







Different types of mechanical vibration application on EMG response and strength performance

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Abstract - Aim: The present study aimed to compare the strength performance and the neuromuscular activity during one maximum repetition test (1RM), and the maximum voluntary isometric contractions (MVIC) performed with whole-body vibration (WBV), local vibration (LV), and no vibration (NV). **Methods:** The sample consisted of 15 males, experienced in strength training for at least 6 months, which performed all strength tests in the barbell curl exercise across randomized trials on the following conditions: NV, WBV, and LV. During all tests, the normalized root means square values of the electromyographic signals (EMG_{RMS}) of the biceps brachii and brachioradialis were recorded and compared between the conditions. The one-way ANOVAs with repeated measures were used to compare the results of 1RM and MVIC tests and the normalized EMG_{RMS} between the conditions. When necessary, a post hoc Scott-Knott test was used to identify the differences reported in the ANOVAs. The significance level adopted was $\alpha < 0.05$. **Results:** The EMG_{RMS} response of the biceps brachii and brachioradialis muscles during the 1RM and MVIC tests presented significantly higher values at LV compared to WBV, and NV ($p < 0.001$). The 1RM tests, and the MVIC results were similar between conditions ($p = 0.9803$; $p = 0.061$, respectively). **Conclusion:** These results indicate that the application of MV was not sufficient to increase strength performance.

Keywords: muscle spindle, electromyography, strength training, one maximum repetition test.

Introduction

In the search of incrementing gains in muscle strength, researchers have been using mechanical vibration (MV) in their studies protocols¹⁻⁶. However, the outcomes of applying MV to improve muscle strength are still controversial^{7,8}. This incongruence, at least in part, seems to be due to different combinations of mechanical parameters, as the time of exposure, frequency, and amplitude of MV. Variations on either MV frequency or amplitude may modify the vibratory impulse accelerations applied to the body⁹⁻¹¹. This fact may alter the neurophysiological response to MV¹⁰. In addition, two types of MV have been the focus of the investigation; the whole-body vibration (WBV)¹², and local vibration (LV)¹³. However, no study has yet compared the neuromuscular response by using both types of MV.

The WBV may be attained with a person standing on a vibration platform while performing an exercise, such as jumps and squats¹⁴ or even in elbow flexion exercises¹⁴. The MV from the platform is transmitted along the body, activating the alpha-motorneuron as a response to stretch reflex via muscle spindles¹⁵, improving strength genera-

tion to higher levels that, probably, would not be achieved without vibration in a similar stimulus¹⁶. However, during the vibration transmission along the body, a dissipation of the vibratory impulse may occur reducing its effects¹⁷. Thus, muscle groups located nearby the vibratory source tend to present greater effects on strength development in comparison to further muscle groups¹². Therefore, the use of WBV by a vibration platform may not be efficient when the muscle strength increase is wanted for upper limbs. However, exercises for upper limbs performed with WBV can be prescribed by coaches in sports and fitness, such as biceps curl, rows, and other exercises with barbell and dumbbell. Nevertheless, the possible attenuation of the vibratory impulse between the source of the vibration and the target muscle in strength performance has yet to be investigated.

Aiming to minimize the vibratory impulse loss, the LV seems to be an interesting alternative^{7,13,18}. The LV occurs when the MV is applied directly on the muscle belly¹³, on the tendon of the target muscle¹², on the weight to be lifted¹⁹, or yet, in the direction of the resultant force of the contracting muscles^{8,20,21}. In this last case, the vibratory impulse generates small muscle stretches that may

elicit greater muscle spindles stimulation and perhaps, greater muscle strength development in comparison to other types of MV⁸.

The MVs, applied by LV²², and WBV²³, may increase the excitability of the neuromuscular sensors by the tonic vibration reflex²² and increasing the electric muscle activity²³. The registration and analysis of the amplitude of the electromyographic signal (EMG_{amplitude}) may contribute to the understanding of the neurophysiological responses in both conditions, LV, and WBV. The EMG_{amplitude} response represents the degree of muscle activation and, at least in part, the recruitment of motor units²⁴. Nevertheless, no studies were found comparing the effects of applying WBV, and LV on the resultant force direction on isometric and dynamic strength response of upper limbs. In addition, it is not yet known what would be the strength response by the one maximum repetition test (1RM), or by the maximum voluntary isometric contractions (MVIC) test between the conditions LV and WBV.

