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# Vibration training for upper body: transmission of platform vibrations through cables

Running title: Vibration transmission through vectran cables

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# Vibration training for upper body: transmission of platform vibrations through cables

ABSTRACT:

The aim of the present study was to evaluate the vibration transmission from a vibration platform through vectran cables to the upper body and its relationship to induced muscular activation.

Fifteen clinically healthy participants performed 3 different arm exercises – biceps curl, triceps curl, and lateral raise. Vibration transmission to the upper body was assessed over a wide range of accelerations (from 1.90 to 5.98 g) and frequencies (from 25 to 40 Hz). To assess the vibration transmission, seven tri-axial accelerometers were attached from the hand up to the head and the root-mean-square (RMS) of acceleration signal of each site-specific body point was calculated. Muscular activity of biceps brachii, triceps brachii, deltoid and upper trapezius was recorded.

The results showed a significant attenuation of the platform accelerations transmitted through the vectran cables to the upper body. Handle vibration ranged between 27 – 44 % of the acceleration delivered by the platform depending on platform vibration parameters (acceleration/frequency). Vibration increased the muscle activity of biceps brachii, triceps brachii, deltoid and upper trapezius muscles significantly only during biceps curl exercises. No frequency and/or acceleration effect was found on the size of the muscle response.

The results of the present study suggest that a cable-pulley resistance system on a vibration platform channels the vibration safely from the platform to the arms and induces additional muscle activation in some arm muscles when biceps curl exercises are performed.


Key words: neuromuscular stimulation; tonic vibration reflex; mechanical loading; biceps curl.

## INTRODUCTION

Whole body vibration (WBV) training has emerged as a potential alternative for, or addition to, traditional resistance training, with increasing evidence for WBV-induced improvements in leg muscle performance in athletes (7), sedentary adults (9) and elderly (3).

Vibration stimulates the Ia-afferents of muscle spindles that in turn activate α-motoneurons in a reflexive manner, known as tonic vibration reflex (TVR) (18). Vibration stimulates the activity of lower-limb muscles (1) and can therefore be used to "exercise and train" these muscles. Additionally, inhibition of the agonist-antagonist co-activation by Ia-inhibitory neurons might be involved when activating the muscles through vibration (6).

Only a few studies have investigated the effect of WBV on upper limb and trunk muscles (11,17,23), typically reporting low or no effects on upper body muscle performance. A major reason for this lack of effect is the attenuated vibration stimulus that reaches the upper limbs due to the distance between the vibration platform and the target muscles and the damping properties of the human body (11,15). As a result, WBV devices designed for lower-limb muscle training may be unsuitable for arm muscle stimulation.

Different tools such as vibrating dumbbells (4), a muscle-tendon vibrator (20) or a vibratory stimulation device attached to a pulley system (14) have been tried to enhance transmission of the vibration stimulus to the upper body and improve upper body muscular performance. Bosco et al. (4) reported an increase in muscular activation of biceps brachii when vibrating dumbbells were used. In contrast, Moran et al. (20) showed no effect of vibration stimulation on muscle activity during dynamic biceps curl when vibration was delivered by a portable muscle-tendon vibrator attached over the biceps tendon. Overall, the effects of vibration on arm and trunk muscular activation remain controversial and inconclusive.

In this context, we tested a new vibration device with cable-pulley resistance system attached to a vibration platform, in an attempt to channel the vibration indirectly from the platform to the upper body and potentially broaden the impact of training to the whole body. Thus, the specific aim of our study was to assess the muscle activation of arm and trunk muscles while performing different static and dynamic arm exercises with a cable-pulley resistance system. We evaluated the vibration transmission through the cables to the upper body and identified dose-response relationships between vibration parameters and induced muscle activation. First, we hypothesized that the vibration transmitted through the cables would evoke higher muscle activation of the arm and trunk muscles than the same exercises performed without vibration. Second, the different vibration parameters delivered by the platform would be considered as safe and would result in different muscle response.

