Muscle Fiber Function during Rapid Movement based Solely on Kinesthesia

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Abstract: This study was designed to examine function of the vastus lateralis muscle (VL) fibers during maximal voluntary contraction (MVC) in knee extension which was exerted based solely on the kinesthesia acquired from repeating the MVC movements. Fifteen men performed 10 consecutive isokinetic knee extensions comprising 7 passive contractions and 3 MVCs, which was repeated for 7 sets. In the first 3 sets, subjects were instructed to perform MVCs immediately a light cue appeared when the leg reached 60 deg knee joint angle in the 3rd, 6th, and 9th extensions; in the next 4 sets, subjects tried to maintain the timing of MVC repetitions without the light cue. VL electromyographic activity was monitored. The point where a fascicle arose from the deep aponeurosis and the pennation angle were measured on VL ultrasonic images. Subjects classified their MVC performance (force and timing) into 5 grades after each set. Based solely on kinesthesia (without the light cue), the VL fibers contracted tightly to a point where the fascicle arises from the deep aponeurosis, and it appeared to compensate for a delay in reaction time to start MVC. However, the subject's self-evaluation remained unchanged despite the changes in muscle behavior during MVC. In the 4th set only, when the light cue was not used for the first time, did their self-evaluation tend to decrease and VL pre-activity was significantly increased. These results suggest that kinesthesia does not always correspond to actual muscle activity.

1 INTRODUCTION

We perform physical movement based on kinesthesia to achieve a given motor task. However, the outcome is not always what we hoped for. If a delay occurs between kinesthesia and our actual movement, a large force must be exerted in a quite short time to bridge them.

In the pennate muscles, contraction is performed by shortening the muscle fibers (Fukunaga et al., 1997; Hawkins and Bey, 1997) and increasing the pennation angle (Ichinose et al., 1997; Maganaris and Baltzopoulos, 1999), which rotate the joints throughout the tendinous tissues elongated by the muscle. However, the interaction between such shortening and the degree of the pennation angle is not constant and varies between low- and high-force contractions (Azizi et al., 2008), suggesting that sudden modulation of the muscle force is likely to induce irregular muscle fiber behavior. In fact, the muscle fibers have been reported to contract more tightly near the deep aponeurosis when the timing to exert force was unexpectedly changed (Hirose et al., 2013).

Muscle contraction which is performed based solely on the kinesthesia may not basically give agreement with muscle fiber behavior which is induced based on a lot of information. Especially in rapid movements, a feed-forward control of the central nervous system which is likened to learned anticipatory responses to known cues plays an important role to control the rapid motions because a feedback component is very slow. This suggests that the function of the muscle fibers may vary depending on whether information has been received to start the muscle contraction.

A clinical report revealed that most muscle strain injuries occur at or near the myotendinous junction during high-intensity or explosive voluntary movements such as sprint and quick turn (Okuwaki, 2009). If the muscle fibers are strong and shorten unexpectedly with an inappropriate timing, it may

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induce irregular muscle fiber behavior and lead to muscle strain injuries with higher probability. Therefore, we designed this study to examine the characteristics of muscle fiber functions during maximal voluntary contraction (MVC) in knee extension which was exerted based solely on the kinesthesia acquired from repeating the movement at a constant timing indicated by a light cue.

2 METHODS

2.1 Subjects

Fifteen men (age, 21.9±1.1 years, height 172.6±9.1 cm, weight 70.5±10.7 kg) participated in this study. All subjects were in good health, with no orthopedic or neuromuscular abnormalities. Subjects were fully informed of the nature and possible consequences of the study before providing written informed consent. The experiments were conducted in accordance with the Declaration of Helsinki. Approval was obtained from the Ethics Committee of Kogakkan University.

2.2 Measurement Procedure

The subjects completed a warm-up consisting of jogging and dynamic stretching for 10 min. Then they were placed in a comfortable, upright, seated position on an isokinetic dynamometer chair, and the dynamometer fulcrum was aligned with the axis of rotation of the left knee joint (Biodex-System 4, Biodex Medical Systems, New York, USA). Subjects were secured using shin, thigh, pelvic, and torso stabilization straps to minimize extraneous body movements and were asked to fold their arms across their chest during the experiment. After correcting for the effects of gravity, several sub-maximal or maximal knee extensions were repeated in a second warm-up period. The knee movement range of motion was from 0 deg extension to 90 deg flexion and was tested at 90 deg/s (0 deg = straight leg).

