ACUTE EFFECT OF STRENGTH EXERCISES WITH SUPERIMPOSED VIBRATION: IMPACT OF FREQUENCY AND AMPLITUDE OF OSCILLATIONS

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ABSTRACT

The aim of this study was to delineate the effect of different combinations of frequency and amplitude of superimposed vibration on attainment of maximal strength in exercises with isometric or isotonic concentric muscular contraction. The study was conducted on male trained adult volunteers (n=8, age=33.5±3.8). The athletes performed one arm pulling action without or with superimposed vibration that was transmitted from vibratory stimulation apparatus via cable and handle on the proximally located muscles of upper body. The exercises mode was isometric or isotonic concentric; in both cases the subjects developed maximal voluntary efforts. Vibration frequency varied between 17–38 Hz, and vibration amplitude between 2–8 mm. The ergogenic effect was evaluated as difference between force/power values attained in control and vibratory stimulated attempts. The findings display significant stimulatory effect of superimposed vibration in isotonic concentric exercise (increase varied between 8.8–38.3%) and, in much lesser extent, in isometric drill (increase varied between 1.7–5.8%). In isotonic exercise increase of vibration frequency and amplitude within the range of 17–38 Hz and 2–8 mm produced gradual elevation of motor output, whereas in isometric exercise only the proper combinations of frequency and amplitude provided appropriate intensity of mechanical signal, which determined maximal stimulatory effect.

***Key words*:** vibration training, muscular strength, isometric and isotonic contraction.

INTRODUCTION

Strength practice incorporating vibration has become especially popular and widely used over the last decade both in high-performance sport and health-related training [2, 8, 12, 23]. The application of vibration in physical training embraces two principal approaches: (1) physical exercises with local vibration (LV), when the superimposed vibration is transmitted to contract or stretched muscles, and (2) motor tasks performed while the whole body is being vibrated. Therapeutic procedures utilizing LV have been exploited in physiotherapy and clinics since the 19th century, but recent interest and extensive research were stimulated by the findings of Eklund and Hagbarth [9] studying the phenomenon of vibratory induced non-voluntary contraction, and introducing the term *Tonic Vibration Reflex* (TVR). The ergogenic impact of superimposed LV was studied in terms of acute and cumulative effects of vibration training. In both cases parameters of superimposed vibration, such as frequency and amplitude of regular oscillations, were of special interest. The spectrum of frequencies and amplitudes, which were employed, varied substantially (for review, see Issurin [12]), and various combinations have been selected empirically or following general theoretical prerequisites [18, 21].

The acute ergogenic effect of superimposed LV was studied using various models of physical exercises. Some examined these effects on isometric exercises [6, 11, 28, 29], whereas the others studied isotonic dynamic contractions [5, 14, 25, 29]. The reported outcomes varied widely, however attained ergogenic effect of LV was eventually larger in dynamic exercises. This difference of attained benefits seems worthy for special investigation. Moreover, it is assumed that the most favorable combinations of the LV frequency and amplitude parameters can vary for isometric or isotonic exercises. The purpose of this study is to delineate the effect of different combinations of frequency and amplitude of superimposed vibration on attainment of maximal strength in exercises with isometric or isotonic concentric muscular contraction.

MATERIALS AND METHODS

Subjects

Eight male trained athletes, former experienced kayakers (age=33.5±3.8 years; height=177±4cm, weight=75.5±3.5kg) volunteered to participate in this study. All participants were accustomed to strength exercises and were very familiar with vibration training. They passed preliminary session where they got familiarized with the intended exercises, equipment, and procedures. Due to their experience in testing exercise and sufficient fitness level, the athletes were able to provide high reproducibility in obtaining maximal effort both in isometric and isotonic exercises. They have signed informed consent before beginning the study.

