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Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes

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Fourteen elite and 14 amateur athletes were subjected to vibratory stimulation during bilateral biceps curl exercises of explosive strength exertion. The athletes performed two separate series of three sets of exercises in random order. The second set of one series was administered with superimposed vibration of 44 Hz and an acceleration of about 30 $m \cdot s^{-2}$ transmitted through the two-arms handle to the arm muscles. The mechanical power of each repetition was measured by the 'Power Teach' instrument. The maximal and mean power values for each set were automatically recorded and shown on the screen. The acute effect was evaluated as the difference between the mean and peak power output in the second (with vibratory stimulation) and first (without vibratory stimulation) sets. Similarly, the residual effect was taken to be the difference between the power values of the third (after vibratory stimulation) and the first (before vibratory stimulation) sets. The results were subjected to a repeated-measures analysis of variance with group as a between-participants factor. The results showed that exercise mode (with *vs* without vibratory stimulation) resulted in a significant immediate effect for mean power and for maximal power. The factor group (elite *vs* amateurs) resulted in a significant effect for maximal power only. The increase in explosive strength exertion attributed to vibratory stimulation was 30.1 and 29.8 W (10.4% and 10.2%) for maximal and mean power respectively in the elite group, and 20.0 and 25.9 W (7.9% and 10.7%) respectively in the amateur athletes. Vibratory stimulation resulted in an insignificant residual effect.

Keywords: acute effect, amateur athletes, elite athletes, explosive strength, vibratory stimulation exercises.

Introduction

Vibration applied to muscle or tendon induces a non-voluntary muscular contraction termed the 'tonic vibration reflex' (Eklund and Hagbarth, 1966). The voluntary impetus increases such a muscular contraction, and thus the maximum voluntary contraction can be facilitated (Matyas *et al.*, 1986). Moreover, vibratory stimulation combined with a substantial voluntary effort was shown to elicit movement in neuromuscular patients who were unable to contract their paretic muscles (Hagbarth and Eklund, 1966). The technique is widely used in neurophysiology and physiotherapy (Granit, 1970; Bishop, 1974). Attempts to use vibratory stimulation in the training of athletes have been undertaken only recently (Nazarov and Spivak, 1987). A substantial increase in muscle strength was observed after 3 weeks of vibratory stimulation strength training when compared with regular strength training (Issurin *et al.*, 1994).

Explosive strength, or the ability to develop force within a very short time, is of primary importance in many sports. Typical exercises for explosive strength training are characterized by fast muscular contractions with an external load of about 50–70% of maximal strength (Vrijens, 1990). The immediate effect of such exercises can be assessed by the power which an athlete can generate in a movement. Several additional training techniques have been used to accentuate power training: the quick release technique, pre-stretching of active muscles before contraction, electrical stimulation and biofeedback. The objectives of these techniques are to improve upon previous achievements, to facilitate motor learning effects and to enhance muscular capacity (Torrey, 1985). Based on the results of a previous study (Issurin *et al.*, 1994), it is likely that similar outcomes may also be achieved using vibratory stimulation.

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Table 1 The physical characteristics of the two groups of athletes (mean ± *s*)

Group	Age (years)	Body mass (kg)	Height (cm)	Mid-upper arm circumference (cm)
Elite ($n = 14$)	21.3 ± 4.1	74.0 ± 9.3	175 ± 6	35.5 ± 2.3
Amateur ($n = 14$)	25.8 ± 7.3	78.5 ± 9.6	179 ± 7	34.4 ± 3.1

Vibratory stimulation of the muscle tendon evokes an excitation of muscle sense organs (Brown *et al.*, 1967). It has also been suggested that vibratory stimulation activates central nervous organization which is responsible for neuromotor control (Granit, 1970).

Another suggestion made recently concerns the difficulty in achieving full muscle activation by voluntary effort during dynamic exercise when large muscle groups are involved (James *et al.*, 1995). It is possible that, owing to vibration, the muscles will be partially activated and their mobilization at the beginning of the effort will be faster. Therefore, it could be hypothesized that this additional vibratory excitation will stimulate the appropriate muscle group activation and the power exertion in explosive strength exercises. Moreover, an increased excitability of peripheral sense organs and the central nervous system may have a positive effect on the subsequent contractions. From an ethical point of view, vibratory stimulation exercises should be viewed as belonging to the group of so-called 'non-conventional training' methods, such as electrical muscle stimulation, velocity-assisted exercises (Maglischo, 1982) and computerized training machines (Torrey, 1985). Thus, superimposed vibration to the muscle may enhance its contraction (acute effect) or elicit post-stimulation facilitation (residual effect). The aim of this study was to establish the acute and residual effects of vibratory stimulation in explosive strength exercises.