After the subjects familiarized themselves with the experimental apparatus and procedure by performing knee extensions at MVC several times, they performed 10 consecutive isokinetic knee extensions comprising 7 passive contractions and 3 MVCs. All MVCs were performed during the passive isokinetic knee extensions and were followed by passive knee flexions. The 10 consecutive isokinetic knee extensions were repeated for 7 sets with 2-min intervals. A photo beam unit consisting of light-emitting and light-receiving devices was set up on either side of the left shank such that an LED placed in front of the subject could be switched on, to act as a light cue to start MVC, when the shin moved through the beam at 60 deg knee joint angle during knee extension in the first 3 sets. Immediately before reaching 60 deg knee joint angle, the angular velocity had reached a constant velocity of 90 deg/s.

In the first 3 sets, subjects were asked to relax their muscles and exert an MVC immediately they saw the light cue during the 3rd, 6th, and 9th repetitions. They were informed beforehand of the timing when the light cue would come on. In the next 4 sets, based solely on the kinesthesia acquired during the first 3 sets, the subjects tried to exert MVCs at the same timing as in the first 3 sets but without the light cue. After each set, the subjects classified the force and timing of their MVC performance into 5 grades (1 = very poor; 2 = poor; 3 = average; 4 = good; 5 = very good).

2.3 Data Collection

The knee joint torque (KJT) exerted at MVC was measured with data on the knee joint angle (KJA). Electromyographic (EMG) activity was recorded from the vastus lateralis muscle (VL) in the left leg, using Ag/AgCl bipolar surface electrodes (diameter, 10 mm; inter-electrode distance, 20 mm; TELEmyo DTS, Noraxon, Scottsdale, USA). EMG signals were amplified. A/D was converted at a sampling rate of 1.5 kHz and transmitted to a computer along with data on KJT, KJA, and timing of the light cue.

Longitudinal sectional images of the VL were obtained at 37 Hz using a real-time B-mode ultrasound apparatus (Prosound α7, Hitachi Aloka Medical, Tokyo, Japan). A linear array probe with a scanning frequency of 7.5 MHz and a scanning length of 60 mm was fixed with a sponge and an elastic bandage over the VL at one-quarter from the distal end of the estimated muscle length. The ultrasonic images with the timing of the light cue were transmitted to a computer and recorded onto Blu-ray discs.

2.4 Data Processing

The EMG signals were full-wave rectified. The following 4 reaction time characteristics were measured: time between the light cue and onset of EMG activity (premotor reaction time; PMT), time between the onset of EMG activity and onset of KJT (electromechanical delay; EMD), time between the light cue and onset of KJT (total reaction time; TRT), and time between the light cue and peak KJT (movement time; MTPT). Average EMG (aEMG) was calculated over 100 ms before the light cue as a measure of pre-activity.

For each ultrasonic image, the following 6 points were digitized and converted to real coordinates: point (P) where a fascicle arises from the deep aponeurosis; point (S) where a perpendicular line from P intersects the superficial aponeurosis; 2 points (F_5 and F_{10}) on the fascicle 5 mm and 10 mm horizontally from P, respectively; and 2 points (D_5 and D_{10}) on the deep aponeurosis 5 mm and 10 mm horizontally from P, respectively (Fig.1). Digitizing the 6 points was repeated 3 times for each image and the coordinates were averaged. The interior angles $\angle F_5PD_5$ and $\angle F_{10}PD_{10}$ were calculated as 2 types of pennation angle (PA_5 and PA_{10}, respectively). The distance between points P and S was taken as the muscle thickness.

2.5 Statistics

Data are presented as the means ± SD. One-way analysis of variance (ANOVA) was used to analyze the differences in aEMGs, reaction times and 5-grade evaluations of MVC performance. To test for the effects of kinesthesia on the behaviour of the muscle fibers, two-way ANOVAs (factors: set vs. pennation angle) for repeated measurements were performed. Fisher's post hoc comparison was performed when significance was found. The probability level accepted for statistical significance was $p<0.05$.

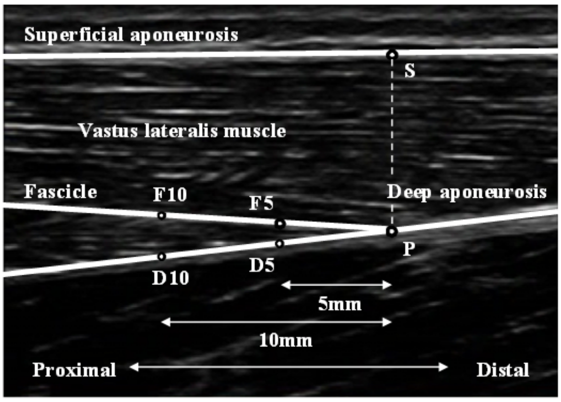

Figure 1: Analysis of ultrasonic image of the vastus lateralis muscle. Six points were digitized. Two types of pennation angle ($\angle F_5PD_5$ and $\angle F_{10}PD_{10}$, respectively) and the muscle thickness (the distance between points P and S) were calculated.

