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# Effects of prolonged vibration to vastus intermedius muscle on force steadiness of knee extensor muscles during isometric force-matching task

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ABSTRACT

Afferent inputs from Ia fibers in muscle spindles are essential for the control of force and prolonged vibration has been applied to muscle-tendon units to manipulate the synaptic input from Ia afferents onto α-motor neurons. The vastus intermedius (VI) reportedly provides the highest contribution to the low-level knee extension torque among the individual synergists of quadriceps femoris (QF). The purpose of the present study was to examine the effect of prolonged vibration to the VI on force steadiness of the QF. Nine healthy men (25.1 ± 4.3 years) performed submaximal force-matching task of isometric knee extension for 15 s before and after mechanical vibration to the superficial region of VI for 30 min. Target forces were 2.5%, 10%, and 30% of maximal voluntary contraction (MVC), and force steadiness was determined by the coefficient of variation (CV) of force. After the prolonged VI vibration, the CV of force at 2.5%MVC was significantly increased, but CVs at 10% and 30%MVCs were not significantly changed. The present study concluded that application of prolonged vibration to the VI increased force fluctuations of the QF during a very low-level force-matching task.



## 1. Introduction

It is important that the relation between the capacity to maintain steady force during submaximal contractions and postural stability or mobility. Force steadiness has thus been used as an index to study adaptations in neuro-motor control (Clark et al., 2007; Durbaba et al., 2013; Enoka et al., 1999; Shinohara et al., 2003; Tracy and Enoka, 2002). In a single-agonist system, timing and variability in motor unit discharges determine the force fluctuation (Moritz et al., 2005). The activation profile of synergistic muscles affects the fluctuations in joint torque, which involve the summation of force fluctuations from several individual muscles (Shinohara et al., 2009). The activation pattern of individual synergists would therefore affect the force steadiness of multiple-agonists muscles.

The quadriceps femoris (QF) muscle group is well known to play an essential role as an anti-gravity muscle in daily physical activities. The vastus intermedius (VI) muscle occupies 30% of the volume of QF muscles (Akima et al., 2007; O'Brien et al., 2010). Given that muscle volume is the major determinant of torque capacity (Fukunaga et al., 2001), the VI muscle could jointly account for about one-third of the torque generated in the knee. However, during isometric low-level torque generation, VI contributed up to 50% of knee extension torque from the QF (Zhang et al., 2003). A study of amputated limbs has also identified VI as the most efficient synergist among individual QF muscles in extension of the cadaveric knee (Lieb and Perry, 1968). From these previous reports, the VI during low-level contraction would represent a significant contributor to torque-generation among the four QF synergists.

When we attempt to match a target during steady low-level contraction, afferent inputs from group Ia fibers in muscle spindles are essential for the control of muscle force (Freund, 1983; Kakuda et al., 1996; Shinohara, 2005). Prolonged mechanical vibration has been applied to muscle-tendon units to amend the excitatory synaptic input from Ia afferents to α-motor neurons (Fry and Folland, 2014; Kouzaki et al., 2000; Roll et al., 1989; Shinohara, 2005; Yoshitake et al., 2004). The vibration technique could induce selective attenuation of Ia afferent fibers originating from the

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vibrated muscle and tendon (Jackson and Turner, 2003; Kouzaki et al., 2000; Saito et al., 2016; Shinohara, 2005). Prolonged patellar tendon vibration did not change fluctuations of knee extensor force during a force-matching task (Saito et al., 2016). However, the effects of prolonged vibration to a synergist muscle on force steadiness during steady contraction are still unclear.

The purpose of the present study was to examine the effect of prolonged vibration to the VI muscle on the force steadiness of knee extensors during a force-matching task. We hypothesized that prolonged vibration to the VI increases force fluctuations in the knee extensor muscles during an isometric force-matching task.

## 2. Materials and methods

### *2.1. Participants*

Nine healthy men provided written informed consent to participate in the present study after receiving an explanation of the procedure, purposes, risks, and benefits associated with the study. Mean ± standard deviation (SD) age, height, and weight of the participants were 25.1 ± 4.3 years, 174.1 ± 5.3 cm and 73.5 ± 8.0 kg, respectively. The Ethics Committee for the Research Center of Health, Physical Fitness & Sports at Nagoya University approved the experimental protocols, which were conducted in accordance with the guidelines in the Declaration of Helsinki.

### *2.2. Experimental protocol*

The participants attended our laboratory for familiarization trials at least 1 week before testing. Participants performed maximal voluntary contractions (MVC) for isometric knee extension and submaximal force-matching tasks before and after vibration of the VI muscle for 30 min. Before MVC measurement, M-wave response was evoked by femoral nerve stimulation.

