Decrease in maximal voluntary contraction by tonic vibration applied to a single synergist muscle in humans

MOTOKI KOUZAKI, MINORU SHINOHARA, AND TETSUO FUKUNAGA
Laboratory of Sports Sciences, Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Meguro, Tokyo 153-8902, Japan

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Kouzaki, Motoki, Minoru Shinohara, and Tetsuo Fukunaga. Decrease in maximal voluntary contraction by tonic vibration applied to a single synergist muscle in humans. J Appl Physiol 89: 1420–1424, 2000.—The purpose of the study was to examine the effect of prolonged tonic vibration applied to a single synergist muscle on maximal voluntary contraction (MVC) and maximal rate of force development (dF/dtmax). The knee extension MVC force and surface electromyogram (EMG) from the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) during MVC were recorded before and after vibration of RF muscle at 30 Hz for 30 min. MVC, dF/dtmax, and the integrated EMG (iEMG) of RF decreased significantly after prolonged tonic vibration in spite of no changes in iEMG of VL and VM. The present results indicate that MVC and dF/dtmax may be influenced by the attenuated Ia afferent functions of a single synergist muscle.

tonic muscle vibration; synergistic muscles; maximal voluntary contraction; electromyogram

BECAUSE IA AFFERENT FIBERS ARE ACTIVATED AS A RESULT OF α-γ COACTIVATION, EVEN IN ISOMETRIC VOLUNTARY CONTRACTION, the fusimotor drive is required to activate the muscles fully during voluntary contraction. Indeed, Hagbarth et al. (7), who used a local anesthetic agent for attenuating γ-loop functions, have suggested that spindle feedback would be important to generate the high motor unit firing rates in the initial phase of a maximal voluntary contraction (MVC). In addition, Bongiovanni et al. (4) reported that the MVC force of ankle dorsiflexor muscles declined as a result of prolonged tendon vibration. It seems possible that MVC force is reinforced by the Ia afferent discharge originating from muscle spindle. However, because previous experiments have investigated the influence of tendon vibration and anesthetic agent on the contracting muscles as a whole, it is possible that decreases in MVC due to activation of Ib afferents and suppression of voluntary drive would be induced by such a perturbation. To remove these factors, we applied the muscle vibration to a single synergist. This perturbation stimulates the Ia afferent fibers but not the Ib afferent fibers and allows a comparison between vibrated and nonvibrated synergist muscles. Furthermore, a recent study (10) points out that vibration applied to a muscle or its tendon induces significant augmentation of motor-evoked potentials elicited by transcranial magnetic stimulation and suggests that vibration has an effect on motor cortex excitability modulation. The excitability of motor cortex may affect the voluntary drive. Therefore, to investigate the vibration effects on the voluntary drive, we compared the neuromuscular activity of vibrated and nonvibrated muscles.

In the present study, the effect of prolonged tonic vibration of the rectus femoris (RF) muscle on neuromuscular activity of each muscle head of the quadriceps muscle, knee extension MVC, and maximal rate of knee extension force development (dF/dtmax) during MVC was examined.

METHODS

Subjects. Eight untrained subjects (7 men and 1 woman) participated voluntarily in the experiment. Their age, height, and body mass were 25.5 ± 2.7 yr, 167.4 ± 6.3 cm, and 63.9 ± 7.4 kg (means ± SD), respectively. They had no history of neurological disorders. All the subjects gave their written, informed consent to participate in the study after receiving a detailed explanation of the purposes, potential benefits, and risks involved. All procedures were in accordance with the ethical standards of the Committee in Human Experimentation at the Department of Life Sciences, The University of Tokyo.

