence. The three second limit to the contraction period necessitated having the ISOK group train through a range of motion which was completed by the end of this time limit; therefore, the training range was about 45 to 135\°. The level of contraction used for the training was based on the MVIS for the ISOM group and the MVKS for the ISOK group. The meter relay was adjusted to display the maximal isometric or isokinetic contraction as 100\%. Sentinel needles on the meter were adjusted to delineate a range from 78 to 82\%.

Data Analysis

Three figures were drawn to illustrate the following: biweekly changes in the MVIS of the ISOM group at 90\° and in the MVKS of the ISOK group at 30\°/second; pretest and posttest MVIS for both groups at the three angles; and pretest and posttest MVKS for both groups.

To perform analysis of variance (ANOVA) tests there is a requirement that sample variances must be equal. Therefore, the F-maximum test for homogeneity of variances\textsuperscript{3} was used to determine if the variances of the pretests and posttests for both groups were or were not significantly different. To examine the isometric test parameters, a three-way ANOVA with repeated measures\textsuperscript{3} was performed particularly to determine 1) if there were or were not significant differences among the three test angles as a result of training and 2) if the two groups did or did not improve equally over the test periods. A two-way ANOVA with repeated measures\textsuperscript{3} was used to examine the isokinetic test parameters.

### TABLE 1

<table>
<thead>
<tr>
<th>Training mode</th>
<th>Age (yr), pre</th>
<th>Height (cm), pre</th>
<th>Weight (Kg)</th>
<th>Body fat (%)</th>
<th>Lean Body Mass (kg)</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
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<tr>
<td>ISOM Mean</td>
<td>22.6</td>
<td>172.6</td>
<td>74.3</td>
<td>74.9</td>
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<td>SD</td>
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<td>10.8</td>
<td>19.8</td>
<td>21.3</td>
<td>5.8</td>
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<tr>
<td>% Δ</td>
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<td>ISOK Mean</td>
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<td>168.0</td>
<td>70.0</td>
<td>70.1</td>
<td>21.6</td>
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<tr>
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<td>T-value</td>
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<td>0.09</td>
<td>0.64</td>
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</table>
particularly to determine if the groups did or did not improve the same amount over the test periods. Multiple comparison of significant main effects were determined by using Tukey's HSD test. For all tests the 0.05 level was chosen to indicate statistical significance.

RESULTS

Table 1 shows the physical characteristics of the subjects before and after the 10 weeks of training. A paired t-test demonstrated that there were no significant changes in weight, percent body fat, or lean body mass as a result of training. The changes in MVIS and MVKS during training are depicted in Figure 2. The patterns of improvement for both groups appear similar.

The results of the isometric tests are depicted in Figure 3. The F-maximum test for homogeneity of variance confirmed that the variances were not significantly different. The three-way ANOVA (Table 2) demonstrated that the groups improved their MVIS. The critical comparison to determine test mode specificity was the test period by groups interaction which was not statistically significant. This indicated that increases in strength were similar for both groups. The critical comparison to determine the angular specificity of training was the test periods by test angles interaction which was not significant. This indicated that there were no differences among the three test angles as a result of training.

The results of the isokinetic tests are depicted in Figure 4. The F-maximum test for homogeneity of variance confirmed that the variances were not significantly different. The two-way ANOVA (Table 3) demonstrated that there were no significant differences between the groups and the groups improved their MVKS. However, there was a significant interaction effect (test periods by groups) which indicated that differences be-
TABLE 2

ANOVA on the isometric test parameters

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>F-value</th>
<th>Probability F-value exceeds</th>
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<td>Groups</td>
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<td>0.99</td>
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<tr>
<td>Error</td>
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<td>417.39</td>
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<td>Test period (pretest/post-test)</td>
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<td>0.67</td>
<td>0.53</td>
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<tr>
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<td>2</td>
<td>195.73</td>
<td>0.42</td>
<td>0.53</td>
</tr>
<tr>
<td>groups</td>
<td>103.54</td>
<td>20</td>
<td>51.77</td>
<td>0.42</td>
<td>0.53</td>
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<tr>
<td>Error</td>
<td>1557.07</td>
<td>20</td>
<td>77.85</td>
<td>0.42</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Fig. 4. Isokinetic strength values (MVKS) on the pretest and posttest (vertical bars denote ± SE).

Increases were very specific to the training angle. Studies that have examined strength at angles greater than 20° from the training angle have shown mixed results. Lindh11 generally exhibited no significant transfer 45° from the training angle and Bilowit2 showed no transfer 70° away. On the other hand, Sterling23 had mixed results demonstrating transfer at both 30° and 60° in one case but not another. Rasch et al.22 showed transfer 45° from the training angle while Meyers16 established transfer as far as 80° from the training angle, if the number of training repetitions were great enough.