Methods

Participants

Altogether, 28 male athletes aged 18–42 years volunteered to participate in the study. They were divided into two groups (Table 1). The first group consisted of athletes from the Israeli national judo, wrestling, weightlifting, gymnastics and track and field teams. These athletes regularly engaged in highly intensive power training. The second group consisted of amateur athletes participating in club or college sports, such as basketball, volleyball, judo, weightlifting, body-building, boxing and track and field. The amateur athletes were also engaged in power exercises but not as extensively as their elite counterparts (2–4 times a week). Because all of the athletes were familiar with power exercises, they were able to perform several repetitions with maximal effort and high reproducibility (see Table 2). This was one reason why elite and highly qualified athletes were enrolled as participants.

The study was approved by the local ethics committee and informed consent was obtained from the participants before the study began.

Instrumentation and tests

The athletes performed bilateral biceps curl exercises in a sitting position on a 'Schnell' dynamic bilateral biceps machine (Schnell, Germany, D.B. Pat. 2213440). They were secured to the machine by pads placed at the elbow, chest and back (Fig. 1). The pulling action began from a position of maximal forearm extension and finished with the elbow at an angle of 90° (1.57 rad). The athletes were instructed to perform each repetition as quickly as possible.

The superimposed vibration during the exercise was transmitted to the muscles by a specially designed vibratory stimulation device (Issurin *et al.*, 1994). It consists of an electromotor with a speed reduction and eccentric wheel. The load is held by a cable which is passed through the eccentric wheel via the pulleys (Fig. 1). The eccentric rotation elicited peak-to-peak oscillations of 3 mm with a frequency of 44 Hz. After vibration damping owing to cable transmission, the acceleration on the handle was about 30 $m \cdot s^{-2}$ (RMS). Vibration from the two-arms handle was transmitted through the contracting muscles involved in the pulling action.

The power of the active phase of exercise was measured using a 'Power Teach' instrument (GE Sport S.A.S., Rome, Italy). Two probes were installed on the counterweight frame. The locations of the probes were established during the warm-up; the lower probe was placed 2 cm above the counterweight start position and the upper probe was placed opposite the final counterweight position. Therefore, the probes covered the complete range of movement. The distance between the probes and the counterweight was transferred to a

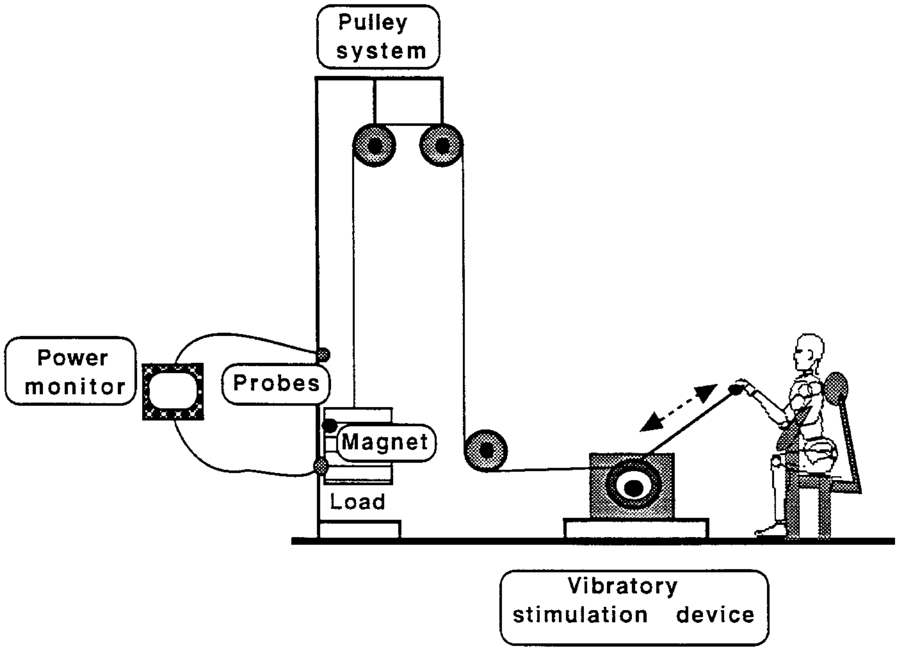

Figure 1 The bilateral biceps curl exercise and instrumentation.