Apparatus

The athletes performed one arm pulling action in sitting position similarly to a kayak stroke (see Figure 1). They were positioned on a special seat with support for two legs; the soft pad was fixed behind the subject on the neck level to prevent body extension during effort. The athletes performed a pulling action by the dominant arm involving upper body muscles and trunk rotation identically to a kayak paddle stroke. During isomeric exercise the cable was anchored to a wall; pulling began by positioning straight arm placed 70° to trunk axis; preliminary measurements revealed that this angular position allows obtaining maximal force values. During the isotonic exercise the cable was connected to a hydraulic training machine “Champion”; pulling was initiated by positioning straight arm with maximally stretched upper body muscles from preliminary rotated trunk position, similarly to a kayak stroke performance, and ending when the hand reached vertical axis of the hip joint. The external resistance of the hydraulic training machine was settled on the force level that corresponded to 300–500 Newton; the force value depended on the pulling velocity.

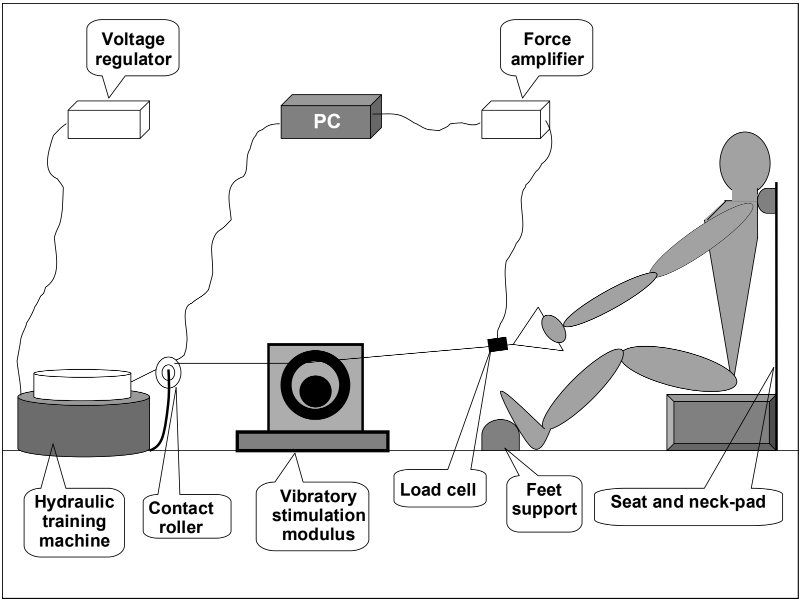


Figure 1. Experimental setup for isotonic concentric exercise; in isometric exercise the cable was anchored to a wall.

The superimposed vibration was produced by a specially designed vibratory stimulation device [13], which contains a three kilowatt 3-phase electromotor with a speed reduction and regulation; eccentric wheel with changeable eccentricity; cable that passed through eccentric wheel via the pulleys, with the arm handle on the edge. Vibration frequency was settled by means of input of appropriate voltage on the electromotor; correspondingly 17, 27 or 38 Hz were programmed. Regulation of vibration amplitude was achieved by alteration of the wheel eccentricity, and was equal to 2, 4 or 8 mm following the protocol of study. The average calculated vibratory acceleration varied between 7.7–160 m/s^2 depending on the proper combination of vibration's frequency and amplitude.

The force values were obtained by measurement of the cable tension via load cell (model TR, BM-Cybernetics); the generated signal was transmitted to force amplifier (Topaz-4, St-Petersburg) and PC. The pulling velocity in dynamic exercise was measured by means of contact roller, where rotations generated proportional signal; the mean power of each single pull was automatically computed and transmitted to a PC.

