©Journal of Sports Science and Medicine (2009) **8,** 548-552
http://www.jssm.org

Research article

Effects of prolonged tendon vibration stimulation on eccentric and concentric maximal torque and EMGs of the knee extensors

Yu Konishi [1]✉, Junjiro Kubo [2] and Akinori Fukudome [1]
[1] Department of Physical Education, National Defence Academy, Kanagawa, Japan, [2] Faculty of low, Heisei International University, Saitama, Japan.

Abstract
The purpose of present study was to compare the effect of Ia afferent attenuation on the activity of alpha motor neuron (MN) during concentric and eccentric action. Eight male subjects were enrolled in the present study. The experiments consisted of two sessions of MVC measurements, since all subjects performed both maximal concentric and eccentric action. EMG signals were simultaneously measured. To establish the baseline of strength, subjects were asked to perform MVC of knee extension in each session. After finishing the measurements, 20 min of vibration stimulation was applied. Immediately after finishing vibration stimulation, the MVC and AEMG were again measured. The means of MVC for concentric knee extension at pre and post-vibration stimulation were 192.2 ± 49.3 Nm and 162.3 ± 47.9 Nm, respectively. The means of MVC for eccentric knee extension at pre and post-vibration stimulation were 299.7 ± 77.0 Nm and 247.3 ± 88.6 Nm, respectively. Two-factor repeated ANOVA detected significant differences in the MVC. Both main effects for pre-post condition ($F(1,7)=$, $p = 0.0033$) and action ($F(1,7)=26.35$, $p = 0.0013$) were noted. No interaction effect (action x condition) was noted. The means of AEMG (vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF)) at pre and post -vibration stimulation were decreased. Two-factor repeated ANOVA detected significant differences in AEMG (VM and VL). Both main effects for pre-post condition (VL;$F(1,7)=7.27$, $p = 0.0308$, VM; $F(1,7)=9.55$, $p = 0.0175$) and action ($F(1,7)=12.40$, $p = 0.0097$) were noted in the VL and the VM but not in the RF. Furthermore, significant interaction (action x condition) effect was noted in the VM ($F(1,7)=7.03$, $p = 0.0328$) but not in the VL. The MVC and the EMG activity of the VL in response to the prolonged vibration stimulation were significantly reduced in eccentric contraction over concentric contraction. These results represented that a deactivation effect on the alpha MN of the VL during eccentric action was greater than that of concentric action.

Key words: Concentric contraction, MVC, Vibration stimulation, QF .

Introduction

Many previous studies have demonstrated that there are neurophysiological differences between eccentric contraction and other styles of muscle contraction, such as concentric and isometric contraction (McHugh et al., 2002; Nakazawa et al., 1997; Nakazawa et al., 1998; Romano and Schieppati, 1987). One of these differences is that the discharge rate of Ia afferents from muscle spindles during eccentric contraction is higher than that during other types of muscle contraction, since an eccentric contraction involves the development of tension in the muscle spindle while the whole muscle is being lengthened (Burke, 1978; Ribot-Ciscar and Roll, 1998). However, the output of alpha motor neurons as a result of the stretch reflex, or H reflex, would be reduced even though Ia afferent feedback during eccentric contraction would increase (Nakazawa et al., 1997; 1998; Romano and Schieppati,1987). Therefore, some inhibitory mechanism directed against the motor neuron pool is considered to exist during submaximal eccentric contraction, even though the exact mechanism has not yet been identified. Actually, this inhibitory mechanism is considered to be essential to attaining the steadiness of movement and to adjust the speed of movement during eccentric contraction (Laidlaw et al., 2000; Laidlaw et al., 1999; Tracy et al., 2004). In contrast, when contracting concentrically or isometrically, the shortening of the muscle would slack the intrafusal fibers of the muscle spindle; therefore, the central nervous system would attempt to increase the tension of the muscle spindle and acquire enough Ia afferent feedback via alpha-gamma coactivation rather than inhibit the motor neuron pool. Therefore, this inhibitory mechanism would not exist during concentric contraction.

