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Research article

EFFECT OF TRAINING WITH NEUROMUSCULAR ELECTRICAL STIMULATION ON ELBOW FLEXION STRENGTH

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ABSTRACT

Neuromuscular electrical stimulation (NMES) may be used to prevent strength loss associated with post-surgical immobilization. Most studies testing the effectiveness of NMES have trained the knee extensors. The purpose of this investigation was to test the effectiveness of NMES when training the elbow flexors. Twenty-four students were randomly assigned to one of three groups: NMES training, isometric training or control. Testing and training were completed using a Biodex™ dynamometer. After a standard warm-up, subjects were positioned on the Biodex™ with left shoulder in anatomical neutral, elbow flexed to 90° and forearm supinated. Subjects performed three maximum isometric contractions of 5 seconds duration, with 1 min rest between repetitions. Average peak torque during three repetitions was calculated. Subjects trained on three days per week for four weeks. Training included 15 maximum contractions of 15 seconds duration with 45 seconds recovery between repetitions. Russian current was delivered by a Forte™ 400 Combo via electrodes placed over ends of biceps brachii. A maximum tolerable ramped intensity was delivered with frequency of 90 bps and duty cycle of 15:45. After training, subjects were post-tested in a manner identical to pretest. Mean normalized strength data were analyzed using a 3 (Group) x 2 (Test) ANOVA. The Group x Test interaction was significant. Post-hoc analyses revealed that the voluntary training group (normalized means of 0.49 to 0.71 for the pretest and post-test, respectively) had a significantly greater increase than the other two groups, which were not significantly different from each other. The lack of significant strength gains with NMES was likely due to low average training intensity, which was only 20.4% of MVIC. Based on these results, NMES training may not be an effective alternative to voluntary training in healthy subjects.

KEY WORDS: Electrical stimulation, upper extremity, biceps, torque.

INTRODUCTION

Significant athletic injury often requires surgical correction and long periods of immobilization. As a result muscles will atrophy and lose strength. Isokinetic and isotonic exercises that require movement through the range of motion are contraindicated because of the excessive stress placed on the damaged part. In addition, neurological deficits can make voluntary contractions difficult. Therefore, therapists often rely on neuromuscular electrical stimulation (NMES) for strengthening.

The results of studies using NMES have been reported widely in the scientific literature. NMES has been shown to increase strength in healthy subjects (Balogun et al., 1993; Caggiano et al., 1994; Fahey et al., 1985; Kramer and Semple, 1983; Kubiak et al., 1987; Laughman et al., 1983; McMiken et al., 1983; Nobbs and Rhodes, 1986;

Selkowitz, 1985). NMES in combination with voluntary exercise has also been shown significantly effective in increasing strength in healthy subjects (Laughman et al., 1983; Wolf et al., 1986) and in those recovering from reconstructive surgery (Ross, 2000; Snyder-Mackler et al., 1991; 1995; Wigerstad et al., 1988). One limitation of this early research was that the vast majority of studies utilized the lower extremity and most often the knee, thus assumptions were necessary when applying this research to the upper extremity. Therefore, the purpose of this investigation was to test the effectiveness of NMES when training the elbow flexors by comparing NMES to voluntary training and a control group. Based on numerous studies showing strength gains with NMES in the lower extremity it is hypothesized that NMES and voluntary training of the biceps will both result in significantly greater strength gains than the control group.

METHODS

Experimental Design

The design for this study was a mixed model with the factor Group being between subjects and the factor Test being within subjects. The dependent variable was the torque produced by the biceps. The independent variable was the mode of training, which included NMES training, isometric training or a control that did not train. The effects of the independent variable on the dependent variable were assessed by changes in torque production from pretest to post-test.

Procedures

Subjects reported to the athletic training laboratory, and were asked to provide their signed consent after being informed of the procedures and potential risks of the study. The office for the protection of human subjects approved the methods for the study. Twenty-four healthy university students (12 male, 12 female; age 23.5 ± 3.9 yr, height 1.73 ± 0.12 m, weight 73.1 ± 16.7 kg) were assigned, with gender counterbalanced, to one of three groups: NMES training, isometric training or a control that did not train. Students were from the general student body therefore their level of training varied. The mean torque during MVIC for elbow flexion for all subjects during the pretest was 59.6 ± 27.6 Nm. All subjects were pretested for elbow flexion strength using the Biodex™ Dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The Biodex™ has been shown reliable for assessing isometric strength in the upper extremity with intraclass correlations (ICC) ranging from 0.97 to 0.99 (Leggin, 1996). After a standard warm-up, subjects were positioned on the Biodex™ with the left shoulder in the anatomical neutral position, elbow flexed to 90° and forearm supinated. Subjects performed isometric contractions by grasping a handle and pushing against the stationary lever arm. Isometric contractions were chosen because NMES is typically used in early rehabilitation when resistance with joint movement is contraindicated. Three maximum isometric contractions of 5 seconds duration, with 1 min of recovery between repetitions were performed.