Some studies adopt the result of the 1RM test, performed without vibrations, as a reference for the prescription of training intensity with and without the MV²⁵. Therefore, the weight to be used during the exercises to which the volunteers will be submitted by MV is based on percentage values of the maximum weight displaced in the 1RM test without vibration. As the application of MV during the 1RM test may influence the result of this test²⁵, the intensity of strength training performed with vibration prescribed based on the 1RM test performed without vibration may be underestimated, highlighting the importance of verifying the effects of MV on this test.

Thus, the objective of the present study was to investigate and compare the strength response, and the neuromuscular activity of the biceps brachii and brachioradialis in isometric and dynamic contractions during the barbell curl exercise with WBV and LV. We hypothesized the LV will lead to greater neural activity by higher EMG_{amplitude}, and a greater strength response, regardless of the type of test (isometric or dynamic).

Methods

Samples

The sample consisted of 15 male volunteers, with a mean age of 25.6 ± 3.96 years, mean height of 178 ± 3.87 cm, and mean body fat of $13.9 \pm 1.93\%$. Volunteers were selected from the Federal University of Minas Gerais, through personal contact, for 4 months. The sample size was calculated using the GPower 3.1 software based on data of a pilot study, following the guidelines proposed by Beck²⁶. In this pilot study, it was noticed the EMG response during the 1RM test performance of the WBV condition on the biceps brachii presented the greatest

values of coefficient of variation between the conditions and muscles analyzed. Therefore, the mean (M1) and standard deviation (SD₁) values of the EMG biceps brachii from the WBV during the 1RM test were used to calculate the effect size (Cohen's d²⁶). For the effect size calculation, the mean (M2) and standard deviation (SD₂) of the EMG values of biceps brachii during the 1RM test of NV condition was used as control values on the following equation:

$$\text{Cohen's } d = \frac{\text{Mean1} - \text{Mean2}}{\text{Standard Derivation (SD)}_{\text{pooled}}} \quad (1)$$

where Mean 1 = biceps brachii mean EMG values of WBV values during the 1RM test, and the Mean 2 = biceps brachii mean EMG values of NV values during the 1RM test, and the $\text{SD}_{\text{pooled}} = \sqrt{(\text{SD}_1^2 + \text{SD}_2^2)}$. The result of Cohen's d equation (effect size = 0.25) was inserted in the GPower 3.1 software. Thus, an effect size of 0.25, power of 80%, $\alpha = 0.05$, the correlation between repeated measurements of 0.75, three groups (NV, WBV, and LV), six measurements (1RM test, MVIC, EMG in these two tests for two muscles) were adopted for the sample size calculation.

All volunteers were regularly enrolled in a strength training program for at least six uninterrupted months, being considered as recreationally trained²⁷. Exclusion criteria were the incidence of lesions, musculoskeletal diseases in either lower and upper limbs for the last 12 months, or any heart disease. All volunteers received complete information about the objectives and methodological procedures and signed a consent term. The local ethics committee approved this study (under the number: 240.834, year: 2013, process number: 13683413.6.0000.5149), which complied with international standards.

Procedures

Materials

In this study, a cable crossover machine was used (Pedalar[®], Brazil), containing on each side 16 plates of 5 kg. For LV application, a three-phase induction motor (WEG W22 PLUS, 2 cv, 3385 rpm, 220-380 V - Siemens[®]) was used. An eccentric shaft with a pulley at the end was attached to the motor, in which the crossover cable passed around this pulley allowing performing the exercise. The motor was fixed to the ground, facing one side of the crossover, making the cable assuming a vertical trajectory between the crossover sheave and the motor. [Figure 1](#) shows the equipment.