Thereby, we designed the present study to compare the maximal strength and EMG in response to prolonged vibration stimulation during maximal eccentric action and maximal concentric action for evaluation of the alpha motor neuron activity. According to previous studies (Avela et al., 1999; Bongiovanni et al., 1990; Gandevia, 1998; Kouzaki et al., 2000), Ia afferents are considered to be necessary for recruiting the high-threshold motor unit. Indeed, prolonged vibration stimulation, which would attenuate Ia afferents, was leads to the reduction of maximal strength and integrated electromyography (I-EMG) during isometric contraction (Konishi et al., 2002a; 2002b; Kouzaki et al., 2000) Theoretically, inhibition of the motor neuron pool must largely affect the activity of alpha motor neurons. While previous studies have reported that the motor neuron pool was inhibited during submaximal voluntary eccentric contraction (Nakazawa et al., 1997; 1998; Romano and Schieppati, 1987), it was not known that the motor neuron pool is also inhibited during maximal eccentric contraction. If the motor neuron pool is also inhibited during maximal eccentric contraction, as previous studies have suggested, the attenuation of Ia afferents due to the application of prolonged vibration stimulation might not affect or have less of an effect on the recruitment of high threshold motor units as compared with concentric contraction. The purpose of the present

Received: 05 August 2009 / Accepted: 15 September 2009 / Published (online): 01 December 2009

study is to compare the effect of prolonged vibration on muscle strength and EMG during maximal concentric and eccentric action.

Methods

Subjects

Eight male subjects (age: 18.7 ± 0.4 years, height: 1.67 ± 0.07 m, mass: 63.4 ± 4.9 kg, mean ± SD), were enrolled in the present study. Patients with any knee joint injury were excluded from this study. All subjects in the present study belonged to division I college gymnastic teams. Since they usually land from high places, they are accustomed to a high intensity of eccentric contraction on their quadriceps. All participants gave their informed consent to participate in the study, and all procedures were approved by the Heisei International University ethics committee.

Figure 1. Experimental setup used during torque measurement.

Experimental protocol and maximal voluntary contraction (MVC) measurements

The present study consisted of two sessions of MVC measurement, since all subjects measured both maximal concentric and eccentric contraction. Each session was spaced at least 3 days apart. The order of sessions was randomly assigned to each subject. Additionally, subjects learned to perform maximal voluntary contraction in a practice session before the study measurements were conducted. During measurements, the subjects were in a sitting position with the upper body and thigh kept tightly secured to the seat of the Cybex NORM dynamometer (Cybex, division of Lumex, Inc., Ronkonkoma, New York, USA) by belts (Figure1). The EMG signals from the muscles were simultaneously measured during MVC measurement. For the measurement of concentric contraction, the isokinetic concentric mode was used. The angle velocity and range of motion were set to 30 deg·sec^{-1} and 90 to 0 degrees, respectively. For the measurement of concentric contraction, the isokinetic eccentric mode was used. The angular velocity and range of motion were set to 30 deg·sec^{-1} and 0 to 90 degrees, respectively. To establish the baseline of strength, all subjects were asked to perform MVC of knee extension three times in each session. Then, the highest peak torque was used as the baseline of strength, were calculated. After finishing torque measurements, 20 min of vibration stimulation was applied. Immediately after finishing vibration stimulation, the MVC of knee extension were measured again using the same method as that used for pre-vibration measurements. Since the effect of the prolonged vibration on the muscle contraction was very important for the purpose of present study, subjects were asked to perform one maximal contraction immediately after finishing the vibration stimulation.

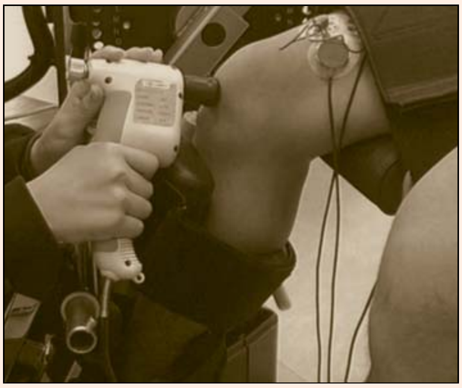

Figure 2. Experimental setup used during vibration stimulation.

Vibration method

The method of vibration administration described by Kouzaki et al. (Kouzaki et al., 2000) was used in the present study. Briefly, subjects sat on the seat of the Cybex NORM dynamometer (Cybex, division of Lumex, Inc., Ronkonkoma, New York, USA) with their legs hanging down from edge of the seat. They were asked to relax their thighs as much as possible during the application of vibration. Vibration stimulation was applied manually to the mid-portion of the infrapatellar tendon using the Hit Masser (Sun.R Co., Tokyo) (Figure 2) to induce attenuation of Ia through the tonic vibration reflex of the quadriceps muscle. The frequency, amplitude, force of application, and duration of vibration stimulation were modified in this study. Theoretically, the induction of Ia discharge is necessary to induce effective attenuation of the Ia afferents. However, the vibration protocol of Kouzaki et al. is less effective in inducing Ia discharge than that used in previous studies (Bongiovanni et al., 1990; Burke et al., 1976; Hagbarth et al., 1986; Roll and Vedel, 1982; Roll et al., 1989). Therefore, we conducted a pilot study to design a protocol that could effectively result in a reduction in MVC and I-EMG. The selected vibration frequency was 50 Hz, which resulted in 1.5 mm displacement which is width of moving head. The force and duration of application were approximately 30 N and 20 min, respectively.