## METHODS

### Experimental Approach to the Problem

Vibration transmission was evaluated over a range of vibration frequencies (from 25 to 40 Hz) and accelerations (from 1.90 to 5.98 g) while the accelerations of several body points were measured during different dynamic and static exercises. Additionally, the EMG of different muscle groups was recorded.

### Subjects

Fifteen clinically healthy volunteers (7 males and 8 females; age 27.4 ± 4.6 years; height 1.73 ± 0.07 m; body mass 65.2 ± 6.8 kg) participated in the study. All participants gave full informed consent to participate in the vibration training protocol approved by the Leuven University's Human Ethics Committee according to the declaration of Helsinki. None of the participants had previously participated in any studies of whole body vibration. The subjects were informed about the purpose of the study, and about the possible risks and benefits of the training. They were free from any muscular injuries or musculoskeletal diseases.

Procedures

The vibration exercises were performed on a commercially available WBV platform which induced synchronous vertical vibrations at frequency of 25, 30, 35 and 40 Hz and two amplitude settings (‘high’ and ‘low’) (Power Plate pro 6TM, Badhoevedorp, The Netherlands). The platform had an additional cable-pulley resistance system of high strength vectran cables to transmit vibrations to the upper body. The resistance of the cables was adjustable which resulted in two different resistances during performance. The low resistance corresponded to 2.5 kg and the high resistance to 5 kg, respectively, as measured with a peak-hold dynamometer.

All subjects participated in a single data – collection session and were encouraged to immediately report any unusual symptoms (e.g., discomfort, dizziness) during the vibration training. Subjects wore only socks to diminish the damping of the vibration due to the footwear (16). The protocol was organized in 9 different series: 8 vibration series – four frequencies (25, 30, 35, 40 Hz) x two amplitude settings (‘high’ and ‘low’) and one non-vibration series including the same exercises but without vibration. Each series included four different exercises: two biceps curl exercises, a triceps curl and a lateral raise exercise (fig. 1).

(Figure 1 about here)

*Biceps curl exercise*

The participants performed a 90° dynamic biceps curl exercise against low resistance and a 90° dynamic biceps curl exercise against high resistance (figure 1a). The subjects performed additionally a 70° static biceps curl exercise for 60 seconds behind the platform only at 40 Hz, high amplitude mode, high cable resistance.

*Triceps curl exercise*

The participants performed a dynamic triceps curl against low resistance (figure 1b).

*Lateral raise exercise*

A 90° dynamic lateral raise exercise against low resistance was performed (figure 1c). During lateral raise exercises the subjects performed a knee squat position of 135 ° (whereby 180° means fully extended knees). To ensure the correct knee positioning of 135°, the knee angle was measured with a goniometer before each trial.

None of the participants was previously involved in any arm-trunk exercise programs and therefore, to maintain the protocol within reasonable limit, the triceps curl and lateral raise exercises were performed only against the lower resistance. The exercises were performed while the subjects were standing behind the platform. Each exercise was performed at the same pace of a metronome (60 beats per minute). The participants were instructed to hold the handles firmly in their hands. To avoid influence of fatigue in the measurements, for each subject, the series were randomized and a sufficient rest of 2 minutes was provided between series.

Specific equipment

Seven tri-axial SMB380 accelerometers were used to measure the vibration accelerations at the 3rd metacarpal bone (hand), styloid process of the ulna (wrist), medial epicondyle of the humerus (elbow), acromion (shoulder), vertebra prominens (C7), manubrium of the sternum, and head. The accelerometers were adhered to the subject’s skin using adhesive tape. All cables were secured by bandages to prevent swinging and movement-induced artifacts. The weight of each accelerometer was 0.6 g and the size 12 mm x 14 mm x 2.5 mm (WxLxH). The calibration of the SMB accelerometers was checked against a standard piezo-accelerometer, revealing a linear relationship up to a magnitude of 7g. Additional two tri-axial SMB accelerometers were placed on the platform and the handle to provide accurate data on the different platform accelerations during the exercise. One uni-axial piezo-accelerometer provided accurate vertical peak accelerations delivered by the platform. Vibration signals were analyzed using Matlab. All accelerations were sampled at 1 kHz. Raw signals were filtered using a high pass 8th order Butterworth filter (10Hz) with a zero-phase forward and reverse filtering (zero phase distortion). The root-mean-square (RMS) of acceleration signal at the platform, the handle and the different body points were calculated. The platform-handle transmission was defined as a ratio of RMS acceleration of handle to the RMS acceleration of the vibration platform. The handle-body transmission was determined as a ratio of RMS acceleration of a site-specific body point to the RMS acceleration of the handle (10).

