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EFFECT OF VIBRATION DURING FATIGUING RESISTANCE EXERCISE ON SUBSEQUENT MUSCLE ACTIVITY DURING MAXIMAL VOLUNTARY ISOMETRIC CONTRACTIONS

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ABSTRACT. McBride, J.M., J.P. Porcari, and M.D. Scheunke. Effect of vibration during fatiguing resistance exercise on subsequent muscle activity during maximal voluntary isometric contractions. *J. Strength Cond. Res. 18(4):777–781. 2004.*—This investigation was designed to determine if vibration during fatiguing resistance exercise would alter associated patterns of muscle activity. A cross-over design was employed with 8 subjects completing a resistance exercise bout once with a vibrating dumbbell (V) (44 Hz, 3 mm displacement) and once without vibration (NV). For both exercise bouts, 10 sets were performed with a load that induced concentric muscle failure during the 10th repetition. The appropriate load for each set was determined during a pretest. Each testing session was separated by 1 week. Electromyography (EMG) was obtained from the biceps brachii muscle at 12 different time points during a maximum voluntary contraction (MVC) at a 170° elbow angle after each set of the dumbbell exercise. The time points were as follows: pre (5 minutes before the resistance exercise bout), T1–T10 (immediately following each set of resistance exercise), and post (15 minutes after the resistance exercise bout). EMG was analyzed for median power frequency (MPF) and maximum (mEMG). NV resulted in a significant decrease in MPF at T1–T4 ($p \leq 0.05$) and a significant increase in mEMG at T2 during the MVC. V had an overall trend of lower mEMG in comparison to NV. The mEMG and MPF values associated with NV were similar to previously reported investigations. The lower mEMG values and the higher MPF of V in comparison to NV are undocumented. The EMG patterns observed with vibration may indicate a more efficient and effective recruitment of high threshold motor units during fatiguing contractions. This may indicate the usage of vibration with resistance exercise as an effective tool for strength training athletes.

KEY WORDS. electromyography, median frequency, motor unit, weight training, recruitment

INTRODUCTION

The purpose of this study was to determine the effects of vibration on muscle activation during maximum voluntary isometric contractions (MVC) immediately after progressive stages of muscular fatigue induced by sets of 1-arm dumbbell curls. During sustained and intermittent isometric elbow flexion contractions, the median power frequency (MPF) has been shown to decrease and amplitude from biceps brachii electromyography (EMG) has been shown to be maintained or increase slightly (19). These observed patterns of decreased MPF and amplitude changes from EMG have been associated with muscular fatigue (29). It has been demonstrated that the values of MPF as a result of fatiguing muscle actions can take over 3 minutes to return to prefatigue values (12). Vibration has been shown to amplify the decrease in MPF associated with muscle fatigue during standing (28). However, this was observed without maximal voluntary muscle contractions. The mechanism associated with this phenomenon is unknown; however, it is unlikely that vibration would affect fatigue from a muscular origin, unless the vibration stimulates mechanically mediated ion channels. Neural mechanisms of fatigue as a result of vibration may include the total expenditure of the neurotransmitter, autogenic reflex inhibition, or supraspinal inhibition (28). Although it is improbable that vibration could facilitate the reuptake or synthesis of acetylcholine, the vibration may counteract neural inhibition by evoking excitatory reflex activity. Due to neural inhibition and an increased excitation state of the muscle associated with vibration, an increased state of muscular fatigue might be induced in a shorter time period in comparison to traditional exercise modes without vibration.

It appears that the superimposition of vibration on an active muscle produces a shift in neuromuscular recruitment patterns. When applied to muscle or tendon, vibration results in excitatory postsynaptic potentials (EPSP) stimulating motor units via polysynaptic pathways (5, 7, 8, 9). This excitatory effect originates from the Ia afferents of muscle spindles and is known as the tonic vibration reflex (TVR). EPSPs are produced monosynaptically via the Ia afferent–α motoneuron loop (2, 9, 13, 26), but this likely only plays a minimal role in the contraction of the muscle. This may cause motoneurons to fire only if already brought close to membrane potential by TVR (9). Vibration may have an inhibitory effect on monosynaptic reflexes in the motoneuron pool (10). However, it appears that this inhibition occurs presynaptic to the Ia–α motoneuron junction, leaving the polysynaptic pathways unaffected (9).