Electromyography recording

Electromyography (EMG) was performed on the vastus medialis (VM), vastus lateralis (VL), and the rectus

Table 1. The mean MVC of knee extension measured before and after vibration and the mean percent change after 20-min vibration stimulation. Data are means (±SD).

Type of contraction	Pre-Vibration (Nm)	Post-Vibration (Nm)		F value	P value
Concentric contraction	192.2 (49.3)	162.3 (47.9)	Pre vs. Post	19.04	.0033
Eccentric contraction	299.7 (77.0)	247.3 (88.6)	Con vs. Ecc	26.351	.0013
			Interaction	3.823	.0915

femoris (RF) during MVC measurement at a sampling rate of 1 kHz. The EMG was recorded using bipolar surface disposable electrodes (Blue Sensor, Medicotest) placed on the belly of the vastus medialis, vastus lateralis, and rectus femoris. The inter-electrode distance was 30 mm. The electrodes were connected to an EMG measurement unit (ME3000, Nihon Medix). EMG data were transferred into PowerLab (ADInstruments) via an A/D conversion unit. Simultaneous recordings of force and EMG signals during maximal voluntary concentric and eccentric contraction were performed. EMG signals during lever arm movement (from 0 to 90 deg in eccentric action and from 90 to 0 degree in concentric action) were sampled in the present study. Then, the sampled signals were full-wave-rectified. To calculate the average EMG (AEMG), rectified EMG signals were integrated and dived by time throughout lever arm movement.

Statistical analysis

Descriptive statistical analysis was expressed with means± SD. A *P* value less than 0.05 denoted the presence of a statistically significant difference. The MVC and Average EMG (AEMG) were analyzed in a 2 x 2 repeated measures analysis of variance (ANOVA) with pre-post condition (pre-vibration vs. post-vibration) as a within-subject factor and action (concentric action vs. eccentric action) as a within- subjects factor. Post hoc analyses were performed using simple main effect analysis.

Results

MVC before and after vibration stimulation

The mean values and SDs for the MVC before and after 20min of vibration stimulation in all actions are presented in Table 1. The MVC were analyzed in a 2 x 2 repeated measures analysis of variance (ANOVA) with pre-post condition (pre-vibration vs. post-vibration) as a within-subject factor and action (concentric action vs. eccentric action) as a within- subjects factor. Both main effects for pre-post condition ($F(1,7)=$, $p = 0.0033$) and action ($F(1,7)=26.35$, $p = 0.0013$) were noted. No interaction effect (action x condition) was noted.

Average EMG (AEMG) before and after vibration stimulation

The mean values and SDs of AEMG (vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF)) before and after 20min of vibration stimulation in all groups are listed in Table 2. The AEMG of the VL, the VM and the RF were analyzed in a 2 x 2 repeated measures analysis of variance (ANOVA) with pre-post condition (pre-vibration vs. post-vibration) as a within-subject factor and action (concentric action vs. eccentric action) as a within- subjects factor. Both main effects for pre-post condition (VL;$F(1,7)=7.27$, $p = 0.0308$, VM; $F(1,7)=9.55$, $p = 0.0175$) and action ($F(1,7)=12.40$, $p = 0.0097$) were noted in the VL and the VM but not in the RF. Furthermore, the repeated measures ANOVA show significant interaction effect (action x condition) in the VM ($F(1,7)=7.03$, $p = 0.0328$) but not in the VL. The significant interaction effect was further analyzed using a simple main effects analysis of action within each level of condition. In the pre-vibration condition, no significant difference was detected between eccentric and concentric actions ($F(1,14) = 0.556$, $p = 0.4683$). In the post-vibration condition, significant difference was detected between eccentric and concentric actions ($F(1,14)=19.20$, $p = 0.0006$). In both concentric and eccentric action, the value of post-vibration were significantly lower (Concentric action; $F(1,14) = 13.524$, $p = 0.0025$, Eccentric action; $F(1,14) = 5.243$, $p = 0.0381$).