For the WBV application, a vibrating platform (Planet for Fitness[®], model PT 004 Professional - USA), adapted with a motor identical to the one used in LV was used. Both the platform and the LV motor were connected

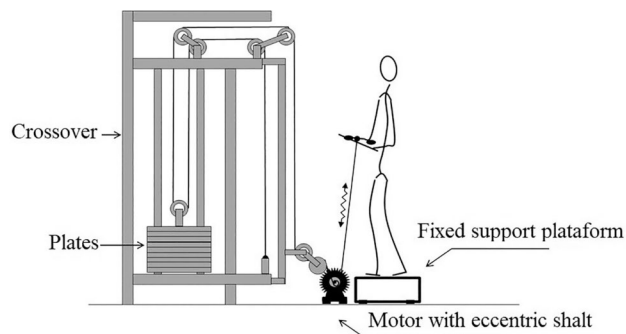


Figure 1 - Motor positioning for localized location application.

to a frequency inverter (WEG, model CFW 09). The vibratory platform was positioned close to the motor at a distance that allowed the cable goes to a vertical trajectory and parallel to the volunteer body. Figure 2 shows how WBV was performed.

The motors from LV and the vibratory platform were only switched on under LV and WBV conditions, respectively. The vibration frequency and amplitude for both cases were 26 Hz and 6 mm, respectively^{21,28}. The time of exposure to vibration was restricted to the time needed to perform the exercise. The frequency inverter was used to control the vibration frequency. The LV amplitude was determinate by the eccentric shaft, which was connected to the cable and in the WBV platform. Subjects were instructed to keep their knees flexed (10°), feet parallel, and positioned at a predetermined location to ensure a peak-to-peak amplitude of 6 mm. To verify the severity of human body exposure to vibration, the estimated vibration dose value (eVDV) was calculated from the head acceleration. The eVDV was 10.77 and 9.93 for the WBV and LV respectively. Values of eVDV greater than 17 are considered harmful to the human organism²⁹.

To collect EMG data, surface electrodes of the 3M brand (3M, Brazil) were used, fixed in the biceps brachii muscle, according to SENIAM project guidelines, and in the brachioradialis at the greater portion of the muscle belly (right arm), located after a voluntary contraction³¹. The range of motion was controlled by an electrogoniometer (Mega Electronics Ltda, Finland) with its axis of rotation fixed on the lateral epicondyle of the humerus

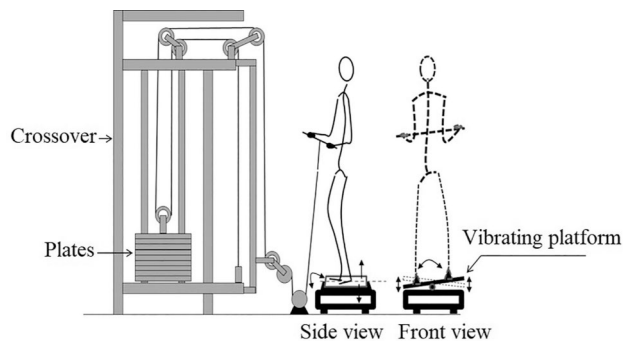


Figure 2 - Platform positioning for whole-body vibration application.

of the left arm. All devices were connected to a biomonitor (Mega Electronics Ltda, Finland - model ME6000) responsible for amplification, analog-to-digital conversion (1000 Hz), and signal transmission to a portable computer, with a sampling rate of 1000 Hz. The EMG and the electrogoniometry data were recorded and analyzed using MegaWin software version 3.0 (Mega Electronics Ltda, Finland). To record the peak force during the MVIC, a load cell (Zb Staniak, Poland) with 1000 Newtons capacity, calibrated, connected to a signal amplifier and decoder (WTM 005-2T / 2P, Jaroslaw Doliriski Systemy Mikroprocesorowe, Poland) was used. The amplifier was connected to a computer interface with the program MAX5 (version 5.1, JBA, ZbStaniak, Poland), which allows analysis of the force curve as a function of time with a sampling frequency of 1000 Hz. For both the EMG, and the electrogoniometer data, a bandpass filter with a lower limit of 26 Hz and an upper limit of 450 Hz, and a 60 Hz band-reject filter were used.