Applied research on vibration in both static and dynamic movements has shown EMG amplitude to remain relatively constant (4, 6, 16) with a concurrent increase in muscle power output, indicative of an improvement to neuromuscular efficiency. Furthermore, studies on vibration have shown transient muscle power increases (2, 3, 4, 15) and enhanced strength (14), which are likely due to neuromuscular adaptation. It remains to be determined if the aforementioned shifts in MPF or EMG amplitude in response to vibration will remain consistent

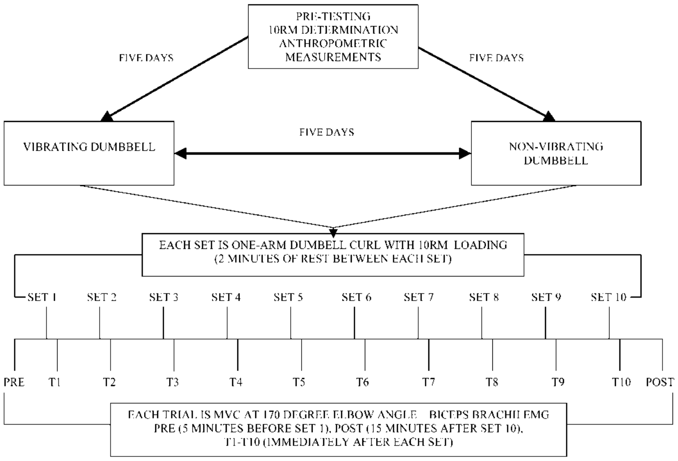

Figure 1. Study design.

during the effects of fatigue as a result of dynamic resistance exercise. In addition, it is unclear if superimposed vibration during resistance exercise will result in an increased or decreased state of muscle fatigue.

Methods

Experimental Approach to the Problem

The design of this experiment was meant to address the implications of performing fatiguing resistance exercise with vibration in terms of its effect on the rate of fatigue and the possible alteration in muscle activity. Subjects performed bouts of resistance exercise to fatigue with vibration (V) and without vibration (NV). Isometric contractions were performed for 3 seconds before and after each set of the resistance exercise bout. During this isometric contraction, muscle activity was recorded from the biceps brachii muscle to determine if vibration would alter muscle activity during fatigue. If vibration did alter muscle activity, then implications for practical application of vibration with resistance exercise can be discussed.

Subjects

Eight males (age = 21.4 ± 1.6 years, height = 69.44 ± 2.62 cm, body mass = 78.06 ± 10.68 kg, body composition = 12.48 ± 2.00%, 10 repetition maximum [RM] = 16.44 ± 2.47 kg) with a minimum of 6 months of periodized heavy weight training experience volunteered to participate in this investigation. Subjects did not have prior exposure to vibration exercise training. To ensure the safety of the subjects, all treatments involved in this study were examined and approved by the University of Wisconsin-La Crosse Institutional Review Board (IRB). In accordance with IRB guidelines, all subjects read and signed an informed consent form prior to participation.

Study Design

Data collection was divided into 3 sessions, each separated by a minimum of 5 days (Figure 1). During the first session (pretesting), a 10 repetition maximum (10RM) was determined for a 1-arm bicep curl. Anthropometric measurements were also taken at this time. The second and third sessions consisted of the resistance exercise protocol designed to evoke muscular fatigue. During one of these sessions (V), a vibration (44 Hz, 3-mm displacement) was superimposed by using a custom-designed dumbbell. The vibrating dumbbell was a standard grip hollow bar with a vibration device inserted in the bar and powered by a standard 12-volt DC power supply. Each side of the bar could be fitted with standard plates and secured into place with collars. The other session (NV) was conducted using a traditional nonvibrating dumbbell. The order of V and NV sessions were randomized to eliminate any effects of sequence.

Ten Repetition Maximum Protocol

In order to determine an accurate 10RM, a theoretical 1 repetition maximum (1RM) was first estimated for each subject as a function of body weight (0.25 × body weight). Subjects then performed several warm-up sets based on 40% (10 repetitions), 60% (4 repetitions), and 80% (one repetition) of that theoretical 1RM. Following execution of a singular repetition with that weight, the resistance was adjusted according to performance on that first maximal effort. Increments and decrements of 5 pounds were used at the discretion of the experimenter. After a 3-minute rest period, each subject performed a single repetition trial with the new weight. This pattern continued until the subject was unable to complete a single repetition of the lift with good form. The subject's 1RM was considered to be the weight used on the last successful trial. Following determination of the 1RM, a theoretical 10RM was approximated using 70% 1RM. The subjects then attempted to move that resistance through ten repetitions, and resistances were adjusted in order to achieve a 10RM. The 10RM loading scheme was utilized for this investigation to stimulate a relatively high level of metabolic and neuromuscular fatigue.

