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Effects of vibration-induced fatigue on the H-reflex

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Abstract

Vibration exercise (VE) has been suggested as an effective training for improving muscle strength and coordination. However, the underlying physiological adaptation processes are not yet fully understood, limiting the development of safe and effective exercise protocols. To better understand the neuromuscular responses elicited by VE, we aimed at investigating the acute effects of superimposed vibration on the Hoffmann reflex (H-reflex), measured after fatiguing exercise. Twenty-five volunteers performed four isometric contractions of the right Flexor Carpi Radialis (FCR) with baseline load at 80% of their maximal voluntary contraction (MVC), both with no vibration and with superimposed vibration at 15, 30, and 45 Hz. Fatigue was estimated by MVC test and estimation of electromyographic spectral compression. H-reflex suppression was estimated as the relative decrease after exercise. Our results show that fatiguing exercise determined a decrease in H-reflex amplitude compared to rest condition while vibration determined a lower H-reflex suppression as compared to no vibration. The superimposition of 30-Hz vibration determined the largest acute reduction in force generating capacity (36 N, $p < 0.05$) and the lowest H-reflex suppression (20%, $p < 0.05$). These results suggest VE to be particularly suitable in rehabilitation programs for rapid restoration of muscle form and function after immobilization periods.

Keywords: Electromyography, Vibration exercise, H-reflex, Tonic vibration reflex, Maximal voluntary contraction, Fatigue

1. Introduction

Resistance exercise and physical training have always been considered the most effective options for improving, maintaining or restoring skeletal muscle form and function [1]. Improvements in muscle form and function are usually sought using conventional training methods such as resistance exercise and plyometrics [2, 3] or less conventional methods like electrical stimulation [4] and blood flow restriction [5]. These training methods have been shown to determine improvements in neuromuscular performance as measured by force increase and mechanical power production in various populations and age groups.

Over the last decade, an alternative form of exercise, characterized by the use of vibration with oscillating platforms [6, 7, 8], has been suggested as an effective methodology for improving strength and power performance [9, 10] mostly in non athletic populations. Whole body vibration as an exercise modality has recently become a topic of great interest, and recent research has focused on its potential benefits. Vibration exercise (VE) seems to elicit a specific warm-up effect, improving muscle power and balance [11], and it is beneficial in reducing chronic lower back pain [8], increasing oxygen uptake [12, 13], glucose uptake [14, 15, 16], bone density [17, 18]. Other forms of vibration exercise characterized by modified exercise equipment with vibrating cables [19, 20], vibrating dumbbells [21, 22, 23, 24, 25], and bespoke vibratory devices [26, 27, 28, 29] have shown to positively influence neuromuscular function suggesting this form of exercise to be potentially a suitable option for several rehabilitation programs.

In an effort to understand the physiological mechanisms involved in VE, studies have demonstrated that mechanical vibration applied to the tendon of the skeletal muscle induces an involuntary contraction termed tonic vibration reflex (TVR) [30, 31]. TVR is defined as the response of the muscle to a vibratory stress that induces an increase in the contractile force of the muscle groups involved, agonist and antagonist [32, 21]. Furthermore, while direct application of vibration has been shown to determine the TVR, consensus is lacking with regards to whole body vibration (WBV) or upper body vibration exercise modalities on their ability to elicit the TVR. Also, recent work seems to suggest this possibility [33]. Upper body vibratory exercise has been also investigated and some literature suggests various mechanisms responsible for the observed increase in neuromuscular activity determined by surface EMG [21, 28].

EMG could be used to assess the effectiveness of VE modalities, however it is important to consider that during VE the EMG spectrum shows sharp peaks at the vibration frequency (SPVF) which might include a combination of signal noise and true muscle activity. Some studies considered these SPVF as motion artifacts [34, 28, 35]. Recent studies, however, have ascribed those SPVF to vibration-induced muscle activity which need to be included in the EMG analysis [36, 37, 38].

While on the upper limbs it is clear that performing resistance exercise with superimposed vibration can cause an increase in EMG activity [21, 28], it is also important to understand the fatigue aspects of such modality. In general, mechanic fatigue is characterized by a decay in force-production capability, which can be assessed by maximum voluntary contraction (MVC) test [39]. Myoelectric evidence of fatigue has been characterized by decrease in the average conduction velocity (CV) of the motor unit action potentials over the course of sustained muscle contractions [40], which can be indirectly assessed by EMG spectral compression [41]. Moreover, during fatigue, decreased excitation from Ia afferents or increased excitation threshold of the nerve fibers, have also been observed [42, 43]. A measure of motoneurons (MNs) pool excitability in different muscle conditions can be assessed by the Hoffmann reflex (H-reflex) [44].