3 RESULTS

Increases in PA_5 from rest to peak KJT tended to be larger in the 4th to 7th sets without the light cue than in the 1st to 3rd sets with the light cue (Fig.2). Standard deviations of the increase in PA_5 among the 3rd, 6th, and 9th repetitions in each set were significantly larger in the 4th to 7th sets than in the 1st to 3rd sets (Fig.3). On the other hand, the influence of the light cue on PA_{10} was smaller than that on PA_5. The moving speed of P became more unstable during MVC in the 4th to 7th sets without the light cue. No significant differences were observed in muscle thickness in each set.

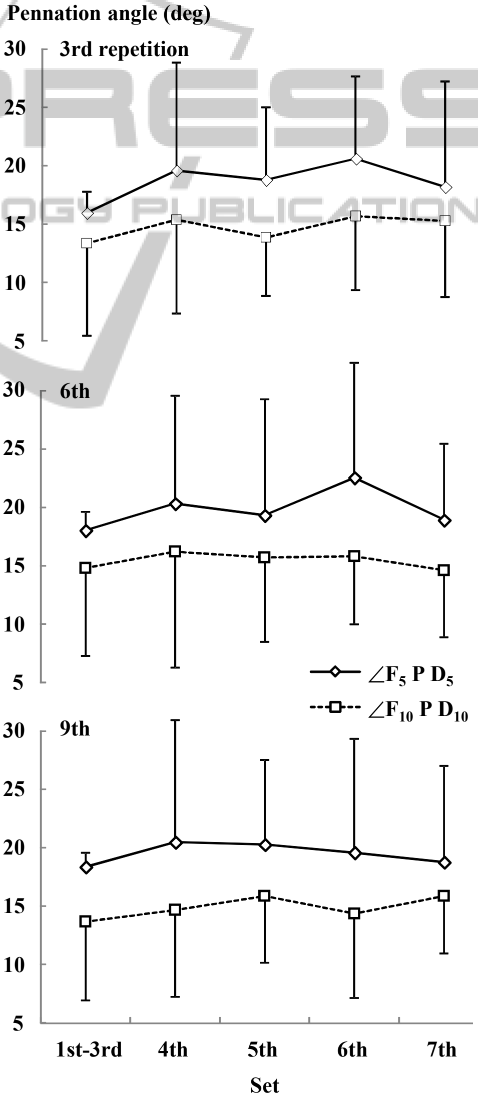

Figure 2: Increase in pennation angle from rest to peak knee joint torque.

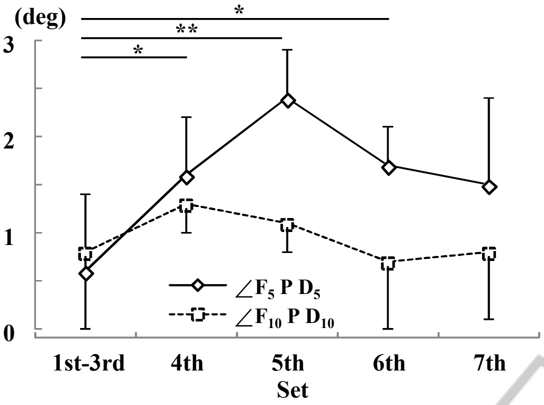

Figure 3: Standard deviation of the increase in pennation angle from rest to peak knee joint torque. Asterisks indicate significant differences between sets (* $p<0.05$, ** $p<0.01$).

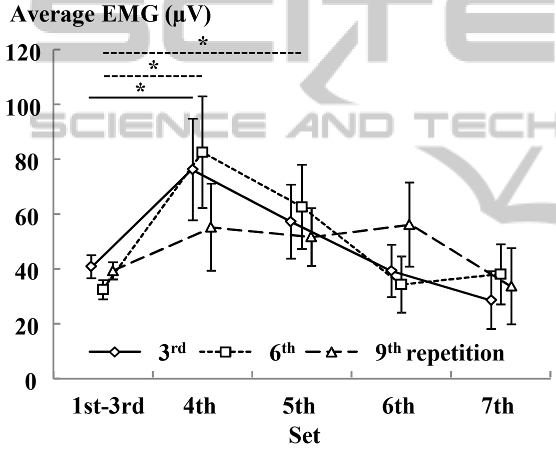

Figure 4: Average electromyography 100ms before flexion to 60deg knee joint angle (pre-activity). Asterisks indicate significant differences between sets ($p<0.05$).