Resistance Exercise Protocol and MVC

Five minutes prior to the first set, subjects performed a maximal isometric contraction (MVC) of the biceps brachii for 3 seconds. This was done from a seated position with the elbow immobilized against a cushion at an elbow angle of 170°. To ensure consistency of body position and elbow angle, the chair and immobilized positions were measured and marked. Immediately after the isometric contraction, subjects performed 10 sets of 10 bicep concentration curls with their predetermined 10RM. Each set was followed by an MVC and a 2-minute rest interval. Resistances were adjusted to maintain 10 repetitions on all sets. Following the 10th set, subjects were allowed a 15-minute rest interval before performing 1 last MVC.

Electromyography

EMG signals from the biceps brachii were recorded for 3 seconds during each isometric contraction, using bipolar surface electrodes (20-mm interelectrode distance) connected to a radio telemetry transmitter (Glonner MESPEC 4000, Planegg, Germany). A reference electrode was placed on the nearest bony landmark. Electrode placement was longitudinal to muscle fibers halfway between the motor point and distal portion of the biceps brachii. Electrode location was marked with a permanent marker for consistent placement between testing sessions. Skin was abraded until impedance was less than 5 kilo-ohms. The EMG signal was sampled at 1,000 Hz and filtered (high-pass filter, 20 Hz; notch filter, 60 Hz). The raw signals were recorded and full-wave rectified and filtered (second order Butterworth low-pass filter with cut-off at

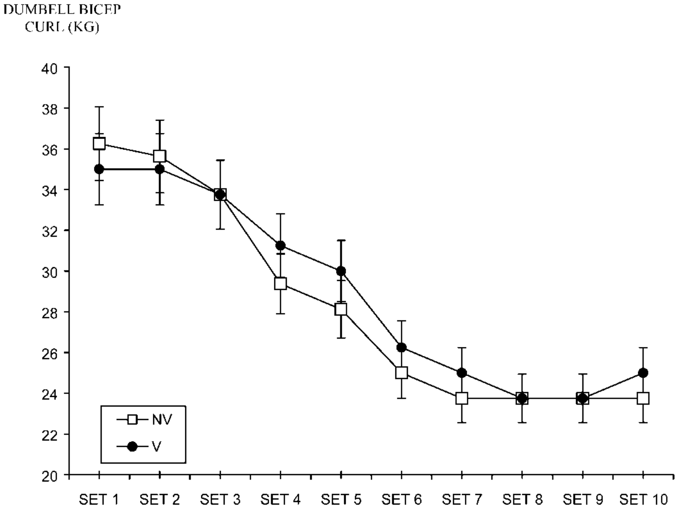

FIGURE 2. Decline in dumbbell mass with progressing sets, as an index of fatigue.

6 Hz). Maximum EMG amplitude (mEMG) was then determined (DATAPAC 2000, RUN Technologies, Laguna Hills, CA). The median power frequency (MPF) of the EMG signal was analyzed using a Fast Fourier Transformation (FFT).

Statistical Analyses

All EMG values were converted into a percentage of the baseline value, which was given the value of 100%. Then, a repeated-measures analysis of variance (ANOVA) with contrasts was used to compare the mEMG and MPF of vibratory and nonvibratory conditions, as well as individual time-point comparisons within each condition. Statistical procedures were calculated using SPSS Version 10.0 for Windows (SPSS Inc., Chicago, IL). The level of statistical significance was set at $p \leq 0.05$.

RESULTS

During the first resistance exercise session, resistances were adjusted, when necessary, in attempts to maintain 10 repetitions per set (average number of repetitions per set—NV: set 1, 9.88 repetitions; set 2, 9.63; set 3, 9.75; set 4, 9.5; set 5, 9.88; set 6, 9.75; set 7, 9.88; set 8, 9.63; set 9, 9.88; set 10, 9.88) (V; set 1, 10.00; set 2, 9.75; set 3, 9.63; set 4, 9.63; set 5, 9.88; set 6, 9.88; set 7, 9.88; set 8, 9.75; set 9, 9.63; set 10, 9.5). For consistency, those same resistances were then used during the second session. Both lifting sessions were adequate for evoking muscle fatigue, as evidenced by the needed decline in dumbbell mass for each subsequent set (Figure 2). There was a significant 71% reduction in dumbbell mass for V and a significant 65.5% reduction in dumbbell mass for NV. There was no significant difference in the decline in dumbbell mass between V and NV.