In the present study, subjects performed 50 repetitions during training which was more than in the other cited studies. Observations of the ISOM PRE and ISOM POST in Figure 3 reveals a larger, although not statistically significant, improvement at the training angle (90°) than at the other two angles. This suggests that improvements may be progressively less as the test angle becomes farther distant from the training angle. This is generally, though by no means totally, supported by the cited studies.

The results of the isometric tests at the three angles (70, 90 and 110°) of elbow extension demonstrated that both ISOM and ISOK groups improved their isometric strength significantly. This indicates that strength gained isokinetically (30°/second) will transfer to an isometric test. Moftoft and Whipple17 reported an improvement in strength when their isokinetic groups were measured isometrically but their control group also displayed a similar improvement. Because of this, they suggested that the improvement was due to decreased neuromuscular inhibition instead of an increase in muscular force.

between the test periods were not independent of the groups. The multiple comparison test indicated that the ISOK group improved significantly more than the ISOM group.

DISCUSSION

The present study was unable to demonstrate angular specificity of isometric training within 20° of the training angle. Thus strength gained isometrically at one angle seems to transfer or overflow at least 20° from the training angle. Other studies support this concept. Logan found transfer 20° from the training angle but not 40° away.16 Gardner's Table 17 revealed significant strength increases 20° from the training angle despite the fact that he concluded that strength increases were very specific to the training angle. Studies that have examined strength at angles greater than 20° from the training angle have shown mixed results. Lindh11 generally exhibited no significant transfer 45° from the training angle and Bilowit2 showed no transfer 70° away. On the other hand, Sterling23 had mixed results demonstrating transfer at both 30° and 60° in one case but not another. Rasch et al.22 showed transfer 45° from the training angle while Meyers16 established transfer as far as 80° from the training angle, if the number of training repetitions were great enough.

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Both groups improved significantly on the isokinetic tests. However, the ISOK group improved significantly more than the ISOM group. Although Sterling utilized isometric exercises as his dynamic exercise, he had similar findings in that both isometric and isokinetic training improved strength, but the isometric training was superior to the isokinetic training in improving isometric strength. Lindh also found that isometrically trained muscles demonstrated significant improvement at a low velocity (30°/second) but not at a high velocity (180°/second) of isokinetic testing. She suggested that the low velocity was more similar to isometric contractions than the high velocity (180°/second), thus making a transfer effect possible. Moffroid et al. found that when testing isokinetically, isokinetic exercise significantly increased the work a muscle group could perform; whereas, there was no significant improvement in work when isometric exercise was performed.

Strength training involves not only physiological changes, such as increased amounts of contractile protein, substrates, and enzyme activities, but also improvements in neuromuscular coordination. In a dynamic task, strength training may involve motor learning in that the firing of a number of motor units in the proper sequence (coordination) may be required to achieve a maximal force. Practice during isokinetic training may have achieved this coordination in the present study but isometric training, due to its static nature, did not. Thus, improvements were greater for the isokinetic group when tested isokinetically. Regardless of the reason, the present study and the consensus from the literature seem relatively consistent: isokinetic training (or other types of dynamic training) will improve isokinetic (or dynamic) strength to a greater extent than isometric training.

The findings of the present study may have clinical relevance. Clients who have their elbows immobilized or who cannot perform dynamic exercises for other reasons should be able to increase their strength within 20° of the angle at which the joint is immobilized by performing resistive isometric exercises in one joint position. The results also suggest that isometric or isokinetic tests (30°/second) may be used to determine strength improvements from isometric training; however, isokinetic tests should be used to determine strength improvements from isokinetic training.

In order to further define the limits of angular specificity, future studies could train at one joint angle and then test at a number of angles. Special attention should be given to controlling variables like exercise intensity, total number of contractions, and total exercise time as well as positioning of subjects and immobilization of syn-kinetic movement patterns. The fact that a small sample size was used in the present study should be considered a limitation.

**CONCLUSIONS**

In this study, the left elbow extensors of one group (N = 6) were trained isometrically at 90° and those of a second group (N = 6) were trained isokinetically at 30°/second. The exercise intensity was 80% of the maximum voluntary contraction. The two groups were pre- and post-tested both isometrically at 70, 90, and 110° and isokinetically at 30°/second. The findings were as follows: 1) there were no significant differences among the improvements in the isometric test angles—all angles showed similar improvements, indicating that isometric training at one joint angle will transfer to at least 20° of the training angle; 2) there were no significant differences between the isometric and isokinetic training groups when tested isometrically indicating that both forms of training will improve isometric strength; 3) there were significant differences between the isometric and isokinetic training groups when tested isokinetically—

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**TABLE 3**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>F-value</th>
<th>Probability F-value exceeds</th>
</tr>
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</table>
isokinetic group demonstrated more improvement indicating that isometric training is not as effective in increasing isokinetic strength.

Appreciation is extended to Kenneth Lowe and Ben Mondrone who served as technicians during the course of the study. Thanks also to Roberta Caramioli and Julie Cyphers for their assistance in preparing this manuscript.

REFERENCES