microcomputer before the primary task. A magnetic element was fixed to the counterweight. When the counterweight and magnet moved through the probes, electrical signals were generated and the time between the signals from the lower and upper probes was recorded. The mean power was computed as a product of force and velocity. The power of each repetition was shown to the performer on-line. After each set of exercises, the maximal and mean values were automatically recorded and displayed on the screen to an accuracy of 1 W.

Anthropometric measures included the determination of height, body mass and bicep girth (i.e. mid-upper arm circumference), according to Tittel and Wutscherk (1972).

Study design

Two separate series of biceps curl exercises were performed in random order by each athlete. Each series consisted of three sets with three repetitions in each set. In one series, the exercise was performed with vibratory stimulation in the second set; in the other series, the exercise was performed without vibratory stimulation. The maximal and mean power values of three repetitions were recorded after each set.

The athletes performed a general warm-up for 5–7 min, including indoor running (2–3 min), general calisthenics (1–2 min) and exercises for the upper extremities (2 min). They then performed 8–10 repetitions of the biceps curl with a low to medium load (20–40% of body weight) to adapt to the exercise and equipment. Then, 3–5 attempts were performed at increasing weight to determine the one-repetition maximum value. The athletes were then allowed to rest for 15 min, during which anthropometric measures were taken and informed consent was obtained.

A weight equivalent to 65–70% of the one-repetition maximum value was selected. Two series of exercises were performed, with the interval between them allowing full recovery (8–15 min); the duration of the rest period was determined by the athletes. The exercise rate within a set was approximately one repetition every 2 s; the period of rest between sets was 2–3 min. The athletes were asked to perform each repetition with maximal effort.

Data analysis

The acute effect of vibratory stimulation was assessed as the difference between the power values in the second set with vibratory stimulation and in the first set without vibratory stimulation. Similarly, the residual acute effect was assessed as the difference between the power values in the third (after vibratory stimulation) and first (before vibratory stimulation) sets. These difference values in the first and second series were subjected to repeated-measures analysis of variance with group (elite *vs* amateur athletes) as a between-participants factor. Significance was accepted at $P < 0.05$. Paired t-tests and Pearson product–moment correlations were computed to establish differences and relationships between the two series for maximal and mean power.

Table 2 Maximal and mean power of bilateral biceps curl exercises for the first set in each of two series (exercise reproducibility) (mean ± *s*)

	Maximal power (W)		Mean power (W)	
Series	Elite	Amateur	Elite	Amateur
Without VS	295 ± 75.1	254 ± 85.6	286 ± 76.6	243 ± 88.3
With VS	295 ± 71.9	254 ± 86.8	281 ± 76.5	241 ± 89.6

Note: VS = vibratory stimulation.

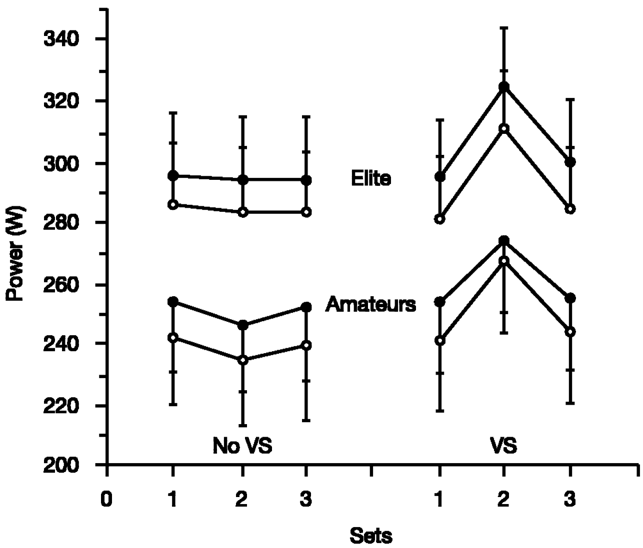

Figure 2 Maximal (●) and mean (○) power in two series of explosive strength exercise for elite and amateur athletes (mean ± $s_{\bar{x}}$).

