Electromyographic evaluation of joint angle specificity and cross-training after isometric training

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Weir, Joseph P., Terry J. Housh, and Loree L. Weir. Electromyographic evaluation of joint angle specificity and cross-training after isometric training. J. Appl. Physiol. 77(1): 197–201, 1994.—The purpose of this study was to examine the effects of unilateral strength training on the strength and integrated electromyogram (IEMG) of the trained and untrained limbs at several joint angles. A training group [TRN; 4 females and 3 males, age 22 ± 4 yr (SD)] exercised for 6 wk with isometric leg extensions at 80% of maximal isometric torque. A control group (3 females and 3 males, age 24 ± 4 yr) did not exercise. The training was performed three times per week at 0.79 rad below the horizontal plane. The subjects were tested at joint angles of 0.00, 0.26, 0.79, 1.31, and 1.57 rad. Bipolar surface electrodes were used to record the IEMG of the vastus lateralis. The results indicated a cross-training effect and joint angle specificity for isometric torque in TRN only, with significant (P < 0.0005) increases in torque (collapsed across limb) at 0.26 (23.3%) and 0.79 (22.3%) rad. There was a dissociation, however, between changes in torque and IEMG with an increase (P < 0.05) in IEMG (collapsed across limb and angle) for TRN. The dissociation between the IEMG and strength changes was possibly due to differential responses to training in the four muscles of the quadriceps femoris.

resistance training; torque; quadriceps

ISOMETRIC TRAINING has been shown to result in strength increases that are joint angle specific. That is, strength increases are limited to angles at or near the training joint angle (10, 19, 27, 28). Additionally, a cross-training effect has been shown to occur after strength training in which exercise of the trained limb results in strength increases of the untrained limb (8). Although not always exhibited (11, 17, 31), cross-training has been shown to occur after isotonic (1, 5, 15, 21), isokinetic (14), and isometric (3, 5, 16, 19, 29) strength training as well as after electrical muscle stimulation training (2, 21). It has been shown that joint angle specificity and cross-training result from neurological adaptations (8, 19, 28). However, the question of whether joint angle specificity is evident in the untrained limb after unilateral isometric training and what role changes in neural drive have in joint angle specificity and cross-training have yet to be fully determined. Therefore, the purpose of this investigation was to examine the effect of unilateral isometric leg extension resistance training on the strength and integrated electromyogram (IEMG) of the trained and untrained limbs at multiple joint angles.

METHODS

Seven females and six males volunteered to be subjects for this investigation. The subjects were assigned into a training group [TRN; 4 females and 3 males, age 22 ± 4 yr (SD), body wt 67 ± 10 kg] and a control group (CTL; 3 females and 3 males, age 24 ± 4 yr, body wt 72 ± 9 kg). All procedures were approved by the Institutional Review Board, and informed consent was obtained before any testing. All subjects were physically active, but none was engaged in strength training of the lower extremities during the 6 mo before the study.

Testing protocol The subjects were tested before and after a 6-wk training program. After a warm-up period consisting of stationary cycling and static stretching, the subjects performed a series of maximal isometric leg extensions on a calibrated Cybex II isokinetic dynamometer. The subjects were familiarized to the machine and protocol immediately before the pretraining test. We found this procedure to result in highly reliable test-retest data (30). The subjects were tested at joint angles where the Cybex II lever arm was 0.00, 0.26, 0.79, 1.31, and 1.57 rad below the horizontal plane. Each subject performed two maximal isometric contractions of 6 s duration at each joint angle. A minimum of 2 min of rest was allowed between each contraction. The order of testing for the joint angles and that of the limbs were randomized during the pretraining test session. The pretraining order of testing was also followed during the posttraining test session.

During all isometric strength tests, the subjects were simultaneously measured for the surface IEMG of the vastus lateralis. A bipolar lead system using silver-silver chloride electrodes was employed, with the head of the fibula serving as the anatomic landmark for the reference electrode. The monitoring electrodes were located over the vastus lateralis midway between the base of the patella and the inguinal ligament. The interelectrode spacing (center to center) was 5 cm for all subjects. To ensure consistent electrode placement for the posttraining test sessions, marks were applied to the subject’s skin around the circumference of the electrodes with silver nitrate applicators.

The electrical activity of the vastus lateralis was measured using a model EMG 1000 digital multimeter set for a 5-s integration period. The characteristics of the EMG 1000 have been described in detail previously (7). Briefly, this device provides a digital readout of the mean rectified IEMG value with a bandwidth of 10–300 Hz at the 3-dB level and a 60-Hz common mode rejection ratio of 100 db. For all tests, the skin was abraded until the impedance was <2,000 Ω. The maximal torque and corresponding IEMG value for each joint angle were used in the statistical analyses.