It has been reported that direct application of tendon or muscle vibration produces a reduction in the Ia afferent transmission [45, 46]. However, the reported reflex responses following indirect vibration, e.g., WBV, are inconsistent in the literature [8]. Some studies observed an inhibition of the soleus H-reflex after WBV [47, 48, 49], in line with the results obtained after direct application of vibration on a muscle or tendon. In contrast, other studies reported increased H-reflex after WBV [50], which were suggested to be beneficial for performance improvement.

It is clear that the neuromuscular reflex response after VE remains controversial. Studies have suggested VE to produce a large degree of mechanic and myoelectric fatigue on the upper limbs while fatigue leads to decreased excitation from Ia afferents [51, 42, 43]. Furthermore, studies have reported increased H-reflex amplitude after non-exhausting VE possibly due to MN hyperexcitability [50]. The objective of this study was, therefore, to investigate the fatiguing effects of vibration on the H-reflex of the forearm muscle, e.g., Flexor Carpi Radialis (FCR), at different frequencies. We hypothesize that VE determined a higher degree of fatigue and a lower decrease in H-reflex amplitude in the FCR compared to the control condition, which could

be confirmed by EMG recordings. To investigate the MN excitability, a dedicated setup was adopted that can apply the superimposition of a baseline and a vibrating load to a muscle. This setup was previously described in Xu *et al.* [52].

2. Method

2.1. Subjects

Twenty five healthy right-handed subjects (21 males and 4 females, mean age = 27 ± 5 years) participated in this study. No effort was made to control for training specificity. Therefore, subjects ranged from sedentary to athletic and were overall heterogeneous. The participants reported no neuromuscular disorder, no history of upper extremity surgery nor injury. Pregnant women and people with implanted pacemakers were not allowed to take part in this study because of the consequences due to possible interference with electrical stimulation. Written informed consent was obtained from every subject prior to participation in the study, and the test procedures were approved by the relevant ethical committee.

2.2. Experimental setup

2.2.1. Actuator

A dedicated electromechanical actuator was adopted for applying the superimposition of a baseline and vibrating load to a muscle [52]. Figure 1 shows a scheme of the adopted setup. The core of the setup was a three-phase permanent magnet motor (MSK060C, Bosch Rexroth, Boxtel, The Netherlands), able to generate a force consisting of a constant baseline with superimposed vibration. Vibration consisted of a sinusoidal amplitude modulation of the baseline force. Figure 2 shows an example of such vibrating force. A 50-cm aluminum bar was mounted perpendicular to the motor output shaft in order to transfer the generated vibrating force via a strap to a handle, which was pulled upwards by the right arm of the subjects. The position of the bar, which was related to the flexion (angle) of the subject's wrist, was measured using a rotary encoder embedded in the motor, thus providing visual feedback supporting the subjects to maintain a stable (isometric) position. The actuator was fixed to a stiff frame of steel to improve the transmission of vibrations by reducing damping effects. A fitness bench, where the subject can lay his arm to pull the handle, was mounted above the actuator. The length of the strap connecting the handle to the bar was

Figure 1: Scheme of the setup. The right side of the bar is blocked during the MVC test while it is free during VE trials.

adjusted to avoid any lesion of the wrist and to impose a proper level of pre-tension.

A load cell LCE-35 Kg (Omega Engineering Inc., Stamford, CT, USA) was embedded in the system to enable force measurements by using resistance-based force sensors (strain gauges) in full bridge configuration, and it was mounted on top of the bar. The input voltage to the motor drive was generated by a wave generator (PCI 5402, National Instruments, Austin, TX) connected to a PC and controlled by dedicated software implemented in LabView[®] (National Instruments, Austin, TX).