To evaluate the safety aspect of vibration training, a basic evaluation method from ISO5394-1:2001 was followed (13). The vibration exposure was evaluated by comparing the A(8) value (8-hour energy-equivalent frequency-weighted acceleration) to a daily Exposure Action Value (EAV, 0.5 $m/s^2$) and a daily Exposure Limit Value (ELV, 1.15 $m/s^2$). The time to reach the EAV or the ELV during a each vibration session was calculated from A(8) value and the weighted root-mean-square acceleration – Aeq.

During the experimental session, a wireless surface EMG system (Zerowire, Aurion Italy) was used to record the muscle activity of the right biceps brachii, triceps brachii, deltoid and upper trapezius. The bipolar surface EMG electrodes were mounted to the arm and back with double-sided contact tape and fixed using adhesive tape to guarantee their position and contact during the vibration. The skin was prepared by abrasion, shaving and alcohol cleaning to ensure a better contact. To avoid crosstalk caused by EMG signals coming from neighboring muscles, the electrodes were placed at the middle of the muscle belly and an appropriate inter-electrode (center-to-center) distance of 20 mm was chosen. EMG-signal validity was checked visually before starting the EMG-recording (12). The EMG signals were amplified and sampled at 1000 Hz. The root-mean-square (EMGrms) was calculated for both non-vibration and vibration trials. The EMG was analyzed by two different approaches – 1) only band-pass filters (between 10 and 500 Hz) were applied and 2) an additional sharp band-stop (notch) filter. The notch filter was implemented to eliminate possible artifacts at the exact excitation frequency of the platform working at 25, 30, 35 and 40 Hz, respectively. An average root-mean-square (RMS) was calculated for non-vibration and vibration periods.

## Statistical Analyses

The dependent variables in the different statistical tests were EMGrms, RMS of the acceleration, and platform-handle and handle-body transmission. A Shapiro–Wilk W test was used to assess the normal distribution for all of the studied accelerations, frequencies and RMS. In case of non-normal distribution, non-parametric statistics (Wilcoxon test) were used. In case of normal distribution, the effect of parameter settings of the vibration or position on the vibration transmission were analyzed by repeated measures ANOVA, Tukey post-hoc testing. All values are reported as mean ± standard deviation (SD). The level of significance was set at $P < 0.05$.

# RESULTS

All subjects completed the full protocol successfully. None of the participants reported any side effects due to the vibration or felt any discomfort, dizziness or fatigue during the training. Table 1 shows the vertical peak accelerations (g) and peak-to-peak amplitude (mm) delivered by the platform and measured with an accelerometer with respect to the different frequencies (where g is the Earth's gravitational field of 9.81 m/s$^2$).

(Table 1 about here)

The average handle acceleration varied between 0.33 – 1.33 g for all exercises, meaning that the average vibration transmission from the platform to the handle ranged between 27 % – 44 % RMS acceleration of the platform. There were no significant differences in transmission to the handle between the different exercises.

The average vibration transmission from the handle through the arm and the trunk followed a similar declining curve for all of the studied parameters and exercises (an example in figure 2).

(Figure 2 about here)

The average transmission of the vibration at the 3rd metacarpal bone (hand) ranged between 0.93 and 1.41 times the RMS acceleration of the handle and was further up significantly reduced at the arm and the head. The RMS acceleration at the head never exceeded accelerations higher than 0.25 g. No significant difference in transmission was found between the different accelerations and frequencies within each exercise.

According to the calculations based on ISO5394-1:2001 (13), the total weighted acceleration never exceeded 0.85 g. The total vibration dose A(8) ranged between 0.35 and 0.45. This would imply that the specific exercises performed in the present study could be maintained 42 minutes before the daily Exposure Action Value (EAV, 0.5 m/s$^2$) was reached, and 172 minutes before the daily Exposure Limit Value (ELV, 1.15 m/s$^2$) was reach.