Design and procedure

The study lasted two days. Each day program included general warm-up for 5–7 min, and task-specific warm-up using the experimental equipment. Participants practiced the exercise employing sub-maximal and maximal modes of effort using 10–12 repetitions. At each day the athletes performed three consecutive series of exercises with LV amplitude of vibration set at 2, 4, and 8mm, respectively. Such sequencing was selected to prevent premature accommodation to vibration excitation of maximal intensity. Therefore, each series contained four attempts, where the first one was always performed without vibration and served for control of basic level, and for monitoring of fatigue during the entire working day. The rest three attempts of each series were performed with LV frequencies set at 17, 27 and 38Hz and practiced in random order. Each attempt included two maximal effort repetitions with an interval of 5–8s; the maximal value was taken for further calculations. The interval between succeeding attempts was set at 2–3 min until the subject was completely ready for next effort. The rest interval between each series lasted 12–15min; the level of fatigue of efforts was controlled by comparison of the force/power values in attempts without vibration in each series; reproducibility level was maintained within interval and reached 1.5%.

The testing procedure both in isometric and isotonic exercises presupposed positioning of the athlete on the seat keeping the handle in dominant arm with preliminary tensioned cable. Vibration device was switched on for 1.5–2s prior the command “Start”. The athletes were asked to develop maximal voluntary contraction immediately after the command as fast as possible. In isometric exercise the athlete maintained maximal effort until command “Stop” during 5 seconds. The second repetition was performed identically after a 5–8s interval. In isotonic exercises the athlete pulled the cable with maximal velocity until the hip joint; pulling time varied in range between 1.2–1.5 s. Afterwards the training machine returned the cable back, and the athlete performed second repetition within the same time interval (e.g., 5–8s).

The registered variables taken for further analysis were the following: isometric exercises – maximal peak force; isotonic exercises – mean power of pulling action. The differences between no- vibration condition and each combination of amplitude and frequency of vibration were computed for each athlete, and were expressed in percent.

Data analysis

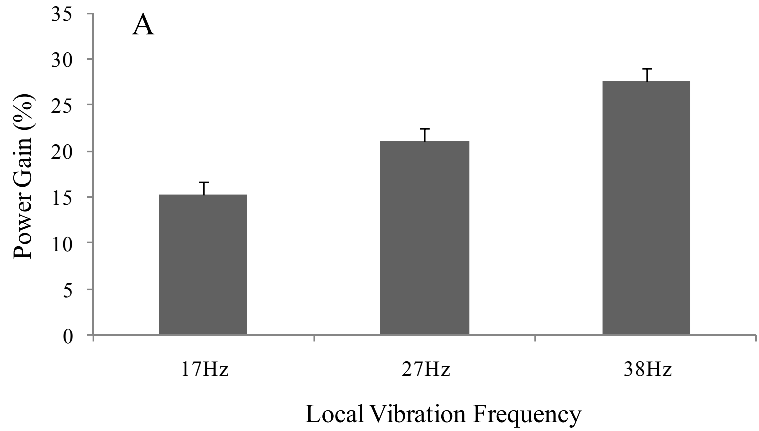
As each participant was exposed to 9 treatments comprising of a combination of 3 levels of LV frequency (i.e., 17, 27 and 38 Hz) and 3 levels of amplitude (i.e., 2, 4, and 8mm), a repeated measures within subjects (RM-WS) analysis of variance (ANOVA) was employed separately for the dynamic and isometric data sets (i.e., % change from control condition). Sphericity assumptions were tested prior to inferential procedures implementations, followed by appropriate adjustment procedures. Descriptive statistics (mean, SD) were computed to illustrate the significant effect in graphical modes. Significance level was adjusted according to Boneffroni procedure

RESULTS

Dynamic data set

Despite the relative small sample size (n=8), Mauchly's test of Sphericity has failed to show any violation for both frequency and amplitude effects (Mauchly's W's=0.88 and 0.51, $p>0.05$, respectively). However the sphericity assumption of the frequency by amplitude interaction was violated (Mauchly's W=0.003, $p=0.001$). Thus, for the main effects, Wilks' λ multivariate tests were employed, while for their interaction Greenhouse-Geisser (GG – no sphericity assumed) within subject effect was used with adjusted degrees of freedom.

