Eur J Appl Physiol (2003) 88: 472–475
DOI 10.1007/s00421-002-0723-0

SHORT COMMUNICATION

C.J. de Ruiter · R.M. van der Linden
M.J.A. van der Zijden · A.P. Hollander · A. de Haan

Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise

Accepted: 2 September 2002 / Published online: 9 November 2002

Abstract Whole-Body vibration (WBV) may lead to muscle contractions via reflex activation of the primary muscle spindle (Ia) fibres. WBV has been reported to increase muscle power in the short term by improved muscle activation. The present study set out to investigate the acute effects of a standard WBV training session on voluntary activation during maximal isometric force production (MVC) and maximal rate of force rise (MRFR) of the knee extensors. Twelve students underwent a single standard WBV training session: 5×1 min vibration (frequency 30 Hz, amplitude 8 mm) with 2 min rest in between. During vibration, subjects stood barefoot on the vibration platform with their knees at an angle of 110°. At 90 s following vibration, maximal voluntary knee extensor force was reduced to 93 (5)% [mean (SD), $P<0.05$] of baseline value and recovered within the next 3 h. Voluntary activation remained significantly depressed (2–4%). Neither the electrically induced MRFR nor voluntary MRFR were significantly affected by WBV. In addition, six WBV training sessions in 2 weeks ($n=10$) did not enhance either voluntary muscle activation during MVC [99 (2)% of the baseline value] or voluntary MRFR [98 (9)% of the baseline value]. It is concluded that in the short term, WBV training does not improve muscle activation during maximal isometric knee extensor force production and maximal rate of force rise in healthy untrained students.

Keywords Electrical stimulation · Whole-body vibration · Recovery · Training

C.J. de Ruiter (✉) · R.M. van der Linden
M.J.A. van der Zijden · A.P. Hollander · A. de Haan
Vrije Universiteit,
Van der Boechorststraat 9,
1081 BT Amsterdam,
The Netherlands
E-mail: c_j_de_ruiter@fbw.vu.nl
Tel.: +31-20-4448578
Fax: +31-20-4448529

Introduction

During recent years there has been a great increase in the use of vibrating platforms as a training device for (recreational) athletes and patients. Ten days of whole-body vibration (WBV) exercise has been shown to increase maximal jump height (Bosco et al. 1998). Even following a single WBV training session, leg extensor muscle power (Bosco et al. 1999, 2000) and countermovement jump height increased (Bosco et al. 2000), although decreased jump performance has also been found (Rittweger et al. 2000).

It has been suggested that the effects of WBV on muscle performance are elicited via reflex muscle activation (Rittweger et al. 2000) leading to "neurogenic adaptation" (Bosco et al. 2000). Indeed, skeletal muscle can be forced into a contraction by prolonged percutaneous mechanical vibration of the muscle belly or, more commonly, the distal tendons. This so-called tonic vibration reflex is induced mainly through activation of the primary muscle spindle (Ia) fibres (Roll et al. 1989). However, it is unclear to what extent WBV will elicit reflex muscle activation and how this would lead to the short-term neurogenic adaptations and improved performance that have been reported (Bosco et al. 1998, 1999, 2000).

To date there is only limited data on the effect of a single standard WBV training session on muscle contractile properties and activation. The present study set out to investigate the acute effects of a standard WBV training session on voluntary activation during maximal isometric force production (MVC) and maximal rate of isometric force rise (MRFR) of the knee extensors. In addition, the effects of a 2-week training program on activation during MVC and MRFR were investigated.

MRFR is an important parameter in relation to instantaneous maximal power production, which is required during maximal explosive movements such as jumping. In the present study, maximal voluntary attempts and (superimposed) maximal electrical stimulation were performed to clarify whether the origin of any changes would be located centrally (in the nervous system) or peripherally (in the muscle). Recovery was studied over a 3-h period following a single training session. Knowledge about muscle fatigue and recovery following WBV is in itself of interest for the development of training programs, especially because WBV training is not only performed by well-trained elite athletes, but increasingly more by recreational athletes, patients and the elderly, who may be at risk for injury during WBV.

Methods

Twelve untrained students (seven male) 23.3 (4.2) years of age [mean (SD)] gave their informed consent to participate in this study, which received local ethical committee approval.

Following habituation to the test procedures, the subjects came to our laboratory to assess baseline values on 2 separate days (3–5 days in between). On the 2nd day the assessment of baseline values was followed by a standard WBV training session and measurements during recovery. In addition, ten of the subjects followed a 2-week WBV training protocol (see below), and for these subjects knee extensor contractile properties and activation were also obtained on a 3rd test day, which was 3 days following the final training session.

The baseline contractile knee extensor properties of the left leg were investigated following fixation of the subjects on a rigid chair with hip and knee angle set at 90°. Knee extensor force was measured at the shin, which was strapped to a transducer placed 27 cm distally from the knee joint. Unless otherwise indicated, there was always 3 min rest in between contractions. Maximal voluntary contraction (MVC) force was determined as the highest value from three to six maximal voluntary knee extensions lasting approximately 2 s.