Results

The means and standard deviations of maximal and mean power in the first set of each series were compared using paired *t*-tests (Table 2). No significant difference between the two series was found for the elite or amateur groups. The test–retest correlation coefficient between the two series was 0.97 for maximal power and 0.97 for mean power of the biceps curl exercises.

The repeated-measures analysis of variance showed that mode of exercise (with *vs* without vibratory stimulation) had a significant effect for mean power ($F_{1,26} = 59.2$, $P < 0.001$) and for maximal power ($F_{1,26} = 56.3$, $P < 0.001$). Also, the group factor (elite *vs* amateur) resulted in a significant effect for maximal power ($F_{1,26} = 4.41$, $P < 0.04$). These effects are shown in Figs 2 and 3.

In the elite athletes, vibratory stimulation resulted in an average gain in maximal power of 30.1 ± 15.3 W and in an average gain in mean power of 29.8 ± 16.6 W; these values correspond to increases of 10.4% and

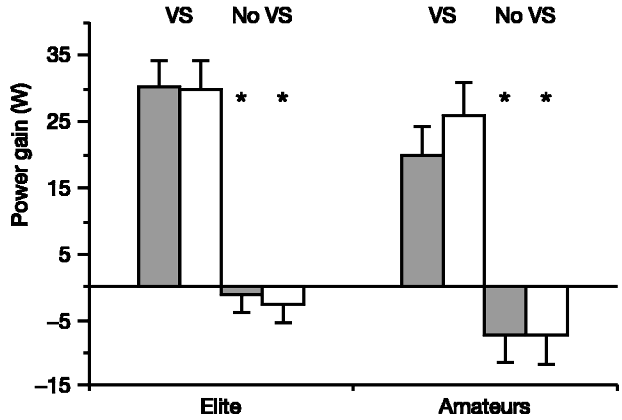

Figure 3 The acute effect of vibratory stimulation (VS). The maximal (■) and mean (□) power difference between the second and first sets in the series, with and without vibratory stimulation, for elite and amateur athletes (mean ± $s_{\bar{x}}$). * Signed significant difference between VS and no VS ($P < 0.001$).

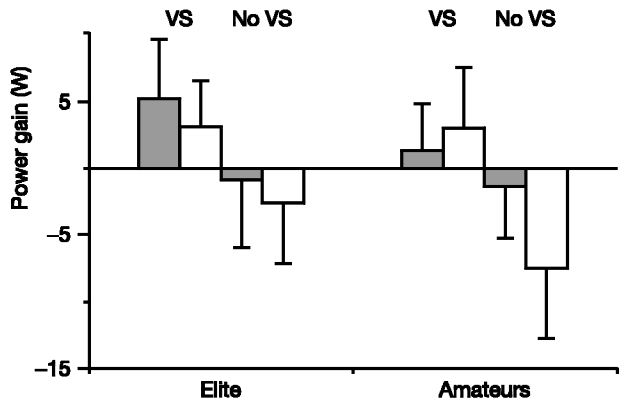

Figure 4 The residual short-term effect of vibratory stimulation (VS). The maximal (■) and mean (□) power difference between the third and first sets in the series, with and without vibratory stimulation, for elite and amateur athletes (mean ± $s_{\bar{x}}$).

10.2% respectively. The series without vibratory stimulation revealed a non-significant decrease in these values of 1.1 and 2.6 W, respectively. In the amateur athletes, the gains in maximal and mean power owing to vibratory stimulation were 20.0 ± 16.9 and 25.9 ± 18.9 W respectively; these values correspond to increases of 7.9% and 10.7% respectively. The maximal and mean power decreased by 7.4 W without vibratory stimulation. We also observed that the immediate acute effect in maximal power was significantly greater in the elite than in the amateur athletes ($F_{1,26} = 7.32$, $P < 0.01$).