Subjects assigned to the control group were asked not to train for four weeks and then return for the post-test. Those assigned to the training groups were asked to return in three days for their first training session. Subjects trained on 3 days per week for 4 weeks. Duration of four weeks was chosen because the strength gains with NMES are thought to be primarily neuromuscular and occur rapidly. Each session included maximum isometric contractions for 15 seconds each minute for a total of 15 min. Subjects performed isometric contractions by pushing against the stationary lever arm of the Biodex™ with maximum effort.

Those training with NMES were positioned on the Biodex™ in a manner identical to the isometric group. Russian current was delivered with a Forte™ 400 Combo Electrical Stimulator (Chattanooga Group, Inc., Hixon, TN) via two, 2 inch round carbon rubber stimulating electrodes. Russian current was chosen because it uses a high carrier frequency of 2500 Hz for which the skin provides less resistant. Thus more current penetrates the skin and reaches the underlying motor nerves. This high carrier frequency is then reorganized into bursts for a resultant frequency that is selected by the clinician (Holcomb, 1997). Several of the studies cited earlier that reported significant strength gains used Russian current (Laughman et al., 1983; Selkowitz, 1985; Snyder-Mackler et al., 1991; 1995). The available parameters were adjusted in pilot work to determine which parameters would provide the greatest contraction force and these parameters were then used for the study. Electrodes were placed at the ends of the muscle belly of the left biceps brachii. A duty cycle allowing a 15 second, ramped intensity with a 10 second sustained tetanic contraction followed by 45 seconds of rest was used. A fixed frequency of 90 burst per second (bps) and a maximum tolerable intensity were used. Maximum tolerable intensity was determined prior to each session and used for the first contraction. The intensity was increased as tolerated during every other contraction. This was possible because motor nerves rapidly accommodate, and was useful because it ensured maximum tolerable contractions throughout the treatment session. Subjects were asked to relax and allow the elbow to flex against the stationary lever arm. Three days after the four weeks of training, all subjects were post-tested in a manner identical to the pretest.

Statistical analysis

The peak torque during each of the three test repetitions was averaged. The average peak torque was then normalized for body weight. Mean normalized strength data were analyzed using a 3 (Group) x 2 (Test) ANOVA with repeated measures on the last factor. The level of significance was set *a priori* at 0.05. Data were analyzed with the Statistical Package for Social Science (SPSS 7.0, Chicago, IL).

RESULTS

The analysis revealed a significant main effect for Test ($F_{1,21} = 15.14$, $p < 0.001$) with normalized means of .48 and .59 for the pre and post-test, respectively. The main effect for Group was not significant ($F_{2,21} = 1.30$, $p = 0.294$). The Group x Test interaction was significant ($F_{1,21} = 4.62$, $p = 0.022$). Post-hoc analyses revealed that the voluntary training group, with normalized means of 0.49 and 0.71 for the pretest and post-test, respectively, had a significantly greater increase in strength than the other two groups, which were not significantly different from each other (Figure 1). These results did not support the study's hypothesis.

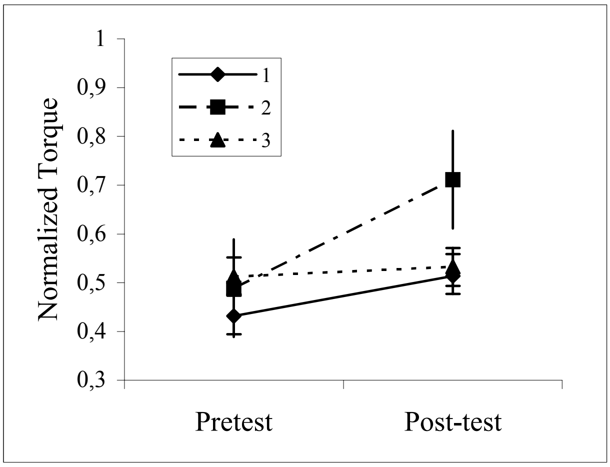

Figure 1. Torque normalized for body weight from pretest to post-test for 1) NMES training, 2) isometric training, and 3) control.

DISCUSSION

Under the conditions of this study isometric training resulted in a significantly greater increase in strength than did training with NMES. Strength gains resulting from four weeks of training with NMES were no greater than for a control that did not train. This is surprising because Russian current has been shown effective in previous studies and the parameters used in this study are recommended for strength development.

The lack of significant strength gains when using NMES in the present study was likely due to the low contraction torque that was achieved during training. The average peak torque measured during the pretest was recorded as the maximum voluntary isometric contraction (MVIC) for each subject. During training with NMES the peak torque during each training repetition was collected and compared to MVIC. The mean training torque averaged for all subjects was only 20.4% of the average MVIC. Holcomb et al. (2000) included a table that reported the contraction torque from ten studies. None of the studies using maximum tolerable stimulation intensity reported torque lower than 20% while only one study using the lesser intense maximum comfortable intensity reported a lower torque. Therefore, the training torque in the present study was unusually low relative to previous studies.