2.2.2. EMG recording

After the subjects' skin was accurately cleaned with an abrasive paste and alcohol, surface EMG was recorded from the FCR muscle by three circular Ag/AgCl electrodes of 1-cm diameter (3M RedDot, Nadarzyn, Poland) in monopolar configuration. Two electrodes were placed on the subjects' right arm. In particular, the reference electrode was placed on the Radial Styloid, and the active electrode on the belly of the FCR muscle, as shown in Fig. 3 (a). The ground electrode was placed on top of the clavicle on the subjects'

Figure 2: Example of vibrating loading function consisting of a baseline force with super-imposed sinusoidal vibrating force of 10-N amplitude.

right side. All the measured signals were amplified and digitized using a 72-channel Refa amplifier (TMS International, Enschede, The Netherlands). The sampling frequency for each channel was 2048 Hz. Active shielding and grounding of the cables was used to minimize the powerline (50 Hz) interference.

2.2.3. *H-reflex elicitation*

In order to elicit the H-reflex, a stimulation electrode was used for transcutaneous stimulation of the median nerve close to the elbow, by the use of a Multi-modality electrical stimulator (Energy Light, Micromed, IT), as shown in Fig. 3, (a). By using a progressive transcutaneous electrical stimulation of the median nerve, the H-reflex tracing began to appear in the sEMG trace at low levels of stimulation as soon as the threshold of the Ia afferents was reached. When increasing stimulus intensity, the H-reflex was followed by the muscle response (M-wave) as α MNs reached their threshold. The peak-to-peak amplitude of the H-reflex increased until a maximum value, H_{max} , which indicates the maximal reflex activation, and subsequently decreased. As more α MNs were recruited, the M-wave increased until its maximum value, M_{max} , which represents the activation of the entire MN pool and, therefore, the maximum muscle activation [47]. When the H- or M-wave

Figure 3: The measurement setup (a) together with visual feedback on the wrist position (b).

147 peak was reached, the corresponding value of current was established as the
 148 value of the stimulation current, I_{Hmax} and I_{Mmax} , respectively. Any further
 149 increase led to a decrease in the H- and M-wave peaks. The stimulus inten-
 150 sity varied among subjects between 5 and 60 mA for the M-wave peak and
 151 between 1 and 20 mA for the H-wave peak.

152 2.3. Measurement protocol

153 The whole measurement protocol is illustrated in Fig. 4. Prior to each
 154 treatment, the isometric MVC for each subject was measured by the embed-
 155 ded load cell. The right side of the bar of the experimental setup was blocked
 156 during the MVC measurements, as shown in Fig. 1. The subjects were asked
 157 to pull the handle with 3-s maximal isometric contraction three times, each
 158 time followed by 45-s rest. For each 3-s contraction, the maximum force was
 159 determined and the maximum of the three measurements was considered as
 160 the MVC. The subjects were sitting on a chair and instructed to keep their
 161 arm attached to the fitness bench with the elbow angle at about 90 degrees,
 162 which was achieved by adjusting the chair height and monitored by a pro-
 163 fessional coach. The subjects then pulled up the handle by curling the wrist
 164 without moving the arm while performing isometric contraction of the FCR.
 165 This procedure was followed for both the MVC estimation and the sustained
 166 contractions during the training protocol. During each contraction, the sub-
 167 jects were supported by the implemented visual feedback in order to maintain

Figure 4: The schematic of the whole protocol.

168 the right position (Fig. 3, b). The wooden block used for the MVC test was
 169 removed during sustained contractions.

170 The best position for placing the stimulation electrode was determined by
 171 H-reflex screening after a transcutaneous electrical stimulation of the median
 172 nerve at 10% of the MVC. According to the H-reflex elicitation procedure, the
 173 recruitment curve of H-reflex and M-wave was then built by varying the stim-
 174 ulus intensity. The maximum I_{Hmax} and I_{Mmax} values were searched. The
 175 training protocol consisted of maintaining a constant muscle tension equal to
 176 80% of the MVC with a superimposed vibration of a chosen amplitude equal
 177 to 70% of the baseline tension.