Although no significant differences were found between the vibratory and nonvibratory conditions, a trend can be distinguished between V and NV conditions for mEMG and MPF. At all but one data point, the mEMG of session NV was elevated above its baseline readings (Figure 3). Although the trend for MPF is not quite as distinct, session V is higher than NV in most instances (Figure 4).

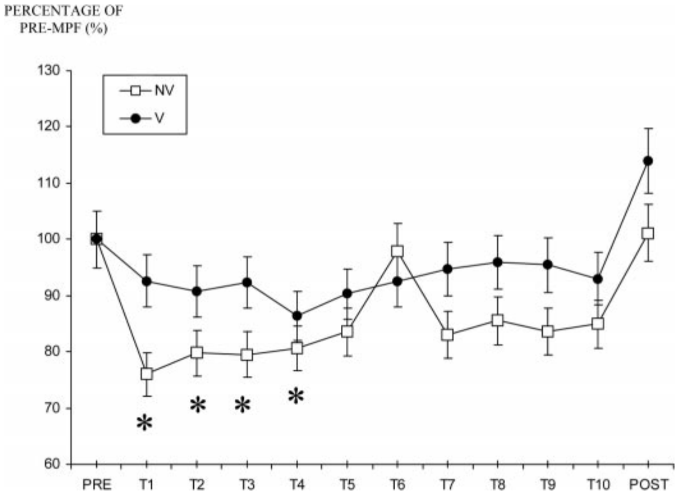

FIGURE 3. Comparison of biceps brachii median power frequency (MPF) for vibration and nonvibration trials over progressing stages of fatigue. * = values are significantly different from the corresponding baseline value ($p \leq 0.05$).

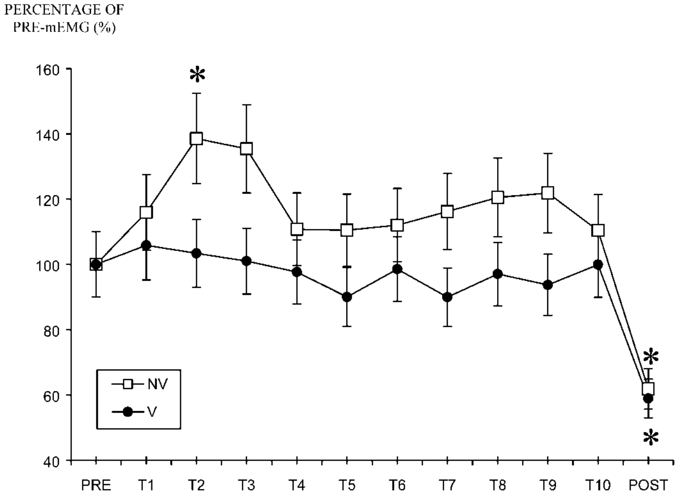

FIGURE 4. Comparison of biceps brachii maximal electromyography (mEMG) for vibration and nonvibration trials over progressing stages of fatigue. * = values are significantly different from the corresponding baseline value ($p \leq 0.05$).

Furthermore, when examining time interaction, the mEMG following the second set (T2) of session NV was significantly elevated above baseline (Figure 3). MPF for session NV was significantly below baseline following sets one through four (T1–T4) (Figure 4).

DISCUSSION

The NV results of this study are consistent with past research (1, 13, 18, 21, 27) in that EMG amplitude tends to increase above baseline levels with fatiguing contractions. This phenomenon indicates an increase in the number of motor units being recruited to assist fatiguing fibers. Our NV results are also consistent (17, 22, 23, 24) regarding a decrease in MPF that may be indicative of a shift to lower threshold, fatigue-resistant (aerobic) muscle fibers. Following vibration (V) during fatiguing dynamic resistance exercise EMG during the MVC resulted in relatively constant EMG amplitude and a slight decrease in MPF during an isometric MVC after each resistance exercise set. Bosco et al. (4) indicted that during vibration root mean square EMG was 200% greater during muscle contractions, and Torvinen et al. (28) indicated that MPF during vibration in standing was dramatically reduced. Unfortunately, in this study EMG was not measured during the vibration stimulus but immediately after. Therefore, comparison of our results to the previous studies is meaningless. The observations in this study are, however, unique in that they are an evaluation of muscle activity immediately after vibration imposed during exhaustive dynamic resistance exercise.