Familiarization

The volunteers came to the laboratory on 7 different days, with, at least, 48 h of rest between days. On the first day, before familiarization begins, subjects performed a single set of 10 maximum repetitions in the barbell curl exercise. The weight lifted was based on the subjects experience and it was used to estimate the value for one maximum repetition (1RM), by using the equation adopted by Shaw et al.³⁰, presented below:

$$1RM = \frac{\text{weight lifted}}{[1.0278 - (\text{number of repetitions until fail} \times 0.0278)]} \quad (2)$$

After five minutes of resting, the familiarization protocol for each experimental condition (WBV, LV, and NV) was started. The familiarization protocol was composed of 2 sets with 2 repetitions at 95% of the estimated 1RM

value. Three minutes rest between sets, and five minutes between each experimental condition were respected.

The barbell curl exercise constituted the bilateral flexion of the elbow, starting from the full elbow extension

position, going to maximum elbow flexion, and returning to the initial position. To control the elbow's range of motion, a rope passing just above and close to the left shoulder of the volunteer was used, in the sagittal plane. The end of the concentric action was considered maximal when the volunteer's left fist touched the rope. Shoulder flexion was not allowed and was controlled by the evaluator's observation. The hands held a straight bar, in the supinated position, at the width of the shoulders. In all day's tests, the subjects respected the initial position, in which they remained standing on a platform, keeping the knees semi-flexed (10° degrees of knee flexion - 0° = knees fully extended) and the feet parallel and positioned in a predetermined place.

Experimental sessions

The other six days were reserved for experimental sessions, consisting of the 1RM test and the MVIC test with the same exercises of familiarization for the following conditions: WBV, LV, and NV. Each condition was performed in two subsequent days, separated by an interval of exactly 48 h. The order of conditions in the test sessions was randomized. In all test procedures, data of the surface electromyography (EMG) activity were collected. The mean values of isometric force (MVIC), 1RM, and EMG from the two days tests (each condition) were used for analysis. An interval of exactly 120 h between pairs of sessions of the same experimental condition was respected.

At the beginning of all experimental sessions, the maximum voluntary isometric contraction normalization test (MVICn) was performed with and without vibration. The MVICn consisted of three maximal isometric contractions lasting six seconds with five-minute rest between attempts¹⁷. During this test, the root means square electromyographic activity (EMG_{RMS}) of the biceps brachii and brachioradialis muscles of the right arm, and the maximum peak force was recorded (window of 250 ms). The highest value of the EMG_{RMS} was used to normalize the electromyographic data, recorded during the 1RM and MVIC tests (window of 250 ms). For the accomplishment of MVICn, the volunteers adopted the initial position (same as the familiarization), keeping the elbows flexed at 90° (0° = elbow fully extended), gauged using the electrogoniometer.

Respecting a 10 min resting after the MVICn, volunteers started the 1RM test in one of the study conditions (WBV, LV, or NV), adopting the same positioning and execution used during familiarization. The test consisted of five maximum attempts, with five-minute rest between each attempt¹⁷. The initial weight was 5% lower than the estimated 1RM value³². The progression of the weight was gradual in the function of the subjective perception of the volunteers and evaluators. Each volunteer was instructed to perform only one repetition per attempt. Whenever

the movement was performed improperly, or if the volunteer used accessory movements, the weight lifted in the previous attempt was considered the maximum weight (1RM).

After the 1RM test, respecting a 30-min interval, the MVIC test was performed in one of the study conditions (WBV, LV, or NV), and its data was used to verify the effects of MV on electromyographic activity and peak force. The procedures and positioning of the volunteers were the same as used in the MVICn tests.

Statistical analysis

Initially, the analyses of descriptive data were performed, and Shapiro Wilk tested the normality of data. The interclass coefficient correlation ($ICC_{3,1}$) and the normalized standard error of measurement (% SEM- SEM/mean data multiplied by 100) were calculated with data collected in sessions with the same experimental condition for EMG, MVIC, and 1RM. To analyze the ICC and SEM, the highest value of EMG, the force peak during the MVIC, and the 1RM test result, found in each of the two sessions for the same condition, were considered. One-way ANOVAs with repeated measures with post hoc of Scott-Knott (when necessary) were used to compare the conditions. The significance level adopted as $\alpha < 0.05$. Additionally, the eta-squared (η^2) was also calculated as effect size (SS_{effect}/SS_{total} , where SS_{effect} = sum of squares for the effect, and SS_{total} = total sum of squares), considering the following interpretation: < 0.06 = small; $0.06-0.14$ = moderate; > 0.14 = large³². All statistical procedures were performed using the software SISVAR 5.7.