According to muscle response, the use of both approaches – without and with notch filter showed a significant increase in the EMG activity for most of the studied muscles during vibration. No significant difference in EMGrms with and without notch filtering was found, however, the application of notch filter showed a tendency to blur the differences between non-vibration and vibration periods and to decrease the number of the significant values. Thus, all results are presented as mean EMGrms +/- SD without notch filtering. The EMG responses to vibration at the different accelerations tested were expressed relative to EMG of the individual muscles in the non-vibration period, normalization relative to maximal voluntary contraction was unnecessary (1).

*Biceps curl exercise*

As can be seen in figure 3a, vibration induced a higher muscle activity in biceps brachii, triceps brachii, deltoid and upper trapezius compared to non-vibration EMGrms during static biceps curl exercise ($P < 0.05$).

(Figure 3 about here)

The EMGrms measured during dynamic biceps curl resulted in a significant increase in EMGrms of biceps brachii (range between 14 – 30.4 %), triceps brachii (range between 29.6 – 84.6 %) and deltoid (range between 24.3 – 59.1 %) due to vibration in most of the studied conditions ($P < 0.05$) (an example in figure 3b). No differences in EMGrms of different muscles between static and both dynamic biceps curl exercises were found ($P > 0.05$) when frequency was set up at 40 Hz, high acceleration mode. Different cable resistance (low and high) did not result in different muscle activation for any of the studied muscles ($P > 0.05$).

*Triceps curl exercise*

EMG activity of biceps brachii and triceps brachii measured during dynamic triceps curl ranged between 22.2 – 60.2 % and 7.8 – 60.1 %, respectively of non-vibration EMGrms, but no significant difference between vibration and non-vibration was found for any of the studied muscles ($P > 0.05$) (an example in figure 3c).

*Lateral raise exercise*

No increase in EMG was found for any of the muscles compared to non-vibration while performing dynamic lateral raise during all studied accelerations and frequencies ($P > 0.05$) (an example in figure 3d).

There were no significant frequency and/or acceleration main effects in all conditions. No clear dose-response relationship was observed between the acceleration and frequency of the platform or the handle and the size of the muscle response with and without notch filtering.

## DISCUSSION

To our knowledge, this is the first study to report vibration transmission through a vectran cable-pulley resistance system on a vibration platform to the upper body in a wide range of vibration accelerations and frequencies and its relationship to muscular activation during different dynamic and static exercises.

The outcomes of the present study confirmed the hypothesis that the vibration delivered through the cables can be considered as safe. The vibration delivered by the platform that reached the handle ranged between 27 % – 44 % depending on platform vibration parameters (acceleration/frequency) and might be affected by the different angles of the vectran cables in different exercises, the distance and the orientation of the handle with respect to the platform (2). Irrespective of the exercise, an amplification of the signal was found at the hand and ranged between 0.93 and 1.41 times the RMS acceleration of the handle, which could be explained by the fact that saturation might have occurred in the signals of the hand. The accelerations entering the body through the handles were not constant during the different exercises but dependent on the movement of the cables, the handles and the hand. Vibration transmission might be affected by the grip strength on the handle. Moreover, the small changes in hand-arm orientation could significantly alter the energy absorption and vibration transmission due to both rotational movements of lower arm bones and of elbow joint (5,21). Additionally, during arm exercises, the person typically combines several exercises with different movements of the handles, which influences the total vibration dose differently. In the present study, the total weighted acceleration never exceeded 0.85 g. Around 42 minutes would be needed before the daily EAV was reached, and 172 minutes before the daily ELV was reach. As this is far beyond the typical duration of arm exercises, the vibration training used in the present study seems reasonably safe and might be considered for daily vibration training. Moreover, the results on total weighted acceleration value showed that the exercise has only a modest contribution to the vibration dose the subject is allowed to receive.