Similar analyses of variance were applied to the mean and maximal power differences between the third and first sets in the two modes of exercise (with *vs* without vibratory stimulation). Group (elite *vs* amateur), exercise mode and the interaction effects were all non-significant ($P > 0.05$) (see Fig. 4). Therefore, vibratory stimulation in the second set resulted in an insignificant residual effect in the third set.

Discussion

An increase in contraction strength induced by the tonic vibration reflex has been widely documented. Hagbarth and Eklund (1966), Johnston *et al.* (1970) and Arcangel *et al.* (1971) all reported that muscle force registered during isometric contractions increased because of local vibratory stimulation applied to the muscle or tendon. A similar result was noted by Armstrong *et al.* (1987), who administered 40 Hz superimposed vibration and registered an increase in grip force of 52%. These studies applied vibratory stimulation to muscles which contracted with low to intermediate levels of effort. Matyas *et al.* (1986) reported the facilitation of maximum voluntary contraction caused by 50 Hz tendon vibration in hemiplegic patients. Samuelson *et al.* (1989) reported a reduction in endurance of a maximal isometric contraction and a decrease in maximal force with 20 Hz superimposed vibration, in contrast to the results of the present study.

Three factors may be attributed to the acute vibratory stimulation effect: (1) the motor pool activation, (2) the frequency of vibratory stimulation and (3) the initial length of the stimulated muscles. Matthews (1966) and Brown *et al.* (1967) found that vibratory stimulation excites the primary afferent endings of the muscle spindles which activate α-motoneurons. Unlike local vibratory stimulation, the low-frequency superimposed vibratory wave propagates from the distal links to muscles located proximally and activates a greater number of muscle spindles. Their discharge activates a larger fraction of the motor pool and recruits many previously inactive motor units into contraction.

There is evidence that an increase in vibration frequency evokes a proportional increase in muscle tension (Matthews, 1966). However, the high-frequency component of vibration is absorbed by soft tissues, whereas the low-frequency component propagates through the human body tissues (Pyykko *et al.*, 1976). Therefore, on the one hand, the effect of vibratory stimulation depends on the frequency; on the other hand, low-frequency vibratory waves can only propagate through the kinetic chain to proximal muscle groups and activate them. It is likely that vibratory stimulation at a frequency of 40–50 Hz may be optimal to combine two different tasks: (1) transmission of vibration and (2) muscle activation before and during voluntary contraction (Issurin and Temnov, 1990).

It is known that stretched muscles are more sensitive to vibratory stimulation and contract more strongly (Eklund and Hagbarth, 1966; Johnston *et al.*, 1970; Rohmert *et al.*, 1989). In Samuelson and co-workers' (1989) study, the superimposed vibration was administered during knee-joint extension in the sitting position with a knee angle of 90° (1.57 rad). Hence, the quadriceps muscle was not in a stretched position. This may be one reason why Samuelson *et al.* did not find any facilitatory effect of vibration on maximum isometric contraction. Another reason may be the lower vibratory stimulation frequency of 20 Hz they used. In contrast, the present study was conducted with extremely stretched muscles before each repetition. This could be why we observed a power increase during vibratory stimulation.

Post-vibratory residual effects have also been widely documented in the literature. Arcangel *et al.* (1971) reported a substantial and significant increase in the Achilles tendon reflex after 10 and 20 s tendon vibration. Cafarelli and Layton-Wood (1986) reported an improvement in force sensation in fresh muscles after short-term vibration. The reasons for such effects are probably associated with an increase in the sensitivity of the muscle receptors to excitation. Elevation of muscle temperatures resulting from the friction between vibrating tissues (Oliveri *et al.*, 1989) and vibration-induced increases in blood flow (Wakim, 1985) may also contribute to the post-vibratory effect. In fact, the residual gain in power observed in this study was relatively small and not statistically significant. Relatively short-term vibratory stimulation, as implemented in this study (6–7 s), is probably not sufficient to affect subsequent muscle strength.

The difference in muscle response between the elite and amateur athletes was statistically significant. The average gain in maximal power owing to vibratory stimulation was greater among the elite athletes. The reason for this marked difference may be associated with the higher sensitivity of muscle receptors and the central nervous system of elite athletes to additional stimulation.

In summary, the superimposed vibratory stimulation allowed a significant facilitation of an explosive strength exertion. This approach may be useful in identifying the hidden reserves of an athlete and in augmenting an acute effect of power training.

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