Discussion

The results of the present study demonstrated that the application of prolonged vibration stimulation to the infrapatellar tendon attenuated the strength of knee extension and the average EMG values of vastus lateralis (VL) and vastus medialis (VM) in both concentric and eccentric action. For the purpose of the present study, we compared the MVC and the EMG activity in response to prolonged vibration stimulation between eccentric and concentric

Table 2. AEMG values in each quadriceps femoris muscle (VL= vastus lateralis, VM = vastus medialis, RF = rectus femoris) measured before and after 20min of vibration and that of relative change after vibration in both study groups. Data are means (±SD).

Muscles	Type of contraction	Pre-Vibration (mV)	Post-Vibration (mV)		F value	P value
VL	Concentric	.071 (.032)	.062 (.190)	Pre vs. Post	7.279	.0308
	Eccentric	.126 (.067)	.105 (.057)	Con vs. Ecc	7.188	.0315
				Interaction	.951	.3619
VM	Concentric	.074 (.015)	.070 (.160)	Pre vs. Post	9.556	.0175
	Eccentric	.130 (.050)	.105 (.040)	Con vs. Ecc	12.403	.0097
				Interaction	7.037	.0328
RF	Concentric	.158 (.069)	.149 (.072)	Pre vs. Post	.411	.5416
	Eccentric	.194 (.102)	.161 (.085)	Con vs. Ecc	4.176	.0803
				Interaction	4.232	.0787

actions. The results revealed that the reduction of maximal eccentric strength in response to the prolonged vibration stimulation was significantly larger than that of concentric action. Additionally, the average EMG values of the VL in response to the prolonged vibration stimulation were also significantly reduced in eccentric contraction over concentric contraction. Assuming that the application of prolonged vibration to muscles was considered to attenuate Ia afferents and the same protocol of vibration stimulation was applied in both condition of eccentric and concentric actions, the result suggested that the attenuation of Ia afferents had a greater deactivation effect on the alpha motor neuron of the VL during eccentric action than during concentric action.

On the other hand, previous studies reported that the activation of alpha motor neurons would not be enhanced as much as Ia discharge would be increased during eccentric contraction (Burke, 1978; Nakazawa et al., 1997; 1998; Ribot-Ciscar and Roll, 1998; Romano and Schieppati, 1987). That is why some inhibitory mechanisms aiming to inhibit activation of the motor neuron pool are thought to exist during eccentric contraction (Laidlaw et al., 1999; 2000; Tracy et al., 2004). If the same inhibitory mechanism against the motor neuron pool is working during maximal eccentric action, the attenuation of Ia afferents due to the application of prolonged vibration stimulation might not affect or might have less of an effect on the activity of alpha motor neuron as compared with concentric action. On the contrary, the results of the present study indicated that Ia afferents have a larger effect on the activity of alpha motor neuron during maximal eccentric action than during concentric action. Therefore, we could speculate that the motor neuron pool might not be inhibited during maximal eccentric contraction. The inhibition of the motor neuron pool during submaximal eccentric contraction was considered functionally important, because this inhibitory mechanism is essential to attaining steadiness of movement and for adjusting the speed of movement during eccentric action (Laidlaw et al., 1999; 2000; Tracy et al., 2004). However, the results of the present study revealed that the inhibitory mechanism of the motor neuron pool would not be working during the maximal eccentric contraction.The inhibitory mechanism against the motor neuron pool during eccentric action might be selectively turned on or off depending on the fluctuation in tension during voluntary eccentric action. Moreover, no significant difference was detected in the average EMG of the VM and RF between concentric and eccentric contraction. Therefore, only the VL might have different neural control during maximal eccentric action from that of the other quadriceps.

Conclusion

Previous studies have reported that the motor neuron pool was inhibited during submaximal voluntary eccentric contraction. If the same inhibitory mechanism against the motor neuron pool is working during maximal eccentric action, the application of prolonged vibration stimulation might have less of an effect on the activity of alpha motor neuron as compared with concentric action. However, the MVC and the EMG activity of the VL in response to the prolonged vibration stimulation were significantly reduced in eccentric contraction over concentric contraction. These results represented that a deactivation effect on the alpha motor neuron of the VL during eccentric action was greater than that of maximal concentric action.

References

Avela, J., Kyrolainen, H. and Komi, P.V. (1999) Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *Journal of Applied Physiology* **86,** 1283-1291.