The current results partly confirm the hypotheses that muscle activation of the arm and trunk muscles would be higher during vibration exposure. An increase in EMGrms of biceps and triceps brachii, and deltoid was found due to vibration only during dynamic and static biceps curl exercises. No effects on muscle activity of any of the muscles were found during dynamic triceps curl or lateral raise exercises. This might be due to the different direction of arm movements in relation to the direction of the vibration signal. Biceps curl exercises were in the line of the vibration while lateral raise and triceps curl exercises were presumably at an oblique angle with respect to vibration direction.

Muscular performance as a result of vibration stimulation might be influenced either by muscle fatigue or by a post-activation potentiation. In the present study, fatigue caused by the vibration training is very unlikely due to the short vibration exposure, the provided rest periods and the randomization of the different series between subjects. Moreover, none of the participants experienced the exercises as fatiguing.

In the current study the muscle performance might have been influenced by a post-activation potentiation. Previously it has been shown that acute whole body vibration could cause a post-activation potentiation of muscle twitch potentiation which resulted in higher muscular activation after vibration stimulation compared to non-vibration (8,22).

Different resistances of the pulley system (2.5 kg – low resistance and 5 kg – high resistance) did not show any difference in muscle response in any of the muscles irrespectively of the vibration parameters. It has previously been suggested that an additional loading during vibration may alter muscle stiffness and tension and thus, the vibration transmission through the body and the induced muscle activation (19). However, in the present study no differences in vibration transmission or muscular activation have been found with respect to the resistances of the pulley system. It should be emphasized that the subjects did not performed exercises without resistance and the ‘real’ effect of resistance on muscle activation and vibration transmission is unknown, and thus, the resistance of the pulley system might be not sufficient to induce additional muscle activation.

In line with our findings, Mischi and Cardinale (19) found an increase in EMG activity at both the biceps and the triceps brachii, during isometric elbow flexions and extensions, but they used a frequency of 28 Hz delivered by an adapted industrial motor magnet and the vibration was transmitted through a lever to a hand grip. They concluded that both muscles are more sensitive to vibration stimulation during extension compared to flexion exercises. In the current study, we only used static flexion and dynamic flexion-extension exercises and, by design, we were unable to compare extension and flexion. Similar static flexion biceps exercises were performed in the study of Bosco et al. (4) where the EMG activity of biceps brachii increased around 100% during vibration compared to non – vibration, which is higher than in our findings (38.2 %). It should be underlined that they delivered vibration directly to the hand by a vibrating dumbbell (dumbbell acceleration of 3.4 g) compared to present study (handle acceleration of 1.34 g or 37.1 % of RMS acceleration of the platform) and allowed more vibration to reach the biceps. In a recent study of Marin et al. (17), a hand strap attached to a WBV platform was used to target the biceps brachii muscle. A significant increase of 27.7% in muscular activity of the biceps was reported while a target group of elderly stood on vibration platform. The increase in EMGrms was somewhat lower compared to our study and the acceleration that reached the hands was not measured.

In the present study, we did not confirm the hypothesis that the different vibration parameters delivered by the platform would evoke different muscle response. No real frequency and/or acceleration effect was found on the size of the muscle response with or without notch filtering. In another WBV study, Marin et al. (17) showed no difference in muscle activation of biceps brachii between frequencies of 30 and 46 Hz during static biceps curl. In contrast, Hazell et al. (11) reported the highest EMG response of triceps brachii when a frequency of 45 Hz (compared to 25, 30, 35 and 40 Hz) was applied and static biceps curl was performed during WBV. In the present study, our frequency did not exceed 40 Hz and no frequency effect was found, probably because of the different vibration approach, the limited vibration transmission at the handle and the high variance in the EMG response.