Results

ICC and SEM for 1RM test, MVIC, and EMG_{RMS}

Regarding the data collection reliability between day 1 and 2 for each condition (NV, LV, WBV), the $ICC_{3,1}$ and normalized SEM values were, respectively, for 1RM test = 0.999 and 1.17-1.18%; for MVIC = 0.996-0.997 and 1.00-1.40%; for EMG_{RMS} (biceps brachii and brachioradialis) = 0.991-0.999 and 0.7-2.6%.

1RM EMG values

The normalized EMG_{RMS} values of biceps brachii during the 1RM test were $98.04 \pm 5.68\%$, $116.79 \pm 11.76\%$, and $106.07 \pm 7.67\%$ for NV, LV and WBV, respectively. According to ANOVA these values are different between conditions ($F_{2,42} = 17.362$; $p < 0.001$; $\eta^2 = 0.452$: large). Post hoc of Scott-Knott detected that LV presented greater values than WBV and NV, and the WBV presented higher values than NV.

The normalized EMG_{RMS} values of brachioradialis presented mean values of $102.56 \pm 6.60\%$, $120.47 \pm 11.87\%$, and $110.90 \pm 12.74\%$ for NV, LV and WBV,

respectively. According to ANOVA these values are different between conditions ($F_{2,42} = 10.408$; $p < 0.001$; $\eta^2 = 0.331$: large). Post hoc of Scott-Knott detected that LV presented greater values than WBV and NV, and the WBV presented higher values than NV. **Figure 3** shows the comparisons among the conditions for both muscles.

MVIC EMG values

The normalized EMG_{RMS} values of biceps brachii during the MVIC presented $99.94 \pm 1.90\%$, $122.09 \pm 12.67\%$, and $111.15 \pm 7.21\%$ for NV, LV and WBV, respectively. According to ANOVA test there were differences between the conditions ($F_{2,42} = 25.536$; $p < 0.001$; $\eta^2 = 0.54$: large). LV presented greater values than NV and WBV, and WBV values were higher than NV.

The normalized EMG_{RMS} values of brachioradialis during the MVIC presented $101.01 \pm 3.30\%$, $123.30 \pm 11.85\%$, and $112.20 \pm 10.33\%$ for NV, LV and WBV, respectively. According to ANOVA test there were differences between the conditions ($F_{2,42} = 21.646$; $p < 0.001$; $\eta^2 = 0.50$ - large). LV presented greater values than NV and WBV, and WBV values were higher than NV. **Figure 4** shows the comparisons among the conditions for both muscles.

1RM

The mean weight lifted during the 1RM test in NV, LV and WBV were 69.03 ± 8.15 kg, 69.17 ± 8.12 kg and 69.6 ± 8.12 kg, respectively. According to ANOVA, there was no difference in the 1RM values between the condi-

tions ($F_{2,42} = 0.020$; $p = 0.9803$; $\eta^2 = 0.001$: small) (**Figure 5**).

MVIC test

The isometric peak force values during the MVIC test were 459.33 ± 38.94 N, 498.87 ± 49.58 N, and 478.42 ± 43.14 N, respectively for NV, LV and WBV. According to ANOVA test there were no differences between conditions, only a trend ($F_{2,42} = 2.983$; $p = 0.061$; $\eta^2 = 0.12$: moderate) (**Figure 6**).

Discussion

The present study aimed to compare the EMG response and the strength performance in dynamic and isometric tests performed with LV, WBV, and NV. We hypothesized the LV would lead to a greater strength response and neural activity. According to the results, the EMG response of the biceps brachii and brachioradialis during the 1RM and MVIC tests presented values significantly higher in LV in relation to the WBV and NV. Thus, the hypothesis of the present study was partially confirmed. The 1RM test performance and the MVIC values were not different between conditions (LV, WBV, and NV). These results indicate that the application of MV did not improve the strength performance.