Constant-current electrical stimulation (always 200 µs pulses and 200 Hz stimulation frequency) was applied using a computer-controlled stimulator (model DS7, Digitimer, Welwyn Garden City, UK) and a pair of self-adhesive surface electrodes (8 cm×13 cm, Schwa-Medico, 283100, The Netherlands) placed transversely over the upper and lower thigh. Current strength was increased until 50% of MVC was produced during a tetanic train of 700 ms duration. This was followed by determination of the maximal force-generating capacity of the muscle (MFGC). The MFGC is the maximal isometric force expected if a subject could activate all muscle fibres maximally, and it was determined as follows: a short 80 ms tetanic train was applied to the resting muscle, followed by superimposition on a MVC (de Haan et al. 2000). Voluntary activation (%) was defined as MVC/MFGC×100%. Subsequently, the stimulation current was adjusted (slightly increased) such that during a 700-ms tetanic train, force reached 50% of the muscles' MFGC. The muscle was stimulated tetanically three times. The stimulated maximal rate of force rise (sMRFR) was taken as the maximum of the positive filtered (30 Hz filter frequency) differentiated force signal of the fastest contraction and is expressed as a percentage of maximal tetanic force (%F_{max}/ms). Voluntary maximal rate of force rise (vMRFR) was obtained from the best of six attempts (duration <500 ms, 15 s in between) during which the subject was encouraged to contract the knee extensors as fast as possible from a fully relaxed state to over 80% of MVC values. vMRFR is expressed as a percentage of MFGC (%MFGC/ms).

On the 2nd test day (always a Monday) the procedure described above was followed by a standard WBV training session: 5×1 min vibration (frequency 30 Hz, amplitude 8 mm) with 2 min rest in between. During vibration, subjects stood with bare feet on a vibration platform (Galileo 2000, Novotec-Germany) with their knees at an angle of 110°. The vibration protocol used is similar to that used by Bosco et al. [i.e. sets of 60 s vibration with amplitudes of 10 mm (Bosco et al. 1999) and 4 mm (Bosco et al. 2000)]. Following vibration, subjects were seated on chair to evaluate the acute post-vibration effects on knee extensor contractile and activation properties. Measurements were performed 1.5, 30, 60 and 180 min following vibration. Between the 60- and 180-min measurement times, the subjects were allowed to sit on a more comfortable chair. The following four measurements were made at each time point, with 1 min rest in between: a MVC with superimposed tetanic stimulation, assessment of vMRFR (six attempts 15 s in between), 700-ms tetanic stimulation, a second MVC with superimposed stimulation. The sequence of these four measurements was different for each subject, but kept the same within each subject over time.

Ten of the subjects performed an additional five training sessions within the following 2 weeks (Wednesday, Friday, Mon, Wed, Fri) and their knee extensor performance was again assessed on the following Monday.

Data are presented as means (SD). Analysis of variance for repeated measures was used to test for statistical differences ($P<0.05$) over time. When significant differences were found, simple contrasts were used to locate the differences compared to baseline values.

Results

Baseline knee extensor contractile and activation values obtained on the 1st and 2nd test day were very similar, which suggests that any possible learning effects had been successfully overcome during the preceding habituation trial (Table 1).

Ninety seconds following WBV, the relative decline in MVC was somewhat greater ($P<0.05$) than the decline in MFGC, suggesting that following vibration the ability of subjects to activate their knee extensors during a maximal voluntary contraction was somewhat depressed (Table 1). Indeed, voluntary activation significantly declined from 95 (2)% before vibration to 90 (4)% at 90 s. Although MVC and MFGC were no longer statistically depressed at 180 min following vibration, voluntary activation had not yet recovered at that time [91 (5)%, $P<0.05$]. At 90 s following vibration, voluntary as well as stimulated maximal rates of force rise (MRFR) were not different from baseline values (Table 1). At no time during the 3 h following WBV was there a tendency for any of the parameters to increase above baseline values.

As expected, 2 weeks of WBV training did not enhance performance of the muscle itself: post-training values of MFGC and sMRFR were not different from baseline values (Table 1). However, there was also no indication of improved muscle activation during voluntary effort: MVC, voluntary activation and vMRFR were unchanged (Table 1).

Discussion

A 7% reduction in MVC 90 s following a single WBV training session is in line with the work of Rittweger et al. (2000). They reported about a 9% reduction in voluntary maximal knee extensor force 2 min following

Table 1 Short-term effects of whole-body vibration (WBV). Contractile parameters means (SD) of knee extensors of two baseline measurements (absolute values) and at 90 s, 30 min, 160 min and 180 min following a single standard WBV training session expressed as a percentage of baseline 2 values (=100%, $n=12$). The right-most column shows post-training values (percentage of baseline 2) following 2 weeks of WBV training ($n=10$). Values for maximal voluntary isometric force (*MVC*), maximal force generating capacity (*MFGC*), the percentage of MFGC the subjects delivered during a MVC (*vol. act.*), maximal rate of isometric force rise during 200 Hz electrical stimulation (*sMRFR*) and maximal rate of isometric force rise during voluntary attempts (*vMRFR*) are given. (F_{max} Maximal force)