178 The experimental conditions were characterized by four sustained (12-s)
 179 isometric contractions of the right FCR muscle with no vibration (control),
 180 and with vibration at 15, 30, and 45 Hz. A randomized cross-over design
 181 was used. Each condition was followed by a 15-min resting period. This was
 182 experimentally proven to permit full MVC recovery. To this end, different

recovery intervals were tested incrementally: 5, 10, and 15 min. Eventually, 15 min were found sufficient for full recovery of the muscle performance, since the subjects could produce the same level of MVC as prior to the fatiguing task. In addition, this choice was in line with literature [51], in which a recovery period of 12 min was adopted due to slightly lower vibration amplitude (60% of the baseline force). Before and after each trial, the FCR MVC, together with the H- and M-wave, were measured following the same protocol as before training. Ten repeated rectangular pulses of 1000 μ s duration each at a triggering frequency of 0.5 Hz were delivered to elicit the H-reflex response for determining the maximal H- and M-waves before and after each trial.

2.4. Signal analysis

2.4.1. Mechanical fatigue

The MVC test was performed before and after each trial in order to assess mechanical fatigue. The MVC for each subject was measured by the embedded load cell. First, the shaft of the motor was blocked in order to perform an isometric contraction and to measure by the embedded load cell the produced force. Mechanical fatigue was then assessed by measuring the absolute change in MVC after each trial as compared to before exercise (ΔMVC).

2.4.2. Myoelectric fatigue

During the four sustained isometric contractions, the sEMG was recorded from the FCR muscle. To provide an exhaustive evaluation of the fatigue effect introduced by VE, myoelectric fatigue was assessed by estimating the mean frequency (MF). According to recent works [36, 37, 38], SPVF during VE consist mainly of vibration-induced muscle activity; therefore the frequency spectrum in a bandwidth of 20-450 Hz [53] was included in the EMG analysis without additional filtering. The MF was then estimated by time-frequency analysis of the bipolar EMG signal. A sliding window of 1-s with no overlap was adopted to compute the Short-time Fourier Transform. The MF was then estimated as the first statistical moment of the obtained amplitude spectrum. For each segment, the MF was obtained as:

$$MF = \frac{\sum_{f=20}^{450} f \cdot S_f}{\sum_{f=20}^{450} S_f}, \quad (1)$$

where f is the frequency [Hz] and $S_{n,f}$ is the amplitude spectrum at frequency f . A linear regression was then applied to the values obtained from all the

216 windows and the angular coefficient of the regression line used as indicator
217 of myoelectric muscle fatigue [27, 51].

218 2.4.3. *H-reflex*

219 According to the H-reflex elicitation procedure described in section 2.2,
220 ten H- and M-waves were recorded before and after VE for each trial by
221 stimulating the median nerve. For each recording the ten H- and M-waves
222 were first averaged. The peak-to-peak amplitude of the averaged H- and
223 M-wave was then calculated. In general, the peak-to-peak amplitude of the
224 H-wave, H_{max} , is an indirect estimate of the number of MNs that are able
225 to activate in a given state while the peak-to-peak amplitude of the M-
226 wave, M_{max} , represents the activation of the entire MN pool; therefore, the
227 calculated H_{max} was normalized with respect to the M_{max} , indicating the
228 fraction of the entire MN pool that can be recruited [54].

229 The normalized H_{max} was estimated both before and after the exercise at
230 different vibration frequencies (0, 15, 30, and 45 Hz). The relative decrease
231 in the normalized H_{max} after each exercise was then calculated as indication
232 of H-reflex suppression, as given by

$$\Delta H = \frac{H_{max,after} - H_{max,before}}{H_{max,before}} \times 100\%. \quad (2)$$

233 2.5. *Statistical analysis*

234 The parameters investigated in our statistical analysis are the H-reflex
235 suppression, myoelectric fatigue, and mechanical fatigue. H-reflex suppres-
236 sion was estimated as the decrease in H-reflex amplitude after each trial.
237 Myoelectric fatigue was estimated as the slope of the regression line to the
238 time evolution of the MF, as assessed during each trial. Mechanical fatigue
239 was estimated as the drop in MVC measured after each trial. Subjects were
240 excluded from the H-reflex analysis (3 subjects) based on one criterium:
241 signal-to-noise ratio < 18 dB for the H-reflex response. This threshold value
242 was based on visual inspection. According to the one-sample Kolmogorov-
243 Smirnov test [55], all data were Gaussian distributed ($p > 0.05$). However,
244 for each subject, the data recorded with different test conditions, i.e., fre-
245 quencies, are not independent. As a consequence, the one tailed Wilcoxon
246 signed rank test was adopted to establish the significance level (p value) in
247 the mean values between control (no vibration) and each vibration frequency.
248 For all the analyzes, α was set at 0.05.