No significant differences were noted in the increasing rate of KJT between the 1st to 3rd sets and the 4th to 7th sets. The standard deviations in the 3rd, 6th, and 9th repetitions increased as the set was repeated and were significantly larger in the 7th set than in the 1st to 3rd sets.

PMT tended to be longer in the 4th to 8th sets than in the 1st to 3rd sets. It increased from about 40ms in the 1st to 3rd sets to about 100ms in the 4th to 8th sets. Standard deviations of the PMT in the 3rd, 6th, and 9th repetitions in each set tended to be increased in the 4th to 7th sets than in the 1st to 3rd sets. A significant difference was observed between the 4th set and the 1st to 3rd sets. However, no significant differences were noted in EMD in each set regardless of the presence of a light cue. TRT, which is the sum of PMT and EMD, tended to be similar to the PMT.

Table 1: Self-evaluation of MVC on a 5-point scale.

	Set				
	1st to 3rd	4th	5th	6th	7th
Force	2.9±0.5	2.6±0.7	2.8±0.4	2.8±0.8	3.0±0.7
Timing	3.1±0.7	2.6±0.5	3.2±0.4	3.0±0.7	2.8±0.8

In terms of pre-activity, some significant differences in aEMG were observed between the 1st to 3rd sets and the 4th or 5th set (Fig.4). The differences seen immediately after the light cue had disappeared decreased as the set or repetition was repeated, and the aEMG eventually tended to be equal to or smaller than that in the 1st to 3rd sets.

No significant differences were observed in the self-evaluation of MVC performance in each set. However, the scores for both force and timing tended to decrease only in the 4th set, which was the first set performed without the light cue (Table 1).

4 DISCUSSION

Loss of the light cue to start MVC altered the behavior of the muscle fibers during contraction. Exerting MVC based solely on kinesthesia without the light cue made the moving velocity of P unstable and increased both PA near the deep aponeurosis and PMT. However, the subjects themselves could not perceive these changes; self-evaluation of the force and timing of MVC repetitions remained unchanged regardless of the presence of a start (light) cue. This concurs with the findings of a previous study which found that subjects also did not perceive differences in the function of the muscles during MVC repeated at a constant timing when the timing of the muscle contraction was unexpectedly changed (Hirose et al., 2013). This suggests that kinesthesia does not always correspond to the actual movement performed.

The subject's self-evaluations tended to decrease slightly in the 4th set only, which was the first set without the light cue. This indicates that alterations in the muscle behavior can be vaguely perceived immediately after the condition for exerting MVC was changed. Indeed, repetitive exercise has been reported to improve the reproducibility of the movement to adjust force and position to target levels (Kaneko et al., 2009), and motor experience has been reported to improve somatosensory functions (Hayami et al., 2008). These findings suggest that sufficient time is needed to perceive the muscle behavior and that it is difficult to maintain kinesthesia acquired only over a brief period.

In the sets without the light cue in this study, significantly larger pre-activity was observed before the onset of MVC. This implies that the muscle was preparing to establish the timing to exert MVC. It is known that pre-activity increases so that fatigue-induced declines in performance do not deteriorate further (Horita et al., 1999). Therefore, pre-activity is likely to be a preparatory condition for generating as large an MVC as possible at an appropriate timing based solely on kinesthesia, which may explain the lower self-evaluations of MVC in the 4th set. Pre-activity gradually decreased after the 4th set and became closer to the smaller values seen in the 1st to 3rd sets, although the standard deviations of PMT and PA_5 in the 3rd, 6th, and 9th repetitions were increased. This suggests a process whereby the accuracy of movement based on kinesthesia is decreased due to the disappearance of kinesthetic information.

Behavior of the muscle fibers during MVC based solely on kinesthesia was characterized by a large and unstable PA_5. The muscle fibers contracted tightly to a point where the fascicle arises from the deep aponeurosis, which appeared to compensate for the delay in the reaction time to start MVC, and similar muscle fiber behavior has been observed when the timing to exert MVC was unexpectedly changed (Hirose et al., 2013). Since muscle force is transmitted through connective tissues to neighboring muscles (Huijing, 2003; Sandercock and Haas, 2009), the behaviour of the muscle fibers near the deep aponeurosis might result from the force transmission, and it might be influenced also by pressure put with a probe fixed over the muscle. Further studies are needed to elucidate the mechanism causing strong muscle fiber contractions near the deep aponeurosis.

