大腿四頭筋の反射機能異常が予測外の着地動作中の下肢筋の応答様式に与える影響

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The Effect of Prolonged Vibration Stimulation to the Quadriceps Femoris of Normal Healthy Subjects on Reflex Pattern of Thigh Muscles during Surprised Landing

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ABSTRACT

Quadriceps femoris（QF）muscle weakness is especially common after knee joint injury and occurs due to both muscle atrophy and deficits in voluntary activation. An important cause of QF voluntary activation deficits is arthrogenic muscle inhibition（AMI）. In present study, neurological changes of the QF induced by prolonged vibration stimulation was used as a model of the AMI. This is because neurological changes leaded by prolonged vibration stimulation were similar to that observed in the QF with the AMI. The purpose of present study is to investigate how the neurological abnormality would affect to reflex activities of thigh muscles during unexpected landing. The prolonged vibration stimulation significantly enhanced the average EMG during time frame of the middle latency reflex（MLR）of the vastus lateralis

（VL）and the biceps femoris（BF）only after the surprised landing even though no alternation of the MLR of the VL and the BF in both normal landings were found even after the application of prolonged vibration stimulation. These results suggested that neurological alternations leaded by the prolonged vibration stimulation have no effect on landings accomplished by accurate feedforwarded information from brain based on visual estimation. However, only when discrepancy was recognized between the feedforward from brain and feedback from the proprioceptors in the lower limbs, the MLRs of the VL and BF were enhanced. the mechanism of the enhancement of the MLR via the attenuated afferents from proprioceptors to their brain might work as a preparatory mechanism in case startle events were imposed to them. In other words, in advance, a human brain might produce neurophysiological state in which the MLR could easily be enhanced via disinhibited Ib interneurons as a compensatory strategy to prepare startle events.

要　旨

膝関節での様々な病変により，大腿四頭筋（QF）の機能が特異的に低下することが知られている．この筋機能低下は Arthogeneous Muscle Inhibition と呼ばれ，多くの研究がなされてきた．この筋機能低下は様々な病態の患者に現れ，リハビリテーションを遂行する上で AMI を克服することは極めて重要な課題である．一方，AMI 研究では，既に病態を有する被験者を用いなければならず，被験者内での比較が困難である．ところが，近年，筋への長時間振動刺激により惹起される筋機能変化が AMI 起因の神経系変化と類似していると報告されている．本研究では，長時間振動刺激を用い，健常者の QF に AMI に類似した筋機能低下を誘発し，サプライズドランディング（SL）中の下肢筋の応答様式を刺激前後で比較を行い，AMI が外乱に及ぼす影響を明らかにすることを目的とした．その結果，長時間振動刺激が SL 中の外側広筋と大腿二頭筋の中潜時域の筋放電を有意に大きくすることが分かった．

Introduction（緒言）

Deficits in muscle strength and neuromuscular control are common after joint injury and pathology[1-3]. Previous studies have shown that not only can joint injury lead to long term muscle weakness, it can also create dysfunction in motor planning, and disrupt visual-motor function [4, 5], with involvement of the somatosensory cortex [6]. Quadriceps femoris（QF）muscle weakness is especially common after knee joint injury and occurs due to both muscle atrophy and deficits in voluntary activation. An important cause of QF voluntary activation deficits is arthrogenic muscle inhibition（AMI）[7-9], an ongoing neural inhibition due to altered sensory output from the damaged joint that prevents the QF muscle from being fully activated. The neural pathways through which AMI operates are numerous and have been described in detail by Rice and McNair [2].

Previous studies investigated the effect of the AMI on the maximal strength exertion. To our knowledge, however, no study has investigated the effect of the AMI on the functional movement like landing. Furthermore, no study has investigated the effect of the AMI on functional movements which were imposed unexpected events. In various situations, athletes would impose unexpected events during practice and competition. Athletes who could not orient to unexpected events would have higher risks to get sports related injuries. According to the previous study investigated the effect of surprised landing on the normal healthy subjects, middle latency reflex played a major role to adapt to the landing [10]. Furthermore, previous study demonstrated that ACL injury also induced the changes of middle latency reflex after surprised landing in vastus lateralis.

