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Effect of vibratory stimulation training on maximal force and flexibility

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In this study, we investigated a new method of training for maximal strength and flexibility, which included [illegible]tion with superimposed vibration (vibratory stimulation, VS) on target muscles. Twenty-eight male athletes were divided into three groups, and trained three times a week for 3 weeks in one of the following conditions: (A) conventional exercises for strength of the arms and VS stretching exercises for the legs; (B) VS strength exercises for the arms and conventional stretching exercises for the legs; (C) irrelevant training (control group). The vibration was applied at 44 Hz while its amplitude was 3 mm. The effect of training was evaluated by means of isotonic maximal force, heel-to-heel length in the two-leg split across, and flex-and-reach test for body flexion. The VS strength training yielded an average increase in isotonic maximal strength of 49.8%, compared with an average gain of 16% with conventional training, while no gain was observed for the control group. The VS flexibility training resulted in an average gain in the legs split of 14.5 cm compared with 4.1 cm for the conventional training and 2 cm for the control groups, respectively. The ANOVA revealed significant pre–post training effects and an interaction between pre–post training and 'treatment' effects ($P < 0.001$) for the isotonic maximal force and both flexibility tests. It was concluded that superimposed vibrations applied for short periods allow for increased gains in maximal strength and flexibility.

Keywords: Flexibility training, muscular strength, vibratory stimulation.

Introduction

The effect of long- and short-term vibration applied to the tendons or to muscle groups is widely documented (Armstrong *et al.*, 1987; Bishop, 1974; Pyykko, 1986). The effects may be negative or positive depending on the specific conditions, such as the task goal, the period of time over which vibrations are applied, and the amplitude and frequency range of the vibration. Curative effects of vibratory treatments have been known for a long time (Granville, 1881). At present, these treatments are widely used in medicine and physiotherapy (Bishop, 1974; Lundeberg *et al.*, 1984; Matyas *et al.*, 1986). Special attention has been given to vibratory stimulation following reports of its effects on muscle contraction (de Gail *et al.*, 1966; Eklund and Hagbarth, 1966; Matthews, 1966).

The vibratory stimulation (VS) effects are attributed mainly to the induced non-voluntary muscular contraction, called the Tonic Vibration Reflex (TVR: Eklund and Hagbarth, 1966). The facilitation of muscular contraction caused by TVR was exploited in some physiotherapeutic techniques. However, the physiotherapeutic approach involves the application of vibratory stimuli locally to a selected muscle or tendon. Such selectivity is not characteristic for the training of athletes who require a more practically appropriate method. Such an approach, in which a vibratory wave is transmitted from distal-to-proximal links of muscle groups, has been developed for some static exercises (Nazarov and Spivak, 1987). Unlike physiotherapeutic treatment, such stimulus transmission activates a large number of muscles and may be applied only at low frequencies. This is because at a high frequency of vibration, there is greater attenuation of the stimulus during its propagation through the human body tissues (Pyykko *et al.*, 1976). The employment of superimposed vibration in dynamic strength exercises would therefore seem to be particularly attractive as a potential means of achieving further gains in muscle strength.

The effects of VS may also be used in flexibility training. It is widely believed by coaches, for example, that stretching exercises must be performed just below an individual's pain threshold (Lycholat, 1990). In this

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regard, induced vibrations affect pain sensations (Lundeberg *et al.*, 1984). Thus, stretching exercises with superimposed vibrations may elevate the pain threshold. Based on the general knowledge gained from the reported investigations, it may be hypothesized that VS may be used as a novel method in physical training. The purpose of this experiment was to determine the influence of this method of training on maximal isotonic force and flexibility.