Figure 5: Example of MF estimates for varying vibration frequencies from 0 (control with no vibration) to 45 Hz.

3. Results

3.1. Myoelectric and mechanical fatigue indicators

Figure 5 shows the MF time evolution for a subject. In all the measurements, the MF evolution over time showed a trend that was well approximated by a linear model. The average R^2 (determination coefficient) value of the regression lines over the full dataset was 0.83 ± 0.11 . Myoelectric fatigue was therefore estimated as the (negative) angular coefficient of the regression lines. Figure 6 shows the averaged MF slope over all the subjects for each corresponding training at 0, 15, 30, and 45 Hz in terms of mean $\pm$ standard deviation. Figure 7 shows the MVC decay over all the subjects for each corresponding training at 0, 15, 30, and 45 Hz in terms of mean $\pm$ standard deviation. The estimates in Fig. 6 and Fig. 7 indicate 30 Hz as the most fatiguing exercise, according to both the MF and the MVC assessment. The results of our statistical analysis on MF and MVC reveal the separation

Figure 6: MF decay estimates for varying vibration frequencies from 0 (control with no vibration) to 45 Hz in terms of mean $\pm$ standard deviation. The asterisk (*) indicates the significant difference ($p < 0.05$) between 0 Hz and 30 Hz.

263 of different groups to be significant only between 0 Hz and 30 Hz ($p < 0.05$).

264 3.2. *H-reflex suppression*

265 Figure 8 represents an example of the ten H-reflex responses recorded for
 266 one subject after VE at 30 Hz. Table 1 reports the normalized H-reflex values
 267 in terms of mean $\pm$ standard deviation, while Fig. 9 depicts the ΔH in terms
 268 of mean $\pm$ standard deviation. These results show a decay in the normalized
 269 H-reflex amplitude after fatiguing exercise at all the frequencies as compared
 270 to before exercise. In addition, as compared to control condition (0 Hz),
 271 the H-reflex amplitude decreases more at 15 Hz than at 30 and 45 Hz. The
 272 lowest H-reflex amplitude suppression is observed at 30 Hz. The results of
 273 our statistical analysis on ΔH reveals the separation of different groups to
 274 be significant only between 0 Hz and 30 Hz ($p < 0.05$).

Figure 7: ΔMVC estimates for varying vibration frequencies from 0 (control with no vibration) to 45 Hz in terms of mean $\pm$ standard deviation. The asterisk (*) indicates the significant difference ($p < 0.05$) between 0 Hz and 30 Hz.

275 4. Discussion

276 In line with previous research [51], as indicated by MVC and MF indica-
 277 tors, our results show that vibration produced a larger degree of mechanical
 278 and myoelectric fatigue as compared to control condition (0 Hz), showing 30
 279 Hz vibration as the most fatiguing exercise. It should be noticed that SPVF
 280 are indeed observed in our EMG measurements. However, since many recent
 281 studies suggest those SPVF to be vibration-induced muscle activity, they are
 282 not excluded in our MF calculation [36, 37, 38].

283 Several studies [47, 56, 57] have investigated the changes in MN pool ex-
 284 citability after the superimposition of vibration, showing how the H-reflex
 285 amplitude is suppressed after vibration-induced fatigue. Our results show
 286 that after fatiguing exercise the H-reflex amplitude decreased by 28% com-
 287 pared to before exercise; this result is in line with literature [58]. When ap-
 288 plying vibration a lower suppression of the H-reflex amplitude was observed
 289 as compared to control condition (0 Hz), with the smallest suppression (20%)

$f(\text{Hz})$	$H_{max, before}$	$H_{max, after}$
0	0.1666 ± 0.1073	0.1185 ± 0.0921
15	/	0.1122 ± 0.0713
30	/	0.1285 ± 0.0822
45	/	0.1208 ± 0.0859

Table 1: Normalized H-reflex amplitude before and after VE at different frequencies.

Figure 8: Example of ten H-reflex responses recorded for one subject with the stimulation current I_{Hmax} .

290 at 30 Hz.