*Study Limitations*

Our study has limitations and they should be interpreted in the context of its design. First, the subjects only participated in a single data-collection session and we did not assess differences in response to vibration within subjects. Second, we only addressed healthy, young subjects and we acknowledge that our results cannot be generalized to other populations. Third, we applied only skin-mounted accelerometers which allow movements of soft tissue and skin that potentially interfere with the transmitted acceleration detected by the accelerometers. Fourth, the rest of 2 minutes provided between the vibration series might have been insufficient to avoid the crossover of the effects of the vibration on the next training series. Finally, although, the participants performed commonly used exercise, the present findings cannot be generalized about other arm or trunk exercises typically used during resistance training. The effect of the vibration on triceps brachii muscle activation might have been higher if the participants were facing away from the platform as a result of the increased range of motion during triceps curl exercise. Moreover, vibration stimulation during lateral raise exercises might have been more efficient if the cables were drawn across the body, which could have also resulted in increased range of motion and higher muscle response, respectively. Further studies should focus on more broad combinations of arm and trunk exercises to be able to provide a better insight on how the different vibration training protocols should be administered for best possible muscle stimulation.

PRACTICAL APPLICATIONS

The results of this study indicate the potential of a whole body vibration platform with a cable-pulley resistance system to stimulate the muscle activity of some arm muscles. Our subjects performed commonly used exercise as biceps curl which resulted in a significant increase in arm muscle activity during vibration stimulation. Coaches and practitioners should know that the specific whole body vibration parameters used in the present study seem safe and suitable for the specific arm exercises when accounting for the total acceptable duration and combining exercises into a training program. Moreover, we found no evidence for dangerous accelerations in any of the studied body points. For the exercises tested in the present study, the commercially available platform with a cable-pulley resistance system can be used on a daily basis for 172 minutes when the studied exercises are performed. The results of the study show involuntary increase in EMG activity in arm muscles only during dynamic and static biceps curl exercises. The vibration signal delivered by the platform through the cables seems insufficient to induce additional EMG activation when dynamic triceps curl and lateral raise exercises are performed.

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Figure legends

Table 1. The peak acceleration (g) was measured with an accelerometer. The peak-to-peak displacement amplitde was computed from the acceleration amplitude: $X = A/w^2 = A/ (2.pi.f)^2$, where A is peak-to-peak acceleration and f – the frequency.

Figure 1. Dynamic exercises performed during the vibration training: a) 90° dynamic biceps curl b) dynamic triceps curl c) 90° dynamic lateral raise in knee bent position (knee angle of 135°).

Figure 2. The average vibration transmission from the handle through the arm and upper body at a frequency of 40 Hz, platform acceleration of 5.98 g during biceps curl exercise (**BC**).

Figure 3. a) Vibration induced a higher muscle activity in biceps brachii, triceps brachii, deltoid and upper trapezius (Tr_Up) compared to non-vibration EMGrms during static biceps curl ($P < 0.05$). The parameters of the applied vibration: frequency of 40 Hz, platform acceleration of 5.98 g. b-d) An example of the relationship between the applied vibrations during dynamic biceps curl, triceps curl and lateral raise (frequencies of 25 – 40 Hz, platform accelerations of 3.26 – 5.98 g, high resistance, no-notch filter). * indicates a greater muscle activity during vibration compared with non-vibration ($P < 0.05$).

Table 1. Peak acceleration and peak-to-peak amplitude delivered by the platform.

| Frequency, Hz | Low amplitude mode | | High amplitude mode | |
|---|---|---|---|---|
| | Peak acceleration, g | Peak-to-peak amplitude, mm | Peak acceleration, g | Peak-to-peak amplitude, mm |
| 25 | 1.90 | 1.51 | 3.26 | 2.59 |
| 30 | 2.02 | 1.12 | 3.66 | 2.02 |
| 35 | 2.84 | 1.15 | 4.73 | 1.92 |
| 40 | 3.60 | 1.12 | 5.98 | 1.86 |