Methods

Subjects

Twenty-eight healthy male physical education students aged 19–25 years volunteered to participate in the experiment. They were randomly assigned to groups A, B and C (10, 8 and 10 persons, respectively). The mean (±S.D.) physical characteristics of the subjects were as follows: group A (height 177.5±6.4 cm, body mass 73.9±13.5 kg), group B (height 179.1±3.2 cm, body mass 78.5±5.2 kg), group C (height 176.1±2.5 cm, body mass 72.1±7.6 kg). One-way ANOVAs revealed no significant ($P > 0.05$) differences between the groups. All the subjects were physically active and participated in club or college varsity sports such as judo, swimming, volleyball, tennis, soccer, track and field, and cycling. The subjects were informed about the purpose and the procedures of the study. They signed a consent form before the start of the experiment.

Apparatus

The VS device was designed especially for this study. It consisted of an electromotor (1500 W, 2800 rev min^{-1}) that rotated an axis which supported two wheels of different diameter, thus allowing speed reduction (frequencies 44 and 60 Hz). The centre of rotation of the wheel could be displaced eccentrically to 3, 6, 9 and 12 mm. A counter-weight pulley system was used to train and perform the tests. The load was held by a stiff cable, which was passed through the eccentric wheel of the vibratory device via the pulleys. Attached to the far end of the cable, a bar or a ring was used to perform either strength or stretching exercises. During the present experiment, the eccentric oscillations were of 3 mm amplitude, and the frequency of vibration was 44 Hz. After vibration damping due to cable transmission, peak-to-peak oscillations of ending elements were reduced to 0.6–0.8 mm and acceleration was set at ~ 22 m s^{-2} for stretching and ~ 30 m s^{-2} for strength exercises. These parameters were defined using the above characteristics of vibration transmission from distal-to-proximal links (Pyykko *et al.*, 1976), and based on the outcomes of previous investigations (Issurin and Temnov, 1990).

Experimental design

Three groups practised three times a week for 3 weeks under the following conditions: group A, conventional exercises for maximal arm strength and VS exercises for leg flexibility; group B, VS exercises for maximal arm strength and conventional exercises for leg flexibility; and group C, irrelevant training, i.e. calisthenics, running and games (control group). Groups A and B performed the same exercises. The content of each workout differed in the application of VS. The athletes performed a warm-up (7–10 min), a series of maximal arm strength exercises (20–23 min) and a series of leg flexibility exercises (20–23 min).

The sitting bench-pull exercise was employed for strength training. The exercises were performed by the athlete sitting astride a bench, with his chest close to the front part of the bench and the trunk angle 80° to the floor. The athlete's upper body was fixed to the bench by Velcro. A 'Schnell' counter-weight pulley system was used. The subject was required to pull the bar attached to the counter-weight using both arms (see Fig. 1).

Flexibility training included one-leg stretching exercises. The athlete stood on one leg while placing the other in a hanging ring, which comprised a softened surface to the level of the ankle. The subject used a stanchion to support his body. The stretching exercise was performed by moving the leg in the ring forward and/or by squatting on the other leg (see Fig. 1). The height of the hanging ring was set initially according to the anthropometric dimensions of the athlete at the hip-joint level. Each set of stretching exercises consisted of three parts: static stretching (6–7 s of stretching across with 3–4 s rest × 2–4 repetitions); stretching together with body flexion (smooth flexion of the body to the straight leg placed within the ring for 6–7 s with 3–4 s rest × 2–3 repetitions); ballistic stretching across (bouncing movements at a rate of 30 bounces min^{-1} lasting 10–30 s). The sets for the right and left leg were performed consecutively.