In present study, neurological changes of the QF induced by prolonged vibration stimulation was used as a model of the AMI. This is because neurological changes leaded by prolonged vibration stimulation were similar to that observed in the QF with the AMI [9, 11-16].

The purpose of present study is to investigate how the neurological abnormality would affect to reflex activities of thigh muscles during unexpected landing. In the studies using subjects with actual pathological conditions, it is impossible to apply cross-over study design. In the present study, however, we could compare the data obtained from the same subjects between before and after induction of dysfunctional neurological system because the neurological abnormality could intentionally be induced by using vibration stimulation. Additionally, we could focus on the effect of neurological abnormality so that other factors such as pain, other pathological conditions and so on could be excluded by the model using the neurological changes induced by vibration stimulation.

1. Experimental Design and Method（実験方法）

1．1　Subjects

19 subjects（11 male and 8 female）were participated in present study（average age:24.8 ± 6.5, average height:71 ± 613.7, average weight:172.7 ± 9.0）. They have no history of knee injuries.

1．2　Experimental procedure

This experiment will be consisted of 2 sessions and all subjects will perform the 2 sessions. The first（habituation）session will be used to familiarize the requirements of the experiment and to habituate them to the unilateral landing movement. During this session, each subject will perform approximately 10 times of unilateral landing from 15cm height of box and approximately 10 times of unilateral landing from 30cm height of box.

The second（main experimental）session, all subjects will perform 4 kinds of unilateral landing tasks（Task 1 to 4）（Fig.1）. The order subject will perform Task 1 to 3 will be randomized. After finishing these landings, subjects will receive 50Hz of vibration stimulation for 20 minutes to their infrapatellar tendon. As soon as finishing vibration stimulation, subjects will perform surprised landing（Task 4）.

1．3　Electromyographic recording

Electromyography（EMG）of the vastus lateralis, the rectus femoris, hamstrings will be recorded during landing movement a sampling rate of 1 kHz. Electrodes of the EMG will be placed on the belly of the vastus medialis, vastus lateralis, the rectus femoris, biceps femoris. The electrodes will be connected to an EMG measurement unit. The

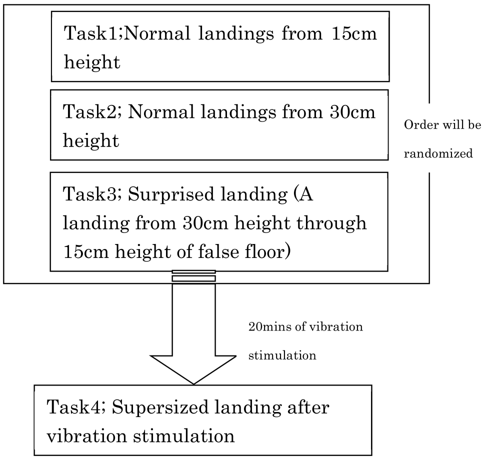

Fig.1 Experimental procedure
The order of tasks 1 to 3 will be randomized. Task4 will always be performed after tasks 1 to 3 will finish

EMG signals recorded by the unit will be digitally filtered. EMG data were transferred into PowerLab (ADInstruments) via an A/D conversion unit.

1. 4 Electromyographic analysis

To compare results among subjects, all of the data from each muscle will be normalized with respect to the average EMG amplitude during maximal isometric contraction. Therefore, subjects will be asked to do maximal isometric contractions of knee extension, flexion, planter flexion, and dorsiflexion to collect EMG data for the normalization before starting second session of the experiments. This average EMG amplitude during maximal isometric contraction will be the baseline used for normalization of all EMG data for all landings both before and after impact. This was repeated for each muscle and for each subject. Once the data will be rendered as a percentage for individual trials. The amplitude of EMGs averaged across subjects will be expressed in these percentage units. The amplitude of the post-landing EMG activity will be considered over three time frames: 0–30 ms post-landing which would represent short latency reflex (SLR), 31–60 ms post-landing which would represent middle latency reflex (MLR) and 61–90 ms post-landing which would represent long latency reflex (LLR). To obtain total EMG activity, all EMG data between these periods will be summed and normalized in the same manner described above [10]. In addition, reflex amplitude was computed on the raw data as the average of 30ms in each time frame. The maximum post-landing EMGs were normalized in the manner described above.