Recording techniques. The subject was required to perform a static unilateral knee extension contraction in the seated position with the hip and knee joint angles at 90° from full extension. The subject’s upper body was firmly secured to the chair by a seat belt. The force of isometric knee extension contraction was measured by a force transducer connected through a strap around the ankle (Fig. 1). Surface electromyogram (EMG) from the RF, vastus lateralis (VL), and vastus medialis (VM) muscles were recorded using two Ag-AgCl electrodes of a diameter of 5 mm with interelectrode distance of 20 mm. The reference electrode was placed at the iliac crest. The electrodes were connected to a preamplifier and a differential amplifier having a bandwidth of 5 Hz to 1 kHz (1253A, NEC Medical Systems, Tokyo, Japan) to avoid electrical and mechanical noise. The force and EMG signals

Address for reprint requests and other correspondence: M. Kouzaki, Laboratory of Sports Sciences, Dept. of Life Sciences, Graduate School of Arts and Sciences, Univ. of Tokyo, 3-8-1 Komaba, Meguro, Tokyo, Japan 153-8902 (E-mail: kouzaki@idaten.c.u-tokyo.ac.jp).

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were stored on a personal computer for later analysis using a 12-bit analog-to-digital converter (Lab-PC, National Instruments, Austin, TX) with a sample frequency of 1 kHz.

Tonic muscle vibration was applied to the proximal portion of RF using a mechanical stimulator (DPS-260, Dia Medical System, Tokyo, Japan), which fixes to the horizontal metal bar of a metal stand supported by an experimental chair (Fig. 1). To avoid spread of vibration to neighboring synergists, we employed a lower force of application (5–10 N) compared with previous studies (3–5). The vibration frequency was 30 Hz, and the displacement was 2–3 mm.

Experimental protocol. One week before the experiment, each subject was fully trained to generate isometric knee extension MVC. The subjects performed three MVCs lasting 3 s each, with sufficient rest between each trial at intervals of 1 min. The subjects were instructed to exert their maximal force as fast as possible. After the MVC measurements, tonic muscle vibration was applied to the proximal portion of RF for 30 min. Immediately after tonic vibration, MVC measurements were performed again.

Prolonged vibration employed in this study may involve a factor of prolonged sitting. To investigate whether this factor affects the EMG activities and MVC, four subjects also participated in a control experiment. The subjects performed three MVCs before and after prolonged sitting for 30 min without vibration.

Data analysis. Simultaneous recordings of force and EMG signals during MVC were analyzed over a 1-s period of steady force output using a computer. The EMG was collected in the same manner and was full-wave rectified and integrated (iEMG). Moreover, the raw force signal was also low-pass filtered by the moving average method and was differentiated to calculate dF/dt_max. An average value from three successive trials was calculated for each MVC, and the mean and SD values for the eight subjects were determined.

Statistical significance in force and EMG values between before and after vibration was tested using a paired Student's t-test. One-way ANOVA with repeated measures was used to execute significant differences in EMG change rate from before and after vibration among the three muscles. Tukey's test was used for post hoc analysis. The significance level for all comparisons was set at P < 0.05.

RESULTS

During prolonged vibration applied to the RF, action potentials were observed in RF only (Fig. 2). Typical recordings of knee extension force, force development, and full-wave rectified EMGs of RF, VL, and VM during MVC before and after tonic vibration are shown in Fig. 1. Diagram of experimental setup for application of tonic muscle vibration to rectus femoris muscle (RF). See text for further explanation.

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Fig. 2. Typical recordings of displacement of the mechanical stimulator, surface electromyogram (EMG) activity of RF, vastus lateralis (VL), and vastus medialis (VM) during the tonic muscle vibration.
Fig. 3. The force and $dF/dt_{\text{max}}$ significantly decreased during MVC because of the prolonged tonic vibration. The iEMG of RF decreased significantly after vibration, although no significant difference in the iEMG of VL and VM was observed between before and after vibration. The magnitude of the decrease in iEMG of RF was significantly larger than that recorded from VL and VM (Fig. 4).

Fig. 4. Relative change in force, maximal rate of force development ($dF/dt_{\text{max}}$), and iEMG of RF, VL, and VM during MVC by tonic vibration (solid bars). Open bars indicate control experiment. *Significant difference ($P < 0.05$) for RF muscle.
We also examined whether there was any influence of prolonged sitting on the knee extension MVC. No difference was observed in MVC, dF/dt_max, and iEMG of quadriceps muscle between before and after prolonged rest (Fig. 4). This indicates that there was no effect from the 30-min period on MVC.