Training protocol TRN subjects performed 6 wk of isometric strength training of the right quadriceps muscle group on the Cybex II. The training was conducted three times per week with a minimum of 1 day of rest between training sessions. Each training session consisted of two sets of isometric leg extensions at ~80% of each subject’s maximal voluntary contraction (MVC). Preliminary MVC values were determined from the pretraining test session. At the end of the 2nd and 4th wk of training, MVC values were reassessed and the training torque values were increased accordingly. The training torque values were increased by 21 and 28.5% from the initial values at weeks 2 and 4, respectively. Each set consisted of 10 repetitions with 30 s of rest between repetitions and 2 min of rest between sets. Each repetition lasted 6 s and was performed at a joint angle in which the Cybex II lever arm was 0.79 rad below the horizontal plane.

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Analysis. Two univariate (torque and IEMG) four-way (group, time, limb, and angle) mixed-factorial analyses of variance with the Huynh-Feldt adjustment (18) were used to analyze the data.

RESULTS

For isometric torque, there was a significant \((P < 0.0001)\) time \(\times\) angle \(\times\) group interaction. The fact that there was no interaction involving the limb variable indicated that the pattern of responses to the training was the same for the trained and untrained limbs (18). Therefore, subsequent analyses were performed with the values collapsed across limb. That is, the average of the right and left limbs was used as the torque score in the subsequent analyses. The time \(\times\) angle \(\times\) group interaction was subsequently decomposed into two (TRN and CTL) two-way (time \(\times\) angle) analyses (collapsed across limb). There was no significant \((P > 0.05)\) time \(\times\) angle interaction or main effect for time for CTL (Fig. 1).

There was a significant time \(\times\) angle interaction for TRN. Pairwise comparisons using paired t tests with the Bonferroni adjustment were performed to examine changes in isometric torque (collapsed across limb) as a result of the training for each joint angle. These analyses revealed significant \((P < 0.0005)\) increases in isometric torque at 0.26 (23.3%) and 0.79 (22.3%) rad (Fig. 1B). The changes in torque for TRN at each joint angle for each limb separately are shown in Fig. 2.

For IEMG, there were significant \((P < 0.05)\) time \(\times\) group and time \(\times\) angle interactions. Follow-up procedures involved performing two-way (time \(\times\) angle) analyses for each group (collapsed across limb). These analyses revealed a significant \((P < 0.05)\) main effect for time (collapsed across limb and angle) for TRN only (Fig. 1D). The changes in IEMG for TRN at each joint angle for each limb separately are shown in Fig. 2.

DISCUSSION

Previous investigations (10, 19, 28) have reported that isometric strength training results in joint angle specificity where strength increases are limited to angles at or near the training joint angle. For example, Gardner (10) found that increases in maximal isometric strength for leg extension were limited to the joint angle at which the training occurred. Other investigations (19, 20, 27, 28), however, demonstrated less restrictive joint angle specificity in which strength increases occurred at a limited range of motion around the trained joint angle. It has been suggested that joint angle specificity is neural in origin (8, 19, 28).

The results of the present investigation supported the concept of joint angle specificity and indicated that, for both the trained and untrained limbs, the maximal isometric torque output increased at the training joint angle (0.79 rad) as well as at an adjacent joint angle (0.26 rad). Interestingly, the increases in strength were dissociated from the changes in IEMG as the IEMG data for TRN revealed only a significant \((P < 0.05)\) main effect for time. Thus, the strength increases were localized to 0.26 and 0.79 rad, whereas the IEMG increases were not. In contrast to the IEMG data reported here, Garfinkel and Cafarelli (11) reported no increases in maximal EMG of the vastus lateralis after unilateral isometric training of the leg extensors. Although our IEMG data and those of Garfinkel and Cafarelli (11) appear in opposition, it should be noted that both investigations indicated a dissociation between strength increases and IEMG of the vastus lateralis.

The physiological mechanisms underlying the dissociation between changes in maximal isometric torque and IEMG are unclear. We propose two potential explanations for the findings in the present study. First, it is possible that measurement of the electrical activity from the vastus lateralis may not have been fully representative of the force production associated with leg extension. Narici et al. (25) reported preferential hypertrophy of the vastus medialis in response to isokinetic leg extension training, which suggests a greater involvement and training stimulus. Future investigations should examine the effect of isometric leg extension training on changes in the maximal IEMG of quadriceps muscles other than the vastus lateralis.