Figure

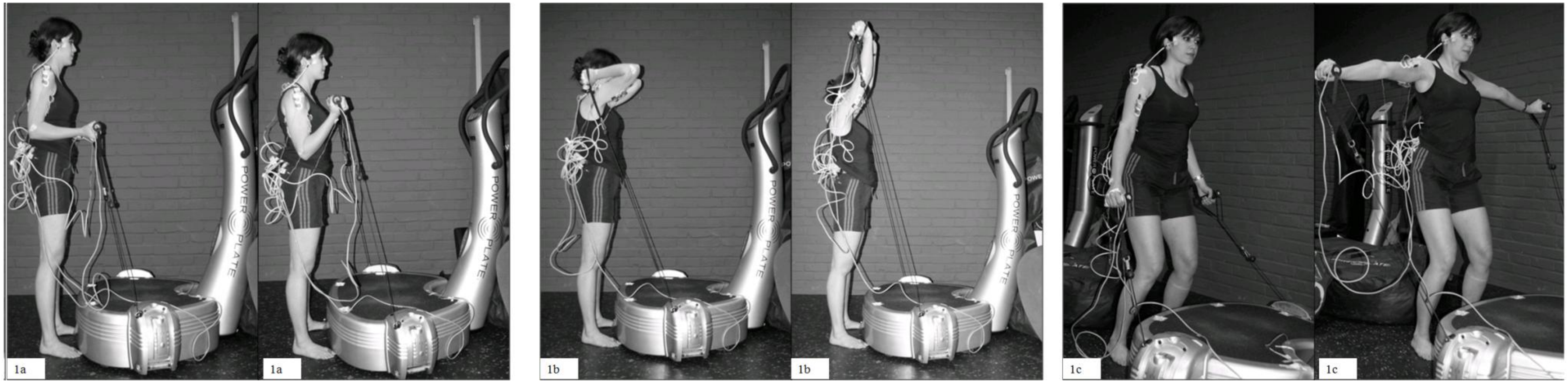
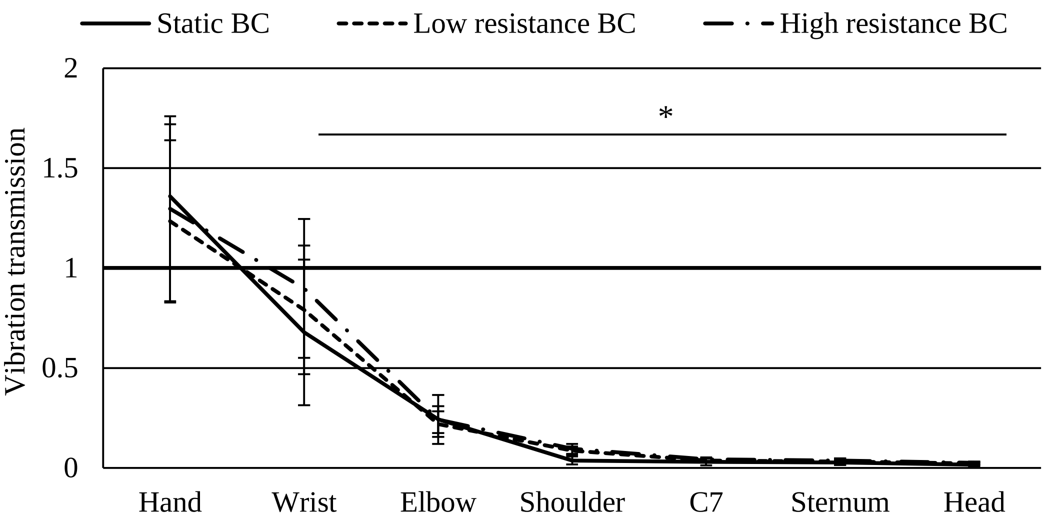



Figure 1



Static BC
Low resistance BC
High resistance BC
2
1.5
1
0.5
0
Vibration transmission
*
Hand
Wrist
Elbow
Shoulder
C7
Sternum
Head