However, the results showed a significant increase in the EMG_{RMS} in either muscle when the MV was applied. Some studies have also demonstrated an increase in EMG during MV application compared to exercises performed

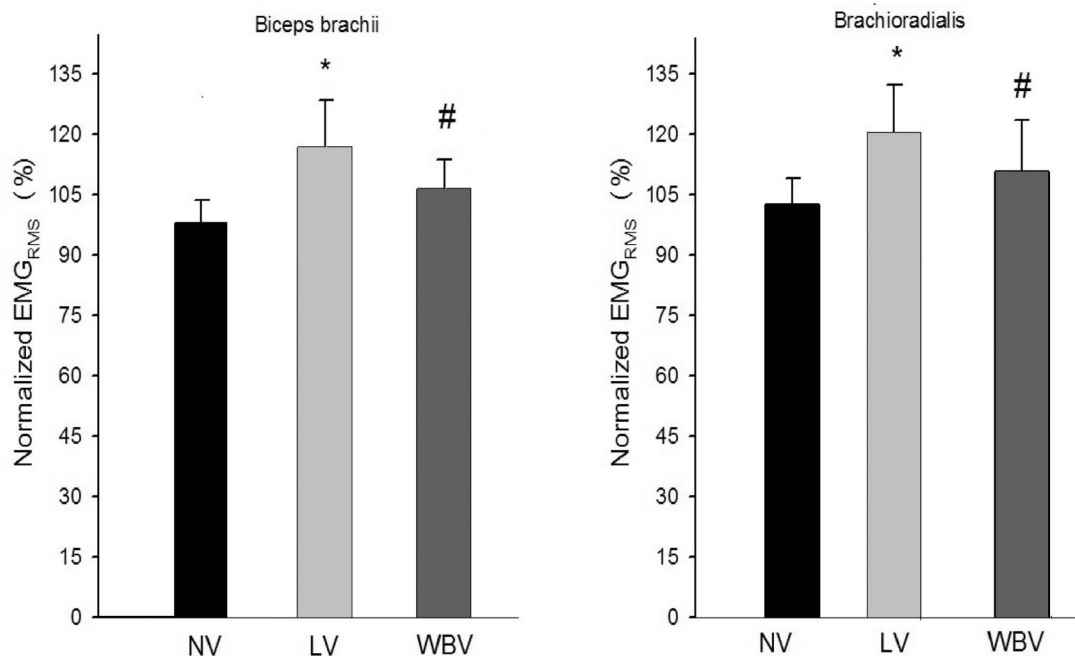


Figure 3 - Normalized EMG_{RMS} of the brachii and brachioradialis biceps during the 1RM. NV = No vibration; LV = Local Vibration; WBV = whole-body vibration. Vertical lines = standard errors. *: Greater than NV and WBV. #: Greater than NV. Significance level at $\alpha < 0.05$. test.