Time	Baseline 1	Baseline 2	90 s (%)	30 min (%)	60 min (%)	180 min (%)	Post-training (%)
MVC	906 (235) N	903 (235) N	93 (5)*	90 (8)*	93 (10)*	94 (7)	100 (11)
MFGC	949 (248) N	939 (253) N	96 (6)*	94 (7)*	95 (7)*	97 (6)	101 (11)
vol. act.	95 (2)%	95 (2)%	96 (3)*	96 (3)*	97 (4)*	98 (4)*	99 (2)
sMRFR	1.34 (0.16)% F_{max}/ms	1.34 (0.22)% F_{max}/ms	104 (7)	96 (16)	94 (15)	96 (11)	100 (14)
vMRFR	0.88 (0.15)% F_{max}/ms	0.89 (0.16)% F_{max}/ms	104 (12)	99 (11)	99 (10)	95 (11)	98 (9)

*Statistically different from baseline 2 value ($P<0.05$)

WBV exercise. The present study shows that about half of the 7% decrease in MVC was due to a decline ($P<0.05$) in voluntary drive and that MVC recovered within 3 h.

A single WBV training session did not affect MRFR, values remained unchanged during the 3 h following vibration. At 90 s, MVC was depressed, but MRFR was not. This may be related to a vibration-induced increase in muscle temperature, which could have countered any fatiguing (slowing) effect of WBV (de Ruiter et al. 1999). In principal, voluntary MRFR (and MVC) could also have been affected by changes in co-contraction of the hamstrings following vibration. Although we measured neither muscle temperature nor co-activation, the net outcome of these (and any other potential) effects did not, at any time, lead to a significant increase of leg extension performance following WBV. In line with the present results, Rittweger et al. (2000) found reduced jump height 10 s following vibration, which recovered within 15 min but never exceeded baseline values. In contrast, increased leg extension power and countermovement jump height were found immediately following a single WBV training session (Bosco et al. 1999, 2000).

Any positive effects of 2 weeks of WBV training on MVC and vMRFR were expected to be of neural origin. However, MVC force remained stable, and although baseline voluntary activation during MVC already was high (95%) in our subjects, leaving only a 5% room for improvement, activation did not increase. Moreover, 2 weeks of WBV training did not bring vMRFR (0.89% of maximal force/ms) closer to sMRFR (1.34% of maximal force/ms), which would have occurred if activation had improved. The present findings do not support the results of Bosco et al. (1998), who found increased jump heights following 10 days of WBV training, and who suggested that activation of the muscles had improved.

It is difficult, however, to see how WBV would lead to neural adaptations and enhanced performance. Firstly, motoneuron recruitment in response to direct muscle tendon vibration is rather limited, probably because vibration also elicits a certain level of presynaptic Ia inhibition, which brakes the further recruitment of motoneurons (Desmedt and Godaux 1978). Secondly, during WBV the vibration is applied on the sole of the feet and each joint will have a dampening effect on the vibration stimulus. In addition, vibration causes reciprocal inhibition of the antagonist muscles, and during WBV several leg muscles, both agonist and antagonist, are simultaneously exposed to the vibration stimulus, which may further enhance the inhibitory effects of vibration (Martin et al. 1986). Thirdly, our (unpublished) observation that the leg muscle surface electromyogram signal increased upon WBV by only 10–20% of maximum values, indicates that additional fibre recruitment during WBV is limited. The main conclusion of the present study, that WBV does not improve maximal voluntary muscle activation during MVC and MRFR, is in line with these theoretical considerations.

Acknowledgement The authors are grateful to Martin Huizing for his advice and for providing the Galileo 2000 vibration platform.

References

Bosco C, Cardinale M, Colli R, Tihanyi J, von Duvillard SP, Viru A (1998) The influence of whole body vibration on jumping performance. Biol Sport 15:157–164

Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, Viru A (1999) Adaptive responses of human skeletal muscle to vibration exposure. Clin Physiol 19:183–187

Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A (2000) Hormonal responses to whole-body vibration in men. Eur J Appl Physiol 81:449–454

de Haan A, de Ruiter CJ, van der Woude LH, Jongen PJ (2000) Contractile properties and fatigue of quadriceps muscles in multiple sclerosis. Muscle Nerve 23:1534–1541

de Ruiter CJ, Jones DA, Sargeant AJ, de Haan A (1999) Temperature effect on the rates of isometric force development and relaxation in the fresh and fatigued human adductor pollicis muscle. Exp Physiol 84:1137–1150

Desmedt JE, Godaux E (1978) Mechanism of the vibration paradox: excitatory and inhibitory effects of tendon vibration on single soleus muscle motor units in man. J Physiol (Lond) 285:197–207

Martin BJ, Roll JP, Gauthier GM (1986) Inhibitory effects of combined agonist and antagonist muscle vibration on H-reflex in man. Aviat Space Environ Med 57:681–687

Rittweger J, Beller G, Felsenberg D (2000) Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 20:134–142

Roll JP, Vedel JP, Ribot E (1989) Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. Exp Brain Res 76:213–222