291 The observed H-reflex amplitude suppression reflected in the reduction of
292 the FCR MN pool excitability and a change in the synaptic efficacy, which
293 can be explained by reflex inhibition from group III and IV afferents [59].
294 The major finding of our study is that the H-reflex amplitude decreased less
295 compared to control condition (0 Hz) when vibration is applied. Therefore,
296 the VE protocol used in this study seems associated with an enhancement in
297 the FCR MN pool excitability, possibly due to TVR [30, 31], reflected in a

Figure 9: ΔH estimates for varying vibration frequencies from 0 (control with no vibration) to 45 Hz in terms of mean $\pm$ standard deviation. The asterisk (*) indicates the significant difference ($p < 0.05$) between 0 Hz and 30 Hz.

298 lower suppression of the H-reflex amplitude as compared to control condition
 299 (0 Hz). This phenomenon was not evident at 15 Hz, possibly because this
 300 frequency is not suitable to stimulate effectively TVR and MN excitability.

301 In the light of these results, we may hypothesize that VE, especially at
 302 30 Hz, enhances mechanical and myoelectric fatigue, which are reflected in
 303 MVC decay and EMG spectral compression, respectively, while limiting the
 304 reduction in MN excitability, which is reflected in a smaller H-reflex suppres-
 305 sion. At this stage, considering recent work on whole body vibration [60], we
 306 should not exclude a central influence, as the reduction in force generating
 307 capacity observed may occur not only because of peripheral changes at the
 308 muscular level, but also because the central nervous system fails to drive the
 309 MNs adequately [61]. This could suggest 30 Hz to provide effective enhance-
 310 ment of the peripheral component as compared to the central component and
 311 neural drive decay. Dedicated studies on the ability to achieve full muscle
 312 activation, e.g., via twitch interpolation techniques [62], may elucidate on
 313 the central and peripheral fatigue involvement as well as on the contribution

314 of spinal mechanisms as attempted with WBV.

315 As Armstrong *et al.* [47] reported, the H-reflex response to a vibratory
316 stress is highly variable and may be dependent on muscle fiber type differ-
317 ences. Moreover, the post-activation of the H-reflex response may be depen-
318 dent on the nature of the stimulus (e.g., frequency and intensity) as well as
319 on the complex interaction between the muscle fiber fatigue characteristics
320 and the nature of the fatiguing protocol. Although our dedicated protocol
321 aims at applying superimposed VE on the FCR muscle, it is not possible
322 to eliminate the involvement of other muscle groups of the forearm. As a
323 result, crosstalk from other muscle groups of the forearm may be present in
324 the EMG recordings.

325 It should also be noted that the aim of the present study is to investigate
326 vibration-induced effects on muscle fatigue and H-reflex. We mainly focus on
327 the different effects between vibration and control condition (no vibration).
328 Moreover, for each subject, the data recorded with and without vibration
329 are not independent. As a consequence, Wilcoxon test between control and
330 each vibration frequency is adopted for the statistical analysis. However, the
331 effects between different vibration frequencies might also be of interest for
332 other purposes. In this case, a multi-comparison should be performed for the
333 statistical analysis by using repeated measures of ANOVA and post-hoc test.

334 5. Conclusion

335 In the present study, the effects of vibration-induced fatigue were inves-
336 tigated by analysis of the H-reflex response and myoelectric and mechanical
337 fatigue indicators. Our results demonstrate a lower fatigue-induced reflex
338 inhibition of the FCR MN pool after VE. This effect was especially evident
339 at 30 Hz. In parallel, 30 Hz caused the largest myoelectric (EMG spectral
340 compression) and mechanical (MVC decay) evidence of acute neuromuscular
341 impairment, resulting in the most fatiguing frequency for training. This sug-
342 gests VE, especially at 30 Hz, to enhance mechanical and myoelectric fatigue
343 while limiting the reduction in MN excitability. These results highlight the
344 need for further investigation of spinal reflex mechanisms involvement as well
345 as their complex interaction with fatigue. They also indicate that in the FCR
346 muscle, undergoing VE in isometric conditions, peripheral inhibitions may be
347 accounted for the MVC reduction with our protocol, but central components
348 should not be excluded and should be verified experimentally. This feature
349 may turn out to be particularly suitable in rehabilitation programs targeting

the arm following immobilisation periods to restore muscle form and function rapidly. In general, our results may be used when personalizing VE training protocols involving the FCR.

Further studies are needed to determine safe and effective protocols of VE using our similar modalities to exercise upper body muscles as well as to understand the acute and chronic implications on the musculoskeletal system.

Conflict of interest

The authors have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

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