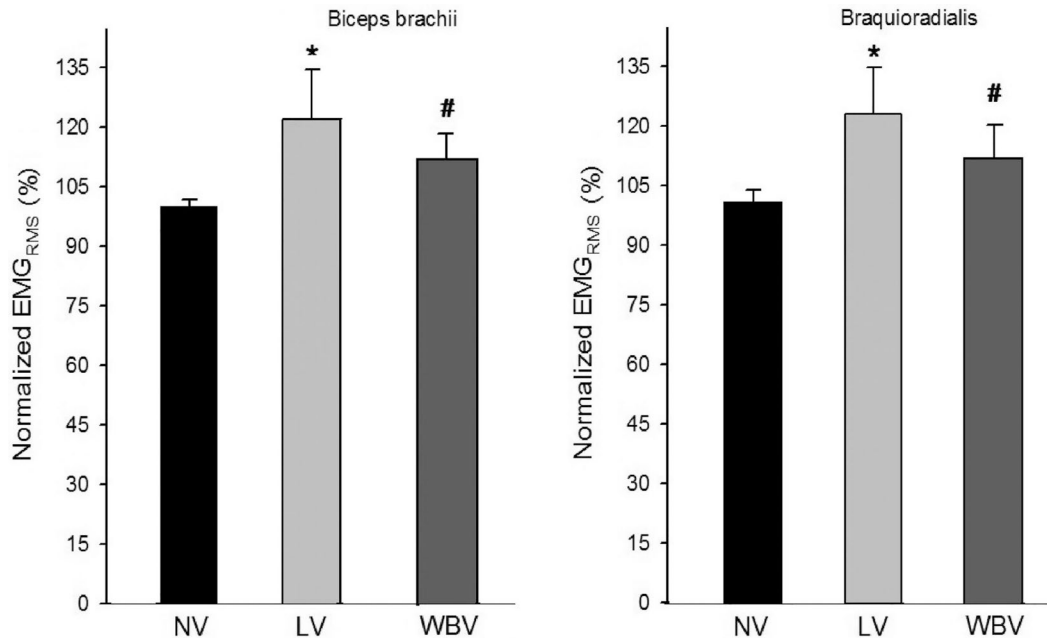


Figure 4 - Normalized EMG_{RMS} of the biceps brachii and brachioradialis during the MVIC. MVIC = maximum voluntary isometric contraction. NV = No vibration; LV = Local Vibration; WBV = whole-body vibration. Vertical lines = standard errors. *: Greater than NV and WBV. #: Greater than NV. Significance level at $\alpha < 0.05$.

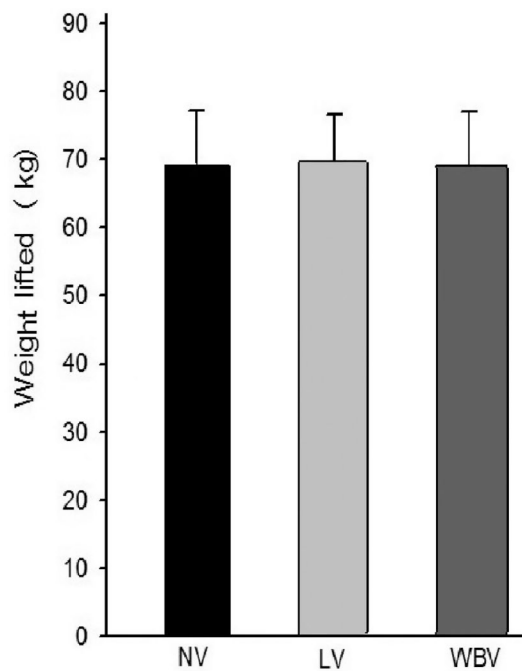


Figure 5 - Weight lifted during the 1RM test. NV = No vibration; LV = Local Vibration; WBV = whole body vibration. Vertical lines = standard errors.

without vibration^{34,35}. Cardinale and Bosco³⁶ found that four sets of 60 s of WBV, with the frequency of 30 Hz and amplitude of 10 mm, were able to significantly increase the EMG_{RMS} in the muscles of the upper limbs during the

elbow flexion exercise performed dynamically. Hazzel, Jakobi, and Kenno³⁷ found an increase in EMG in the muscles of the lower and upper limbs. In this study, squat and elbow flexion exercises were performed, both isometric and dynamic, with frequencies of 25, 30, 35, 40, and 45 Hz. The presence of tonic vibration reflex may justify the higher EMG activity of the muscles exposed to vibration^{13,36}. Thus, perhaps the MV may have interfered with the EMG values and consequently the interpretation of the results. Notwithstanding, no study that compared the EMG response in activities performed with LV, and WBV were found. We suggest that new studies investigate this possibility.

During the WBV, the vibration impulse may have dissipated during its transmission through the body tissues¹². The oscillation amplitude of the elbow joint in the WBV condition may have been smaller in comparison to the LV, generating smaller accelerations. Greater amplitude of displacement is associated with greater tonic vibration reflex and consequently, activation of several muscle spindles¹¹. This phenomenon may explain the lower values of EMG_{RMS} found during the WBV when compared to the LV that received the same frequency of vibration.