Also, we will observe the EMG activity at the moment subjects penetrate through false floor. To know the timing of penetration, we will set photo cell at the 15cm height. EMG data obtained when subjects penetrate through false floor in surprised landing will be normalized by those of in the 15 cm height of normal landing.

1. 5 Vibration method

Subjects sat on the seat of a seat with their legs hanging down from the edge of the seat, and they will be asked to relax their thighs as much as possible during the application of vibration. Vibration stimulation will be applied to the mid-portion of the infrapatellar tendon to induce attenuation of Ia through tonic vibration reflex of the quadriceps muscle. Vibration stimulation will be applied to the side subjects will land. The selected vibration frequency was 50 Hz and duration of application will be 20 minutes [11].

1. 6 Landing protocol of each landing patterns

Portable force plate would be set on 2 kinds of height (15cm and 30cm). This time force plate was used to know timing of landing. For the adjustment of height during the normal landing from 15cm height, height of the box subject will jump off will be 45 cm height and 15 cm of firm box underneath force plate which is 15cm of height (Fig.2b). For the adjustment of height during the normal landing from 30cm height, height of the box subject will jump off will also be 45 cm height, and force plate will be placed on the floor directly (Fig.2d). The force plate will be covered by corrugated board to prevent for subject to visually recognize it during normal landings.

For the adjustment of height during the surprised landing, height of the box subject will jump off will also be 45 cm height, and force plate will be placed on the floor directly, but false floor made by corrugated board will be secured easily at 30cm height from surface of the force plate (Fig.2c).

1. 7 Statistical design

In present study, we will examine the effect of prolonged vibration stimulation on the EMG of muscles of lower extremities during surprised landing. There are 3 kinds of independent variables in present study as follows. 1. Two kinds of reflex amplitude of EMGs (short latency reflex and middle latency reflex), 2. Vertical ground reaction force after landing. 3. The ratio of force development which was calculated as follows; (Maximal force after landing) - (Force at the moment of landing) /Duration (ms) which is between time of landing and time of maximal force. All EMG data will be expressed in these percentage units with respect to the average EMG amplitude during maximal

Fig.2a Preparation for landing

Fig.2b Setting for 15cm of normal landing
White floor is secured by a box underneath

Fig.2c Setting for surprised landing
White false floor is falling down

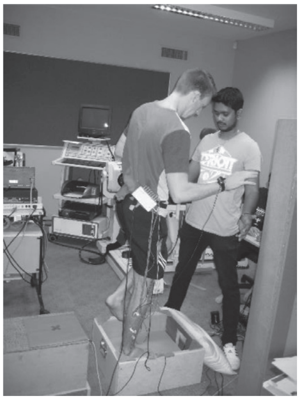

Fig.2d Setting for 30cm of normal landing

isometric contraction of each muscle. EMG data obtained from each muscle were analyzed using 2 x 3 repeated measures analysis of variance (ANOVA) for comparison between pre- and post-vibration and among landing conditions (normal landing from 30cm height vs. surprised landing vs. surprised landing after vibration). All EMG data will be normalized by average EMG during isometric maximal contractions of each muscle.

2. Results （実験結果）

Average EMG amplitude during 3 kinds of time frames (0-30ms, 31-60m, and 61-90ms) after landing in each muscle (vastus lateralis, rectus femoris, and biceps femoris) were described below. 2 x 3 repeated measures analysis of variance (ANOVA) was detected significant interaction in the 31-60ms of vastus lateralis and biceps femoris. The EMG was significantly larger than those of 15cm of normal landing (15cm NL) and 30cm of normal landing (30cm NL) in surprised landings (SL).