Muscle strain injury was reported to occur at or near the myotendinous junction in frog myotendinous units when the muscle was strained (Tidball et al., 1993). Similarly, in human muscles, muscle failure is created by combining a large force with substantial stretch near the aponeurosis (Garrett, 1990), and a clinical study reported most muscle strain injuries occurring at or near the myotendinous junction during high-intensity or explosive voluntary movements (Okuwaki, 2009). If the muscle fibers are strong and shorten unexpectedly near the deep aponeurosis with an inappropriate timing during stretch, the contraction will increase the inhomogeneous strain on the aponeurosis (Zuurbier et al., 1994; Kinugasa et al., 2008), which may cause a muscle strain injury at or near the myotendinous junction.

In conclusion, behavior of the muscle fiber during MVC which was exerted based solely on kinesthesia without the light cue was characterized by stronger and more unstable contraction near the deep aponeurosis with longer premotor reaction time and larger pre-activity. However, the subjects could not perceive these changes. Such irregular muscle fiber behavior may be related to a mechanism of muscle injury.

REFERENCES

Azizi, E., Brainerd, E.L., Roberts, T.J., 2008. Variable gearing in pinnate muscles. *PNAS 105: 1745-1750.*

Fukunaga, T., Ichinose, Y., Ito, M., Kawakami, Y., Fukashiro, S., 1997. Determination of fascicle length and pennation in a contracting human muscle in vivo. *J Appl Physiol 82: 354-358.*

Garrett, W.E., Jr., 1990. Muscle strain injuries: clinical and basic aspects. *Med Sci Sports Exerc 22: 436-443.*

Hawkins, D., Bey, M., 1997. Muscle and tendon force-length properties and their interactions in vivo. *J Biomech 30: 63-70.*

Hayami, T., Kaneko, F., Kizuka, T., 2008. Differences in the Function of Somatosensory-Motor Integration depend on the Motor Experiences. *SOBIM 19: 47-56.*

Hirose, K., Tarodachi, N., Tsutsumi, M., Ogiso, K., 2013. Timing of muscle contraction influences function of muscle fibers. In *Book of Abstract, 18th annual Congress of the European College of Sport Science.* SporTools.

Horita, T., Komi, P.V., Nicol, C., Kyrolainen, H., 1999. Effect of exhausting stretch-shortening cycle exercise on the time course of mechanical behaviour in the drop jump: possible role of muscle damage. *Eur J Appl Physiol 79: 160-167.*

Huijing, PA., 2003. Muscular Force Transmission Necessitates a Multilevel Integrative Approach to the Analysis of Function of Skeletal Muscle. *Exerc. Sport Sci. Rev 31(4): 167-175.*

Ichinose, Y., Kawakami, Y., Ito, M., Fukunaga, T., 1997. Estimation of active force-length characteristics of human vastus lateralis muscle. *Acta Anat 159: 78-83.*

Kaneko, F., Hayami, T., Yokoi, T., Kizuka, T., 2009. Research on Examination Indicator of Motor Performance Corresponding to the Active Kinesthetic Perception: from the Viewpoint of Detection of Repetitive Practice Effect. *Physical Therapy Japan 36(1): 9-17.*

Kinugasa, R., Shin, D., Yamauchi, J., Mishra, C., Hodgson, J.A., Edgerton, V.R., Sinha, S., 2008. Phase-contrast MRI reveals mechanical behavior of superficial and deep aponeuroses in human medial gastrocnemius during isometric contraction. *J Appl Physiol 105: 1312–1320.*

Maganaris, CN., Baltzopoulos, V., 1999. Predictability of in vivo changes in pennation angle of human tibialis anterior muscle from rest to maximum isometric dorsiflexion. *Eur J Appl Physiol 79: 294-297.*

Okuwaki, T., 2009. Muscle strains of top-level athletes in Japan. *J Japan Soc Clin Sports Med 17: 497-505.*

Tidball, J.G., Salem, G., Zernicke, R., 1993, Site and mechanical conditions for failure of skeletal muscle in experimental strain injuries. *J Appl Physiol 74: 1280-1286.*

Zuurbier, C.J., Everard, A.J., van der Wees. P., Huijing, P.A., 1994. Length-force characteristics of the aponeurosis in the passive and active muscle condition and in the isolated condition. *J Biomech 27: 445–453.*