The MVIC tests did not show significant differences between the experimental conditions. Oliveira et al.³⁸ corroborate these results, as they verified that the application of MV, in the frequencies of 10, 20, 30, and 40 Hz was not able to increase the strength production in trained individuals. According to Oliveira et al.³⁸, the fact that MV does

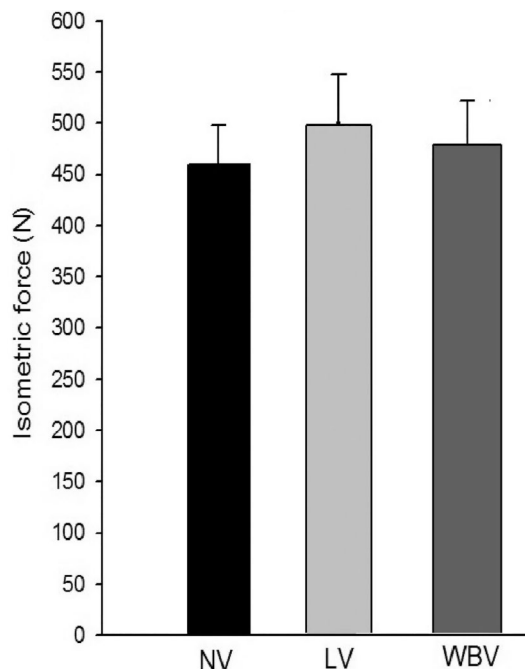


Figure 6 - Comparison of maximum isometric voluntary contraction. NV = No vibration; LV = Local Vibration; WBV = whole body vibration. Vertical lines = standard errors.

not increase strength in MVIC tests may be related to individual characteristics, such as the level of experience in training with vibration and the MV settings. Still, Warman, Humphrtes, and Purton³⁹ also did not find significant differences in the isometric strength with or without the MV. The non-increase in the MVIC indicates that the higher EMG generated by the vibratory stimulus was not sufficient to recruit additional motor units that promoted greater force production in the specific task evaluated. The angle at which the MVIC test is performed can also influence the transmissibility of the vibratory impulse since changes in the angle interfere with the tension present in the target muscle³⁹. In the present study, only the 90° angle of elbow flexion was used during the test, and future studies are needed to assess the effect of MV application at different angles during the MVIC.

No significant differences were found in the 1RM tests between conditions. Hammer, Joshua, and Linton⁴⁰ also found no significant differences in the 1RM test with and without MV application. According to these authors, the vibratory stimulus may not have been specific enough to promote increases in strength in trained individuals. Cochrane⁴¹ also did not find an increase in the concentric strength in the elbow flexion exercise with MV application. However, the findings of the present study oppose the result presented by the previous studies^{18,19,35}, which found a positive effect of MV application in the 1RM tests in upper and lower limb exercises. Such divergence may be since the response to the vibratory stimulus depends on

aspects such as the time of exposure to vibration⁴², the frequency of vibration^{9,10}, the range of displacement¹¹, and/or type of muscle action¹⁰.

It was expected a greater strength performance during MVIC and 1RM tests with MV application because of the presence of tonic vibratory reflex due to muscle stretches that occurred throughout contractions with MV⁴³. According to Issurin et al.⁷, Torniven et al.⁴³, and Mileva et al.¹⁸, the tonic vibratory reflex may improve the synchronization firing discharges and causing a larger number of motor-units recruitment, leading to greater strength production. However, the result of this study does not corroborate this reasoning. Perhaps, the higher EMG response for MV application was not sufficient to promote significantly higher strength production. Other MV configurations can be effective to generate higher strength performance. This suggests that other studies with different MV parameters could be conducted to respond to this literature gap.

Some studies adopt the result of the 1RM test, performed without the application of vibrations, as a reference for the prescription of training intensity with and without the application of mechanical vibrations^{7,25}, therefore the results of the study may contribute to decisions regarding of application of VM or the type of VM in future works or the physical training. The limitations of the study, we can mention the need of using filters in the EMG signal, aiming to exclude the noise from cable vibrations; and the non-measurement of the cross-talks effect. Additionally, the results found in the present study should be limited to the vibration parameters. Further studies are required using different vibration parameters to verify the effects of MV on strength development.

Conclusion

The MV application resulted in higher EMG activity in the 1RM and MVIC tests, The LV promotes higher EMG than WBV. However, the MV application was not able to increase the strength production compared to the non-application of MV in the 1RM and MVIC tests.

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