Second, previous studies have shown that during isometric contractions there is activation of both the agonist and antagonist muscles (4). In theory, a reduction in the opposition to force production by antagonist muscles may result in increased maximal torque production without changes in the IEMG of the agonist muscles. A recent investigation supports this hypothesis (4). It is also possible that the specific pattern of strength increases reported here was not mediated by an increase in neural drive. Garfinkel and Cafarelli (11) suggest that muscular hypertrophy is exclusively responsible for increases in muscle strength after isometric training of the leg extensors. However, if muscular hypertrophy were the only adaptation, it would be expected that a uniform increase in muscle strength would occur across the test angles. Thus, the joint angle specificity exhibited by TRN argues against exclusively hypertrophic adaptations.

In addition, it should be noted that the largest increase in IEMG (collapsed across limb) occurred at the training angle of 0.79 rad (18.2%). Thus, there was a trend for angle specificity in the IEMG data that was not significant in the statistical analysis. However, at 0.26 rad, where torque increased by 23.3%, the IEMG increased by only 8.4%.

The results of the present investigation indicated a cross-training effect. The cross-training effect involves an increase in the force production capabilities of the untrained limb after unilateral training (8). In the present investigation, strength increases were found at 0.26 and 0.79 rad for both the trained and untrained limbs. It has been suggested that the cross-training effect may be a result of a centrally located neural adaptation. This may involve motor impulses to the muscles of the untrained limb (15) by way of the small percentage of somatic efferent neurons that remain on the same side of the body as they originate (9). As with the data for the trained limb, however, the present findings did not directly link the angle-specific strength increases of the contralateral limb with increases in IEMG. However, the main effect for time for the IEMG data was present in
FIG. 1. Maximal isometric torque and integrated EMG (IEMG) values for training (TRN) and control (CTL) groups collapsed across limb. Values are means ± SD. Solid bars, pretraining; open bars, posttraining. A: maximal isometric torque at various joint angles for CTL (collapsed across limb). B: maximal isometric torque at various joint angles for TRN (collapsed across limb; * P < 0.0005). C: maximal IEMG values at various joint angles for CTL (collapsed across limb). D: maximal IEMG values at various joint angles for TRN (collapsed across limb). Data represent significant main effect for time (P < 0.05) and indicate non-joint angle-specific increase in IEMG.

both limbs, since the effect was found when collapsed (statistically) across limbs.

Additionally, muscle posturing, which involves contraction of the muscles on the untrained side of the body to maintain balance and assume the proper position for the unilateral training, may induce a training effect in the untrained limb (13). However, previous EMG studies (6, 12, 23) have examined the activity of the muscles of
the untrained limb during unilateral exercise and generally found that the level of activation was quite low. Thus, it is not known whether the activation in the untrained limb is sufficient to stimulate improvement in the force production capabilities of the muscles involved. In addition, Ikai and Fukunaga (16) and Lewis et al. (22) found that increased strength in the untrained limb after unilateral isometric training occurred without evidence of muscle hypertrophy. Therefore, although there are several plausible hypotheses, the physiological mechanism that mediates the cross-training effect is presently unknown.
It should be pointed out that verification of maximal test contractions by twitch superimposition (4, 11) was not performed in this investigation. Thus, the subjects may have been performing submaximal efforts during the pretraining tests. It may then be argued that the increases in torque in TRN may be simply due to increased effort during the postraining tests. However, this is unlikely for the following reasons. First, if this were true, it would seem likely that increases in torque would be evident at all joint angles and the joint angle specificity of this study would not be present. Second, high test-retest reliability has previously been reported with our procedure (30). If subjects were producing submaximal efforts, high test-retest reliability indicates that the subjects were able, without feedback, to accurately reproduce the same submaximal effort on the postrtest. Therefore, although we cannot absolutely rule out the presence of an effect of increased effort, we feel it is much more likely that the increases in torque represent increases in force production capability.

In summary, the results of the present investigation demonstrated joint angle specificity and cross-training. There was, however, a dissociation between training-induced increases in maximal isometric torque and changes in maximal IEMG that requires further examination.

We thank Dona Housh for critique of the manuscript and Dave Pavlat and Jeff Soucie for assistance in training the subjects. Present address and address for reprint requests: J. P. Weir, Applied Physiology Lab., Teachers College, Columbia Univ., Box 199, New York, NY 10027.

Received 11 February 1993; accepted in final form 15 February 1994.

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