The basic part of the workout for groups A and B consisted of: (1) Six sets of sitting bench-pulls (2.0–3.5 min rest between sets) with the load gradually being increased from 80 to 100% of one-repetition maximum (1-RM). Each set was performed to temporal exhaustion. (2) Six sets of stretching exercises with the duration of exercise increasing from 40–45 s to 70–90 s (2.0–2.5 min rest between sets). Thus, the net work time was 2 min for the strength exercises and 7 min for the two-leg stretching exercises. The superimposed vibration was administered as flexibility exercises per-

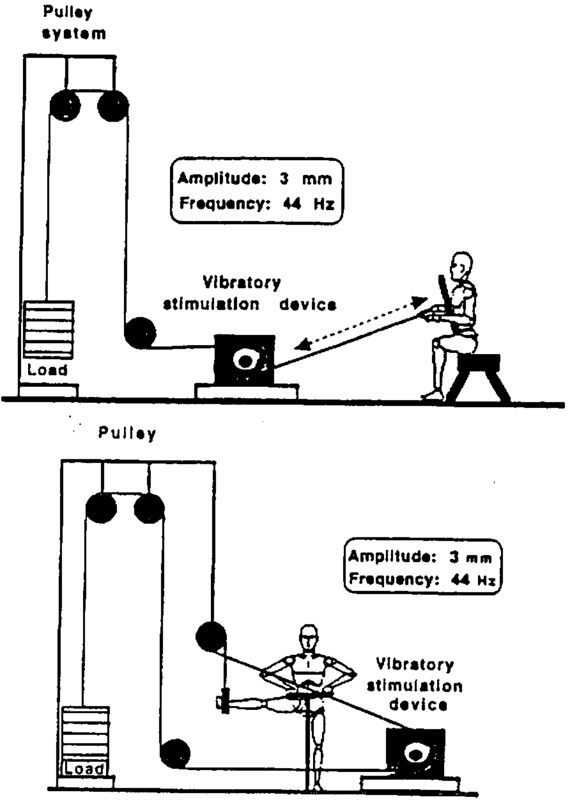


Figure 1 (Top) Apparatus and strength exercises; (bottom) apparatus and flexibility exercises.

formed by group A and as strength exercises performed by group B.

The control group C (irrelevant exercises) performed the warm-up exercises for 7–10 min, followed by listhenics without arm strength exercises or leg xibility exercises for 22–25 min. Then the subjects ged and/or played a basketball game (20–23 min). Each group's total workout lasted approximately 55 min.

The pre- and post-training tests included:

1. *Isotonic sitting bench-pulls.* This exercise was the same as that used in training. The subjects pulled the bar smoothly and uniformly along a controlled range of motion. A number of attempts were performed to achieve the 1-RM value. Full recovery was then allowed.
2. *Two-leg split across exercise.* Standing with their backs close to the wall, the subjects spread their legs as wide as possible, whereupon heel-to-heel length was measured within an accuracy of ±0.5 cm. During these measurements, the subjects kept their trunk position supported with their arms on the floor.
3. *Flex-and-reach test.* The subjects flexed their hip–trunk joint forward (Lycholat, 1990), and the distance between their fingertips and a horizontal mark at foot level was measured within an accuracy of ±0.5 cm.

The flexibility tests were performed twice with the best score being recorded.

Statistical analysis

A series of two-way, repeated-measures ANOVAs (2 pre–post × 3 treatment factors) was carried out for each of the dependent variables in the study. Descriptive statistics were also incorporated. The probability level was set at $P<0.05$.

Results

The statistics for the subjects in the three groups before and after treatment are presented in Table 1 for the physical measures used in this study.

The ANOVA applied to the isotonic 1-RM value for sitting bench-pull showed significant main effects for the treatment ($F_{2,25}=6.90$, $P<0.005$) and pre–post ($F_{1,25}=143.39$, $P<0.001$) factors. Their interaction ($F_{2,25}=61.16$, $P<0.001$) was also significant. The VS strength treatment resulted in an average increase of 49.8%, whereas the conventional strength training resulted in a 16.1% increase. As expected, the control group showed no gain in 1-RM. The differences between the VS strength and VS flexibility treatments were also significant in favour of the VS treatment. Figure 2 illustrates these results. The descriptive statistics of the two flexibility tests (split and trunk flexion) in the three treatment groups are displayed in Fig. 3.