Both frequency and amplitude of LV resulted in significant effects on power gain, Wilks' $\lambda=0.008$, $F(2,6)=368.99$, $p<0.001$, $\eta^2=0.992$, and Wilks' $\lambda=0.014$, $F(2,6)=211.13$, $p<0.001$, $\eta^2=0.986$, respectively. These effects are shown in Figure 2a,b. Pertaining to LV frequency, power gain increased by 13.60%, 19.03%, and 25.67% following practices with LV frequencies of 17Hz, 27Hz, and 38Hz, respectively. With respect to LV magnitude, percent increase in dynamic power associated with 2mm, 4mm, and 8mm was 12.07%, 20.10%, and 25.63%, respectively.



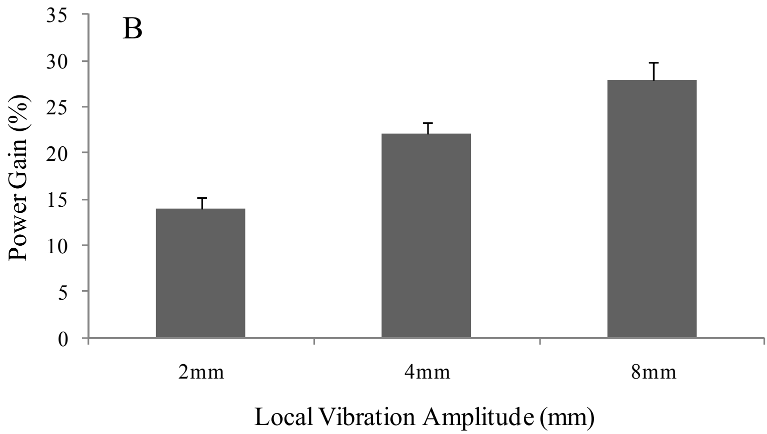


Figure 2. Means and SDs for power gains with respect to (A) 3 levels of LV frequency (17, 27, and 38 Hz), and (B) 3 levels of LV amplitude (2,4, and 8 mm)

The frequency by amplitude interaction resulted in a significant effect on dynamic power gain, GG=536.23, $F(1.84, 12.70)=82.67$, $p<0.001$, $\eta^2=0.92$, and is presented in Figure 3.

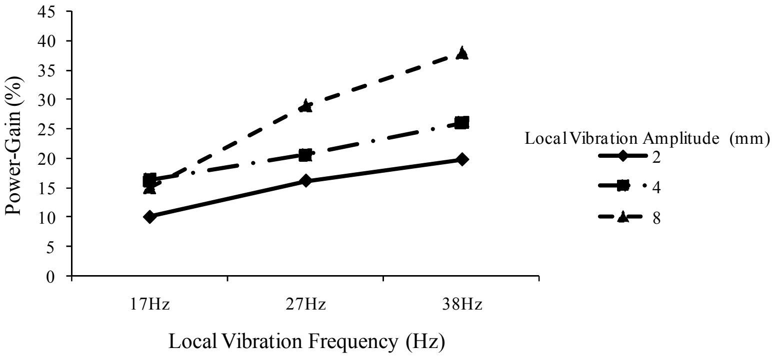


Figure 3. Dynamic power gain means for the 9 interventions comprised of frequency and amplitude of LV.

The results show a monotonic and sharp increase in power gain as LV frequency and amplitude increase simultaneously. Under 8mm amplitude, dynamic power increased by 15.14%, 29.34% and 38.33% following 17Hz, 27Hz, and 38Hz, respectively. While less than 4mm amplitude the increase in power associated with frequency increase was 16.81%, 20.56%, and 25.94%, respectively. A somewhat moderate increase in dynamic power was noticed when practice was carried out with 2mm amplitude, resulting in an increase of 9.88%, 16.39%, and 19.67%, respectively.