As stated above, muscle fatigue induced by maximal voluntary muscle contractions results in increased EMG amplitude and decreased MPF. It appears that vibration has some effect on this EMG pattern observed with traditional fatigue protocols. It is possible that vibration induces a lasting potentiating effect on muscle activity that maintains recruitment of high threshold muscle fibers. This means force levels could be maintained with lower EMG amplitudes and would result in a less dramatic decrease in MPF with fatigue. A possible explanation is that V promotes and maintains more synchronous motor unit recruitment in comparison to NV (20). Under normal resistance exercise conditions, motor units are recruited asynchronously in order to prevent fatigue (21). However, literature has shown that motor units fire in synchronicity with vibration frequency up to approximately 100 Hz (20); the present research used a frequency of 44 Hz. Additionally, in the present protocol, vibration was not localized to a single motor unit. Therefore, the tonic vibration reflex (TVR) may have promoted neural stimulation for the motor units of the agonist and all synergistic muscles throughout the muscle both during the resistance exercise set and immediately after during the MVC. The vibration also may stimulate the contractile ends of intrafusal spindle fibers via gamma motoneurons (11, 20, 25). Romaiguere et al. (25) postulated that the resultant removal of slack would prolong spindle sensitization and that the subsequent increase in Ia firing would combine with voluntary contraction to lower the threshold of motor units, even after vibration had been removed. However, with lower thresholds, EMG amplitude would increase, whereas the MPF would be expected to decrease. Therefore, it is unlikely that the mechanisms described in their hypothesis occurred in the present study.

All of the aforementioned mechanisms are merely speculations based on previous literature, because in the current study EMG was not collected during application of the vibratory stimulus. Therefore, any effects of the vibration treatment that are observable in the present results are actually residual effects of vibration. Romaiguere et al. (25) found that muscles remained potentiated for 10 seconds after the removal of vibration stimulus. They speculated that the potentiation was due to a remnant increase in motoneuron excitability, similar to posttetanic potentiation. Issurin and Tenenbaum (15) reported observable, though not statistically significant, increased EMG amplitude 4–6 minutes postvibration. In the present study all EMG data were collected within 5 seconds postvibration, well within the timeframe in which residual effects could be expected. The higher MPF results in the V condition of the present study support this potentiation hypothesis. However, in a facilitated state, EMG amplitude would be expected to increase as well, contrary to the present findings. It is possible that vibration produced a fatigue resistance mechanism by rerecruiting fatigued motor units and increasing or maintaining the MPF both during and immediately after the sets of 1-arm dumbbell curls.

The present study found nonsignificant trends in muscle activity in response to a vibratory stimulus that differed from nonvibration. EMG amplitude was suppressed following the treatment, whereas MPF was elevated as a result of the vibration in comparison to nonvibration. This observed phenomenon most likely represents the ability of the muscle to maintain recruitment of high threshold motor units and indicates a more efficient neuromuscular mechanism for producing force with fatigue. The study design limits our conclusions of the in-treatment physiological responses to vibration, but the posttreatment results suggest a potentiation of high threshold motor units, in agreement with previous literature (2, 3, 20). This potentiation may allow fatigued low threshold motor units to recover, while driving the high threshold motor units to continue. Further research should be conducted into TVR and postvibratory potentiation to determine their potential benefits and hazards in utilizing vibration with resistance exercise.

Practical Applications

The possible use of vibration to enhance strength gain is intriguing. The current investigation indicates that although vibration does result in alteration of muscle activity with resistance exercise, it is not clear what application or implication this altered muscle activity may have. The amount of fatigue as a result of the application of vibration did not appear to be different in the resistance exercise protocol used in this investigation. However, there is a possibility that vibration results in the ability to maintain recruitment of high threshold motor units and allows for higher force/EMG ratios. This could have implications for its effectiveness in strength training. If an individual can continue to maintain recruitment of high-threshold motor units with fatiguing exercise, then a heavy resistance protocol involving vibration may supply a synergistic effect for increasing muscle strength with training. Additional acute and longitudinal investigations into the use of vibration with resistance exercise need to be completed before any further meaningful practical applications can be recommended.

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