The ANOVA applied to the split gain values revealed a significant pre–post effect ($F_{1,25}=73.65$, $P<0.001$), and also a treatment × pre–post interaction ($F_{2,25}=24.49$, $P<0.001$). The split values were on average significantly higher at the end of the training than at the beginning. However, the VS flexibility treatment resulted in a mean increase of 8.7%, compared with a 2.4% mean increase for the conventional group and a 1.2% increase for the control group.

Similar results were obtained for the trunk flexion component, that is, a significant pre–post effect ($F_{1,25}=30.74$, $P<0.001$) and a treatment × pre–post interaction ($F_{2,25}=7.32$, $P<0.005$). The VS flexibility group achieved a mean gain of 43.6%, compared with 19.2% and 5.8% gains for the VS strength (i.e. conventional flexibility) and control groups, respectively.

Discussion

Effect of VS on maximal force

From our results, force enhancement may be attributed to the neuromotor effect of VS. The vibratory wave

Table 1 Marginal pre–post means (±S.D.) of subjects in different training conditions

Group/parameter	Sitting bench-pull (kg)	Legs split (cm)	Trunk flexion (cm)
Conventional strength/VS flexibility			
Pre-test	88.25±12.48	166.75±12.05	10.90±5.55
Post-test	102.50±15.55	181.25±8.66	15.65±4.41
VS strength/conventional flexibility			
Pre-test	84.69±7.84	171.63±7.67	11.06±5.53
Post-test	126.88±18.84	175.81±7.71	13.19±5.16
Control (irrelevant training)			
Pre-test	85.25±8.70	169.30±13.20	11.95±5.98
Post-test	84.75±8.54	171.30±11.88	12.65±5.50

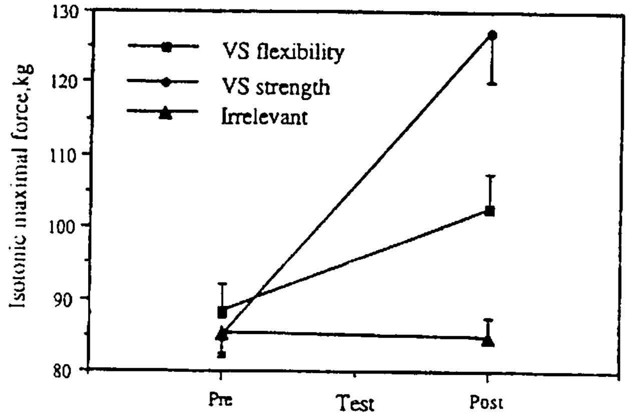
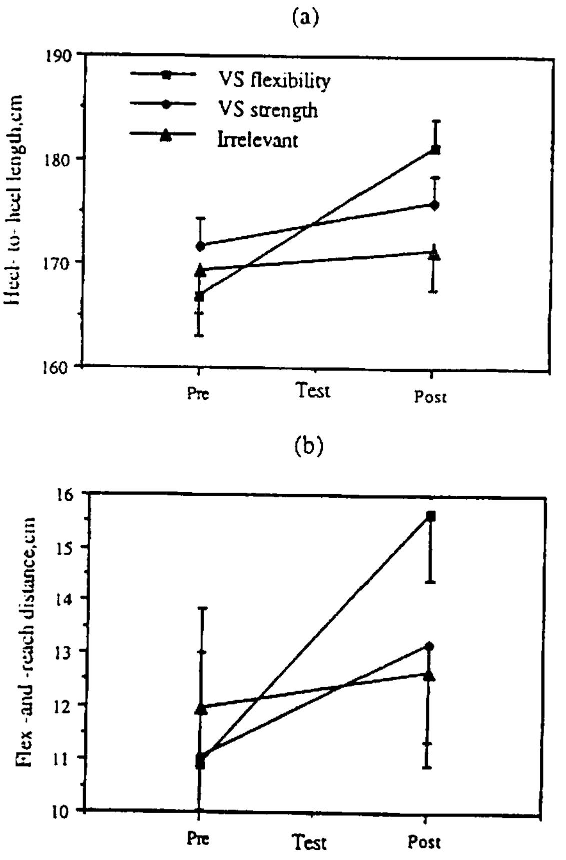


Figure 2 Mean (±S.D.) gains in isotonic maximal force after 3 weeks of training in the three treatment groups.