Isometric data set

Mauchly's test of Sphericity has failed to show any violation for both frequency and amplitude effects, as well as their interaction (Mauchly's W's =0.90, 0.48, and 0.22, $p>0.05$, respectively), thus Wilks' λ multivariate tests were employed to these 3 effects. Both main effects for frequency and amplitude of LV reached significance, Wilks' $\lambda=0.05$, $F(2,6)=353.21$, $p<0.001$, $\eta^2=0.95$, and Wilks' $\lambda=0.08$, $F(2,6)=36.36$, $p<0.001$, $\eta^2=0.92$, respectively. These effects are shown in Figure 4a,b.

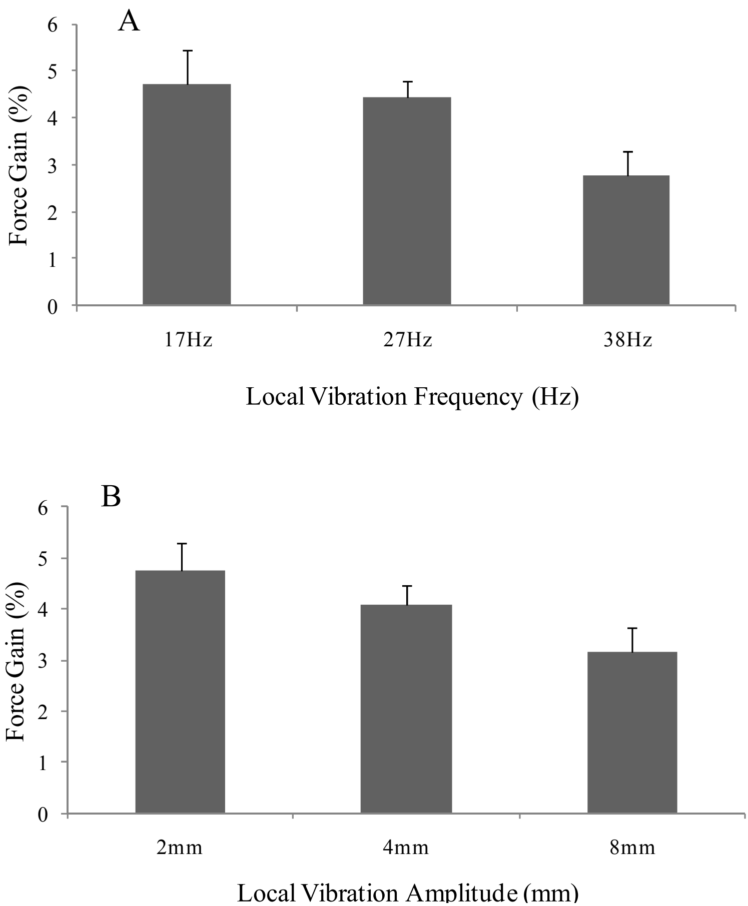


Figure 4. Means and SDs for force gain with respect to (A) 3 levels of LV frequency (17, 27, and 38 Hz), and (B) 3 levels of LV amplitude (2,4, and 8 mm)

The frequency effect resulted from a monotonic decrease in force gain as LV frequency increase: 3.57%, 3.83%, and 1.67% associated with frequency of 17Hz, 27HZ, and 38Hz, respectively. Similar decrease was associated with increase in LV amplitude from 2mm, through 4mm, to 8mm: 4.07%, 3.40%, and 2.13%, respectively.

The frequency by amplitude LV interaction effect on force using the multivariate test reached significance, Wilks' λ=0.01, F(4,4)=89.05, p<0.001, η^2=0.99, and is presented in Figure 5.