DISCUSSION

The results of the present study demonstrated a decreased knee extension MVC force after prolonged tonic vibration to the RF muscle. Moreover, similar decreases were observed in the EMG activity of RF. Bongiovanni et al. (4) reported that the decrease in dorsiflexion MVC was accompanied by a decline in EMG activity of the working muscles during vibration applied over the tendon. However, even high-frequency tendon vibration would induce activation of Ib afferent fibers (8). Moreover, Avela et al. (2) recently presented evidence of a decreased plantar flexion torque after prolonged and repeated passive stretching of the triceps surae muscle. The protocol employed in that study might cause compliance changes in both target muscles and tendons as well as metabolic changes in the extrafusal muscle fibers (1). In the present study, muscle vibration was employed to eliminate these problems. Previous studies have provided evidence that prolonged vibration causes attenuated functions in Ia afferents due to integrated results of the mechanisms, such as presynaptic inhibition of Ia terminals (9), an increased firing threshold of Ia fibers (8), and transmitter depletion (6). On the basis of results obtained from recordings of firing rates of motor units, Bongiovanni et al. (4) suggested that the above mechanisms induce a reduction of afferent link of the γ-loop support to voluntary contraction and thereby cause attenuation of an ability to generate firing of high-threshold motor units. In the present study, therefore, muscle vibration-induced MVC would be related to an attenuation of Ia afferent function, which is caused by presynaptic inhibition, increased firing threshold of Ia fibers, and transmitter depletion.

The recent report using the transcranial magnetic stimulation technique pointed out that the muscle vibration affects motor cortex excitability (10), which may have effects on voluntary drive. To examine whether muscle vibration induces the modulation of voluntary drive, the present study investigated the effects of vibration of a single muscle on neuromuscular activities of synergistic muscles. As demonstrated in Fig. 2, action potentials were found in only RF, and thus it seems likely that the current vibration technique is appropriate for inducing Ia afferent activity in the vibrated muscle only. If the muscle vibration employed in the present study considerably affected cortical sites, EMG activities of all synergistic muscles should change after the prolonged tonic muscle vibration. However, significant change in iEMG was found only in RF. This result implies the possibility that dramatic decrease in knee extension MVC due to prolonged muscle vibration is not related to attenuation of voluntary drive for knee extension, but to the impaired Ia afferent activity of RF.

It is of interest that dF/dt_max during MVC decreased dramatically after tonic vibration although no instruction had been given as to the speed of force development at the onset of voluntary contraction. On the basis of results obtained in single motor unit recordings, Bongiovanni et al. (4) indicated that vibration-induced MVC suppression is primarily affected by the high-threshold motor units and not by the low-threshold ones. According to Hagbarth et al. (7), there is an inability to generate high-threshold motor units with high firing rates at the initial phase of MVC. Thus the lack of afferent feedback from muscle spindles may limit the excitation of high-threshold motoneurons. Therefore, an inability for excitation of high-threshold motoneurons at the onset of contraction would probably be related to the decrease in dF/dt_max. In fact, by observing the EMG activity of RF shown in Fig. 2, it seems that the larger EMG bursts at the onset of contraction disappear after vibration. Judging from these findings, the dF/dt_max observed in the present study could support the idea that vibration-induced MVC suppression was not attributable to α-motoneuron inhibition but rather to a decrease in the accessibility of motoneurons to the voluntary commands.

In conclusion, this study showed that declines in force and dF/dt_max during MVC were caused by muscle vibration to RF. Because the muscle vibration employed in this study did not affect the neuromuscular activity of the nonvibrated VL and VM muscles, it seems that the current technique may induce selective attenuation of Ia afferent fibers originating from the vibrated muscle.

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REFERENCES