Bongiovanni, L.G., Hagbarth, K.E. and Stjernberg, L. (1990) Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *Journal of Physiology* **423,** 15-26.

Burke, D., Hagbarth, K.E., Lofstedt, L. and Wallin, B.G. (1976) The responses of human muscle spindle endings to vibration during isometric contraction. *Journal of Physiology* **261,** 695-711.

Burke, D.H. and Lofstedt, L. (1978) Muscle spindle activity in man during shortening and lengthening contractions. *Journal of Physiology* **277,** 131-142.

Gandevia, S.C. (1998) Neural control in human muscle fatigue: changes in muscle afferents, motoneurones and motor cortical drive [corrected]. *Acta Physiol Scand* **162,** 275-283.

Hagbarth, K.E., Kunesch, E.J., Nordin, M., Schmidt, R. and Wallin, E.U. (1986) Gamma loop contributing to maximal voluntary contractions in man. *Journal of Physiology* **380**, 575-91.

Konishi, Y., Fukubayashi, T. and Takeshita, D. (2002a) Mechanism of quadriceps femoris muscle weakness in patients with anterior cruciate ligament reconstruction. *Scandinavian Journal of Medicine and Science in Sports* **12**, 371-375.

Konishi, Y., Fukubayashi, T. and Takeshita, D. (2002b) Possible mechanism of quadriceps femoris weakness in patients with ruptured anterior cruciate ligament. *Medicine and Science in Sports and Exercise* **34**, 1414-1418.

Kouzaki, M., Shinohara, M. and Fukunaga, T. (2000) Decrease in maximal voluntary contraction by tonic vibration applied to a single synergist muscle in humans. *Journal of Applied Physiology* **89**, 1420-1424.

Laidlaw, D., Bilodeau, M. and Enoka, R.M. (2000) Steadiness is reduced and motor unit discharge is more variable in old adults. *Muscle and Nerve* **23,** 600-612.

Laidlaw, D., Kornatz, K., Keen, A., Suzuki, S. and Enoka, R. (1999) Strength training improves the steadiness of slow lengthening contractions performed by old adults. *Journal of Applied Physiology* **87**, 1786-1795.

McHugh, M., Tyler, T., Greenberg, S. and Gleim, G. (2002) Differences in activation patterns between eccentric and concentric quadriceps contractions. *Journal of Sports Science* **20,** 83-91.

Nakazawa, K., Yamamoto, S. and Yano, H. (1997) Short- and long-latency reflex responses during different motor tasks in elbow flexor muscles. *Experimental Brain Research* **116**, 20-28.

Nakazawa, K., Yano, H., Satoh, H. and Fujisaki, I. (1998) Differences in stretch reflex responses of elbow flexor muscles during shortening, lengthening and isometric contractions. *European Journal Applied Physiology and Occupational Physiology* **77,** 395-400.

Ribot-Ciscar, E. and Roll, J. (1998) Ago-antagonist muscle spindle inputs contribute together to joint movement coding in man. *Brain Research* **791,** 167-176.

Roll, J.P. and Vedel, J.P. (1982) Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. *Experimental Brain Research* **47**, 177-190.

Roll, J.P., Vedel, J.P. and Ribot, E. (1989) Alteration of proprioceptive messages induced by tendon vibration in man: a microneurographic study. *Experimental Brain Research* **76**, 213-222.

Romano, C. and Schieppati, M. (1987) Reflex excitability of human soleus motoneurones during voluntary shortening or lengthening contractions. *Journal of Physiology* **390**, 271-284.

Tracy, B., Byrnes, W. and Enoka, R. (2004) Strength training reduces force fluctuations during anisometric contractions of the quadriceps femoris muscles in old adults. *Journal of Applied Physiology* **96**, 1530-1540.

Key point

- A deactivation effect on the alpha motor neuron of the vastus lateralis during eccentric action was greater than that of maximal concentric action.

AUTHORS BIOGRAPHY

Yu KONISHI
Employment
National Defence Academy
Degree
PhD
Research interest
Sports medicine, Rehabilitation,
E-mail: yu57@nda.ac.jp

Jyunjiro KUBO
Employment
Heisei International University
Degree
PhD
Research interest
Exercise physiology, growth.

Akinori FUKUDOME
Employment
National Defence Academy
Degree
BS
Research interest
Biomechanisms, volleyball.

✉ **Yu Konishi, PhD, ATC**
Department of Physical Education, National Defence Academy, 1-10-20 Hashirimizu, Yokosuka City, Kanagawa, Japan 239-686