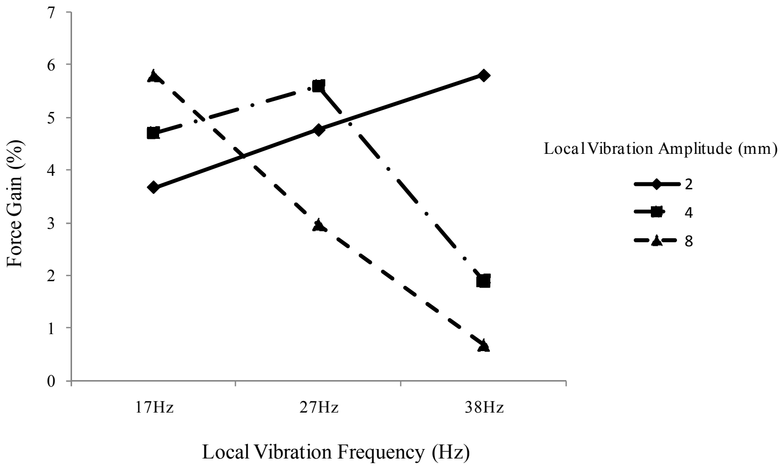


Figure 5. Isometric force changes for the 9 interventions comprised of frequency and amplitude of LV.

As noticed in Figure 5, increases in LV frequency resulted in sharp decreases in force gain under 8mm amplitude: 5.80% with 17Hz, 2.98% with 27Hz, and 0.68% with 38Hz. When practiced with 4mm LV amplitude, force gain was the lowest when practiced with 38Hz LV (1.90%), and increased with LV frequencies of 27Hz and 17Hz (5.80% and 4.71%, respectively). Finally, when amplitude of LV was 2mm, monotonic increase in force gains were obtained with frequency increase from 17Hz thorough 27Hz to 38Hz: 3.68%, 4.76%, and 5.80%, respectively.

DISCUSSION

The different magnitude of ergogenic effect elicited by LV in isometric and isotonic exercises has been reported and considered in a number of previous publications. Several studies employing LV in isometric exercises failed to obtained any acute effect on maximal force attainment [4, 11, 29], whereas others reported moderate, but significant, gain in maximal force [6, 7, 28], and pronounced increase of EMG activation [22]. Unlike the studies employing isometric contractions accompanied with LV, the effects of isotonic exercising with LV resulted in substantial gains on maximal force and/or power [14, 17, 25, 29]. Thus, it seems that exercising with LV produces greater ergogenic effect while applied to dynamic than to isometric muscular contraction. Findings of the current study support this supposition. Moreover, the magnitude of power gain (38%) in the present study substantially exceeded the gains' values ranging from 4.8–26.4% obtained in previous studies [5, 14, 17, 25].

The marked stimulatory effects of LV on isometric and isotonic muscular contractions is attributed to neural and biomechanical factors. The underlying neural mechanism of vibratory stimulation presupposes that vibration causes excitation of primary afferent endings of motor spindles, and recruitment of muscular receptors, which activate a larger fraction of α-motoneurons whose discharges recruit previously inactive muscle fibers into contraction. The exercises employing LV in the current study provided vibration transmission via cable and handle to a distal link with further propagation of vibratory wave through big mass of proximally located muscles. This caused severe activation of vibratory sensitive muscle receptors, and recruitment of many additional motor units into contraction. This proposed mechanism can be relevant both for isometric and isotonic contractions; however a number of specific circumstances cause the marked difference, which can be more beneficial to motor response in dynamic exercises. More specifically, unlike isometric exercise, the isotonic drill initiated a pre-stretched position and preliminary acted vibration, which elicited the active state prior to contraction. In these conditions the stretch reflex largely contributes to the force development [16].

It is known that force enhancement in Stretch-Shortening Cycle (SSC) exercises is strongly affected by reflexive facilitation of efferent caused by Ia afferents [27]. Likewise, isotonic concentric exercises being preliminary affected by superimposed vibration benefit from Ia afferent inflow, which produce excitatory effect on the α-motoneurons [3, 4, 20]. Therefore, it is maintained that superimposed vibration facilitates stretch reflex, which in turn produces a decisive impact on force and power generation in dynamic exercises.