Figure 2

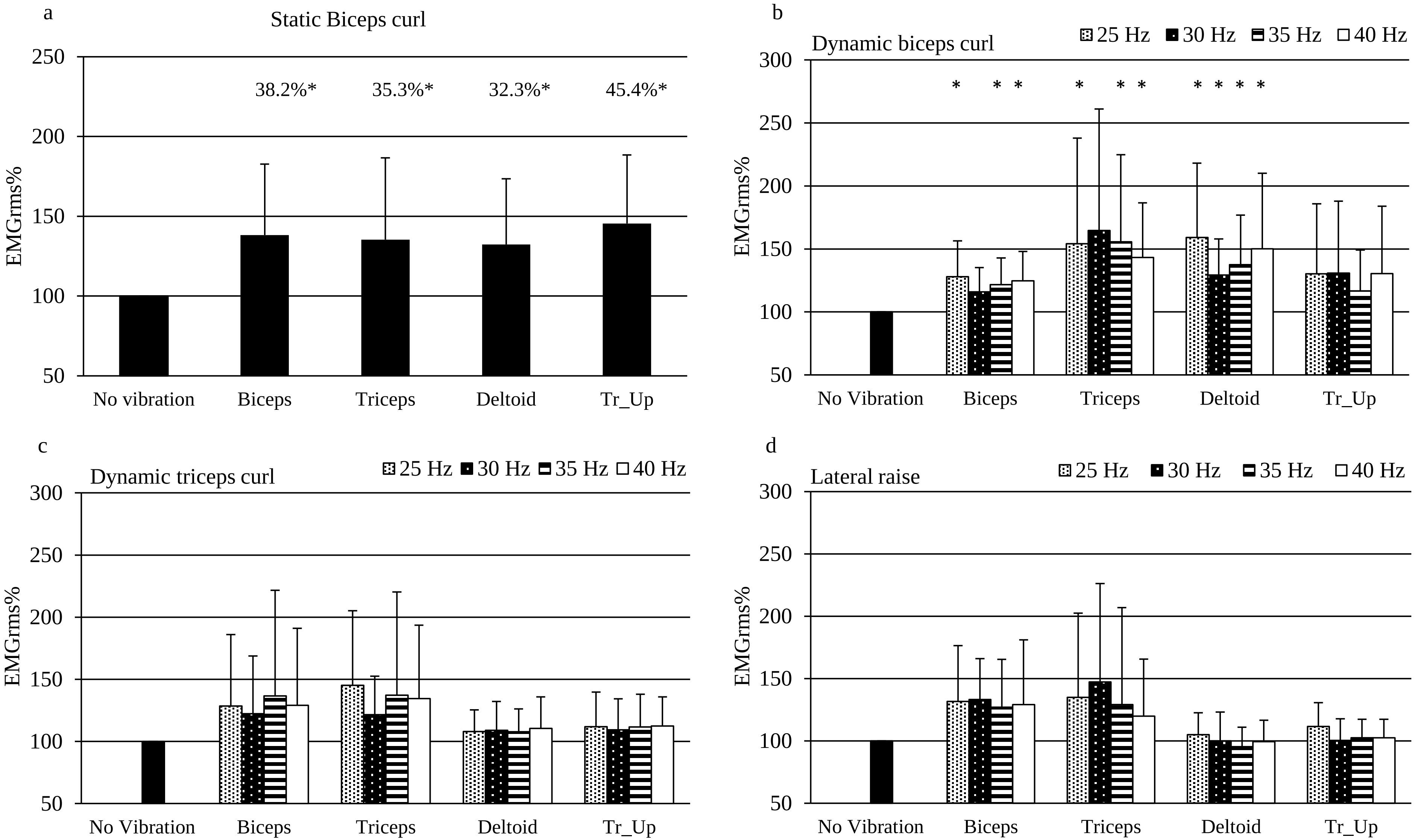

a
Static Biceps curl
38.2%*
35.3%*
32.3%*
45.4%*
EMGrms%
250
200
150
100
50
No vibration
Biceps
Triceps
Deltoid
Tr_Up
b
Dynamic biceps curl
25 Hz
30 Hz
35 Hz
40 Hz
300
250
200
150
100
50
EMGrms%
No Vibration
Biceps
Triceps
Deltoid
Tr_Up
c
Dynamic triceps curl
25 Hz
30 Hz
35 Hz
40 Hz
300
250
200
150
100
50
EMGrms%
No Vibration
Biceps
Triceps
Deltoid
Tr_Up
d
Lateral raise
25 Hz
30 Hz
35 Hz
40 Hz
300
250
200
150
100
50
EMGrms%
No Vibration
Biceps
Triceps
Deltoid
Tr_Up

Figure 3