(a)

(b)

Figure 3 Mean (±S.D.) gains in flexibility in the two-leg split across (a) and flex-and-reach tests (b) in the three treatment groups.

irritates muscle receptors and in particular the primary endings of muscle spindles (Eklund and Hagbarth, 1966). Their discharge activates a larger fraction of the motoneuron pool and recruits previously inactive motor units into contraction (Bishop, 1974; Granit, 1970). At a vibration frequency of 40 Hz, the motoneurons may become synchronized (Homma *et al.*, 1970; de Gail *et al.*, 1966). This may result in a more efficient use of the force production potential of the muscle groups involved.

Muscle tension increases as the discharge increases, which is characterized by a change in frequency or neural input to the muscles. Its maximum for isometric and concentric muscular contraction is within 40–50 pulses per second (Adrian and Bronk, 1929; Bjork and Kugelberg, 1953). The VS frequency of 44 Hz used in this experiment corresponds to these reported values. Vibratory stimulation at lower frequencies (e.g. 20 Hz) failed to increase the force in maximal isometric leg extension (Samuelson *et al.*, 1989). Therefore, recruitment of previously inactive motoneurons, their activity synchronization, and increased discharge of neural drive could improve neuromotor control during voluntary muscle contraction.

The motor learning effect seems to be the major factor of such force increment in a relatively short period of training. It is well known that initial high rates of increase in muscle strength occur mainly at the expense of the neural factor (Klausen, 1990). The present results suggest that this 'learning' effect may be augmented by VS.

Effect of VS on flexibility

Three factors should be considered during flexibility training: increase in pain threshold, blood flow accompanied by temperature increase, and relaxation of the stretched muscle induced by the vibrations. The reduction in pain during the performance of stretching exercises was, in our opinion, the major factor contributing to the positive effect found following VS training. There is evidence to show that VS has analgesic effects during and after the immediate application of such stimuli to muscle or tendon (Lundeberg *et al.*, 1984). The subjects in our experiment reported that sensations of pain were reduced 10–15 s after the beginning of static stretching during which vibration was applied. Also, muscle vibration enhances local blood circulation, and thus generates additional heat (Wood, 1974; Wakim, 1985). This effect during stretching exercises benefits from this by-product of vibrations, particularly because the warm-up itself enhances muscle elasticity and facilitates flexibility. Neurophysiologically, the effects of VS observed during flexibility training are caused by stimulation of the Golgi tendon organs. Unlike the muscle spindles, excitation of the Golgi tendon organs results in inhibition of the contraction, followed by relaxation of the muscle (Fox and Matthews, 1981). It is this muscular relaxation that was exploited during stretching with VS.

The negative effects of exposure to vibration were also considered during this experiment. According to the epidemiological studies of Miyashita *et al.* (1983), the appearance of the initial symptoms of vibration syndrome depends on the total operating time with a vibrating hand-tool. Such symptoms appeared after 2000 h with 2–8 h of daily exposure. The latent interval of vibration symptoms depends also on the weighted acceleration of the tool (Brammer, 1986). An acceleration equal to 30 m s^{-2}, as was applied during the strength exercises in this study, may create such symptoms after 2 years of occupational exposure. The weekly vibration exposure in the present experiment was about 6 min for strength exercises and about 21 min for stretching. This is at least 50–100 times lower than in such occupational settings. Thus, the risk of the adverse effect of vibration created by the use of VS exercises is probably negligible. Nevertheless, more research needs to be conducted in this direction.

In conclusion, it was found that novel VS exercises for both strength and flexibility had significant training advantages over the conventional isotonic mode. In addition, the subjects did not report any of the negative effects attributed to VS.

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