The prolonged vibration employed in the present study may involve prolonged maintenance of a body posture. To investigate whether this factor affects MVCs, electromyographic (EMG) signals, or force steadiness, eight participants also performed the MVC and force-matching tasks before and after prolonged seated rest for 30 min without vibration. These control experiments were performed on a separate day.

### *2.3. Knee extension task*

Participants performed the isometric knee extension MVC and the low-level force-matching tasks at a knee joint angle of 90°. Tasks were performed using a custom-made dynamometer (Takei Scientific Instruments, Niigata, Japan) mounted onto a force transducer (LTZ-100KA; Kyowa Electronic Instruments, Tokyo, Japan). The hip was strapped to the dynamometer, with the hip joint in 110°, and the ankle was attached to a pad linked to the force transducer.

Participants attempted three MVCs before prolonged vibration for the VI. Each MVC lasted approximately 3 s and participants rested for 1 min between attempts. One repetition of the MVC was performed after the vibration. When the generated force reached a plateau, the participants was encouraged by supervisors to further increase the knee extension force. Submaximal force-matching tasks were performed at three different target forces with 30 s rest intervals between trials. Target forces were 2.5%, 10%, and 30% of the pre-vibration MVC and the order of these targets was randomized. Participants maintained knee extension force as steady as possible for 15 s (Clark et al., 2007). Each recording task was completed within 10 min, because depression of H-reflexes in the vastus medialis (VM) remained for at least 10 min after patellar tendon vibration for 30 min (Fry and Folland, 2014). The produced force was shown to the participant on a personal computer monitor as visual feedback with the target line for reference.

### *2.4. EMG recording*

Surface EMG signals were recorded from the VI, vastus lateralis (VL), VM, rectus femoris (RF), and long-head of biceps femoris (BF) muscles during the isometric contractions using active electrodes. EMG sensors consisting of two silver bars ($0.1 \times 1$ cm each), with a 1 cm inter-electrode distance, were used for EMG acquisition from each muscle. Signals were recorded in differential derivation, with a pre-amplifier gain of 10, input impedance >$10^{15}$ Ω/0.2 pF, and a 92 dB common mode rejection ratio. The DE-2.1 sensor pre-amplifier and main amplifier, with a Bagnoli-8 bandpass filter at 20–450 Hz (Delsys, Boston, USA), were set at gains of 10-fold each, providing 100-fold amplification. Signals were sampled at 2000 Hz (16 bits) using a Power Lab analog-to-digital converter (ADInstruments, Melbourne, Australia) and synchronized with the force data on a personal computer using Chart 5.5 software (ADInstruments).

Electrodes were positioned at specific locations for each muscle, after shaving, abrading, and cleaning skin with alcohol. Electrodes for VL and VM were placed 8–10 cm proximal and lateral to the patella, and 3–5 cm proximal and medial to the patella, respectively (Rainoldi et al., 2004). Electrodes for RF and BF were placed at the mid-point between the anterior superior iliac spine and superior patellar pole, and at the mid-point between the ischial tuberosity and lateral femoral epicondyle, respectively. We determined the superficial regions of VI and BF using Logiq e ultrasonography (GE Healthcare, Duluth, USA). We identified the superficial region of VI at a knee joint angle of 90° under ultrasound guidance (Akima et al., 2012; Saito et al., 2013, 2015; Watanabe and Akima, 2009) and marked the location on skin (Fig. 1). Electrode for VI was positioned on skin over the superficial region of the VI. All electrodes were oriented as much as possible in parallel with the estimated direction of muscle fascicles. A reference electrode was placed over the iliac crest.

### *2.5. Vibration*

Following the pre-vibration force-matching tasks, the participant was asked to relax and remained seated in the experimental

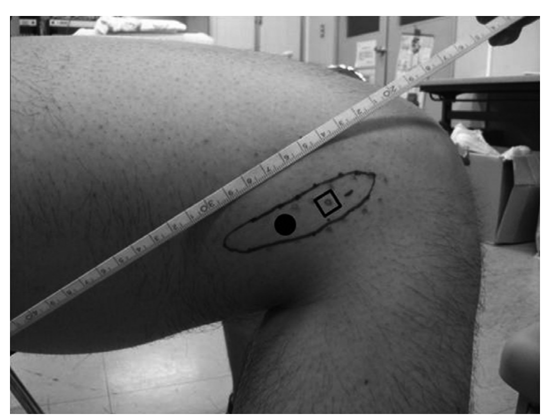

**Fig. 1.** Representative image of the superficial region of vastus intermedius muscle marked under the guidance of ultrasonography. The square with black outline represents actual size of the surface electromyographic electrode and corresponds to the location of electrode attachment. The black circle indicates the location of the plastic shaft of the mechanical stimulator.