One more suggestion is concerned with difficulty in activation of large muscle groups in dynamic voluntary contraction [15]. In our study vibratory stimulation was administered prior to the muscular contraction, and this pre-activation could result in a facilitatory effect on subsequent voluntary effort.

Additional factor determining ergogenic effect of LV in isometric and isotonic exercises is the initial length of the muscles prior contraction. Three decades ago, Bishop (1974) found that preliminary lengthened muscles were more sensitive to vibration, and contract more strongly. Both in industrial activities [26] and physical exercises [12] increased muscles length provided higher motor output. In our study the isotonic exercise was initiated by straight-arm with maximally stretched upper body muscles, whereas the isometric pulling action started from arm position set at 70° to trunk axis; correspondingly, the initial muscles length was greater prior to dynamic then isometric efforts. Therefore, such factors like higher stretch-sensitivity, facilitated pre-activation and increased muscle length largely contribute into pronounced ergogenic effect produced by LV in dynamically contracted muscles as compared with isometric contraction.

LV frequency was found to evoke a proportional increase in muscle tension [19]; a finding confirmed in the present study with isotonic concentric contraction, whereas the isometric contraction gained maximal stimulatory effect under specific conditions unrelated to maximal intensity of mechanical signal. The marked difference in motor output between isotonic and isometric contraction needs special consideration. It should be noted that the most integrative indication of the vibration's intensity can be given by considering vibratory acceleration as a function of the frequency and amplitude in mechanical signal [10]. Figure 5 displays those different combinations of frequency and amplitude i.e. 2 mm-38 Hz, 4mm-27Hz, and 8mm-17 Hz, which elicited maximal and almost the same gain of isometric force. Importantly, these three combinations are characterized by similar average vibratory acceleration ranged within 32–40 m/s^2. The lower and higher magnitudes of vibration's intensity produced lower ergogenic effect. Thus, it can be suggested that stimulatory effect has reached a critical intensity of mechanical signal from which any further increase results in a suppressive response. Such inhibition can be associated with aggravated activation of Golgi tendon organs. Indeed, when the muscle contracts isometrically, it develops tension, and the in-series-attached Golgi tendon organ increases its discharge [16, 24]. Presumably the severe vibration signal (up to 160 m/s^2 of average vibratory acceleration) exceeds reserves of the force receptors' accommodation and Golgi tendon reflex evokes inhibition of motor output.

In summary, the current findings display apparent stimulatory effect of superimposed LV on isotonic concentric power and, in much lesser extent, on isometric strength. However increase of the frequency and amplitude of LV within the range 17–38 Hz and 2–8 mm produces very different ergogenic impacts. In isotonic exercise this increase elicited gradual elevation of motor output, whereas in isometric exercise the proper combinations of frequency and amplitude provide certain intensity of mechanical signal, which determines maximal stimulatory effect of LV.

CONCLUSION

Exercising incorporating vibratory stimulation belong to the branch of new sport technologies that draw much attention in both practitioners and researchers. The sport industry produces various devices and training machines, which facilitate the implementation of vibratory exercises into the practice. Thus, determination of the most efficient training regimes has apparent scientific and practical importance. The outcomes of the present study can be reasonably adapted in three following directions: (1) dynamic concentric exercises with superimposed vibration have much higher ergogenic effect on maximum strength abilities than similar exercises with isometric muscular contraction; (2) more pronounced stimulatory effect of superimposed vibration in dynamic exercises demands higher intensity of mechanical signal, which is provided by higher frequency and larger amplitude of oscillations; in the present study the most beneficial regime was obtained with frequency 38 Hz and amplitude 8 mm, (3) in the isometric vibratory exercises the maximal stimulatory effect is conditioned by lower intensity of mechanical signal (i.e. 38 Hz and 2 mm; 27 Hz and 4 mm; and 17 Hz and 8 mm of frequency and amplitude respectively). These data can be utilized for planning similar studies using vibratory stimulation incorporated with exercising under various training modalities.

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