Training torque is an important consideration because several investigators have suggested a minimum percentage of MVIC is required for strength development. For healthy subjects, the required resistance has been estimated to be greater than 60% of MVIC or greater (Currier and Mann, 1983; McDonagh and Davies, 1984). However, Soo et al. (1988) demonstrated that a training intensity of 50% was sufficient to significantly increase strength when ten training sessions were used. Miller and Thepaut-Mathieu (1993) suggested that a minimum intensity of only 33% must be achieved during a majority of the training sessions. Even considering the more conservative estimate, the training torque in the present study of 20.4% of MVIC was insufficient for healthy subjects.

Authors must be careful when applying the results of studies using healthy subjects to a clinical population since the response to NMES may be different. However, in this case the very explanation for the lack of positive findings in the healthy population may not apply to those who are injured. Snyder-Mackler et al. (1994) suggested that the minimum training torque could be different for deficient muscle. The authors used a regression analysis to show a direct relationship between training intensity and recovery of muscular strength after ACL reconstruction. The analysis showed an apparent minimum threshold of only 10% of MVIC is required for a training effect. This is much less than the suggested minimum training torques for healthy subjects that ranged from 33-60% of MVIC (Currier and Mann, 1983; McDonagh and Davies, 1984; Miller and Thepaut-Mathieu, 1993; Soo et al., 1988). According to these results the training intensity of 20.4% reported in the present study may have been sufficient if training deficient muscle.

Another potential explanation for the lack of strength gains with NMES is the difference in skeletal muscle activation when achieved voluntarily versus involuntarily. With voluntary exercise muscles are recruited in an asynchronous fashion thus a greater number of fibers are involved in the training and fatigue is reduced. Whereas when training with NMES the same lower threshold fibers are recruited again and again so that fewer fibers are trained and fatigue is increased (Ruther, 1995). The fatigue then results in less force later in the set thus a lower training stimulus, which was the case in the present study.

Although many of the early studies investigating the effectiveness of NMES used the quadriceps, several more recent studies have trained muscles in the upper extremity. Therefore, direct comparison of these results to the literature is possible. The results of the present study were consistent with those of Rich (1992) who also found no significant increase when training either the biceps brachii or triceps brachii with NMES. The training torque in this study ranged from 30% of MVIC with males in the biceps brachii group to 62% of MVIC with females in the triceps brachii group. Even though these training torques are much larger than in the present study, Rich (1992) cited low training torque as the primary explanation for the lack of strength gains.

Several studies did show strength increases when using NMES on muscles in the upper extremity and two of these lend support to the importance of training torque. Colson et al. (2000) was able to achieve training torques of 60-70% of MVIC while training the biceps, and Pichon et al. (1995) was able to achieve training torques of 60% of MVIC while training the shoulder extensors. In both studies training with NMES resulted in a significantly greater strength increase than a control group that did not train. Willoughby and Simpson (1996) also found that training the biceps brachii with NMES produced significant strength gains when compared to a control that did not train but no training intensities were provided.

Training with NMES is primarily used during early rehabilitation when voluntary exercises, particularly those requiring movement through the range of motion, are contraindicated. Training with NMES is not considered an effective alternative to resistance training but rather a substitute in early rehabilitation until voluntary training is possible (Holcomb, 2005). One limitation of the present study and many others in the literature is the fact that a therapy primarily recommended for injured patients is tested with healthy subjects. The reason for using healthy subjects is simply due to the availability of a homogeneous subject population. Finding a sufficient number of subjects with similar significant elbow injury that affects strength of the biceps brachii would be difficult. With that said there remains the potential problem that deficient muscle may respond differently to NMES than healthy muscles.

Because NMES is primarily recommended for use with deficient muscle and because most studies dealing with muscles of the upper extremity have used healthy subjects, it is recommended that future studies include subjects with upper extremity injury. This would test the notion that lower training torques are required for recovery of deficient muscle. While at the same time, efforts should be made to identify parameters that will provide more forceful contractions and delay fatigue so that higher average training torques may be achieved.

CONCLUSION

Within the limits of this study, training the healthy biceps brachii with NMES is not as effective as training with isometric contractions and no more effective than no training when attempting to increase strength. These findings, which are not consistent with a number of others studies, are likely due to low training torques. When training with NMES the average training torque was only 20.4% of MVIC, which is less than all recommendations for training healthy muscles that were found in the literature.

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KEY POINTS

- Training the elbow flexors with voluntary isometric contractions produced significantly greater strength gains than did training with NMES.
- Strength gains when training with NMES were no greater than with no training.
- The lack of strength gains with NMES was likely due to a low average training torque of 20.4% of MVIC.

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