3. Discussion

The prolonged vibration stimulation had been utilized to investigate the effect of AMI on the landing movement since similar neurological changes as the AMI which are leaded by actual pathology could be induced by the prolonged vibration stimulation [17, 18]. For the purpose to induce similar neurological changes of the AMI, the prolonged vibration stimulation was applied to their QF in the present study. Previous studies indicated that neurological alternations leaded by the prolonged vibration declined maximal strength due to hindrance of the recruitment of high threshold motor units. To our knowledge, no study has investigated the effect of the AMI on landing. Moreover, no study has investigated how the AMI would affect to neuromuscular control in landing with unexpected events. Furthermore, since a previous study reported that a surprised event in landing alter reflex activities [10], we mainly focused on observing effects of neurological alternations leaded by both the prolonged vibration stimulation

Table. 1 Vastus lateraris

Time span	0-30ms			31-60ms **			61-90ms		
Jump types	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)
Pre-vib	77 ± 25	83 ± 25	83 ± 25	110 ± 28	108 ± 25	94 ± 39	110 ± 35	102 ± 29	83 ± 25
Post-vib	76 ± 18	79 ± 28	79 ± 40	102 ± 29	102 ± 30	130 ± 55 †	97 ± 46	79 ± 28	103 ± 48

** Significant interaction
† Significant different from 15cm NL (%) and 30cm NL (%)

Table. 2 Rectus Femoris

Time span	0-30ms			31-60ms **			61-90ms		
Jump types	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)
Pre-vib	66 ± 20	87 ± 34	83 ± 55	106 ± 45	107 ± 41	145 ± 109	104 ± 59	106 ± 57	148 ± 83
Post-vib	68 ± 36	72 ± 23	79 ± 38	121 ± 60	100 ± 37	154 ± 108 †	102 ± 81	105 ± 74	132 ± 71

** Significant interaction
† Significant different from 15cm NL (%) and 30cm NL (%)

Table. 3 Biceps femoris

Time span	0-30ms			31-60ms			61-90ms		
Jump types	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)	15cm NL (%)	30cm NL (%)	SL (%)
Pre-vib	39 ± 17	58 ± 33	56 ± 33	44 ± 19	57 ± 28	59 ± 32	104 ± 59	106 ± 57	148 ± 83
Post-vib	38 ± 15	50 ± 20	64 ± 51	44 ± 22	56 ± 26	80 ± 46	102 ± 81	105 ± 74	132 ± 71

and the surprised landing on three epochs of reflex activities after landing such as short (SLR), middle (MLR) and long latency reflexes (LLR) in the present study.

As a result, the short latency reflex (SLR) of the all muscles measured was not changed by vibration stimulation in all types of landings. Additionally, height of taking off platform and the surprised event was not affected to the SLR. In present study, while, surprised event enhanced long latency reflex even though height of landing platform was not affected. Additionally, both he LLR and SLR was not affected by neural changes caused prolonged vibration stimulation. As with the results of the SLR and the LLR, the middle latency reflex (MLR) of all muscles measured before the application of the prolonged vibration stimulation was not affected by height of landing platform in the present study. Those results might suggest that the reflex activities would remain steady if distance to actual landing surface were visually estimated accurately. Indeed, human brain could predict patterns and magnitude of signals from proprioceptors of lower limbs at the moment of landing accurately by using the visual estimation [10]. Based on the prediction, thus, human brain could build up a proper activation pattern of muscle in advance and avoid unnecessary muscle activation to achieve smooth landing [10]. Since their brain judged no increment of reflex activities would be needed based on this feedforwarded information, reflexes during 15cm and 30cm of normal landing would not be altered in the present study. Furthermore, similarly as the LLR and the SLR, there was no effect of the neurological alternations caused by prolonged vibration stimulation on the MLR as long as feedforwarded information based on the visual estimation of height was accurate. Whereas, the response to the surprised landing were various depend on which muscles were. Indeed, previous studies examined the effect of surprised landing on landing behavior of normal healthy subjects demonstrated that reflex activities were altered by surprised landing but the alternations were not consistent in each muscle [10]. The MLRs of the VL and the BF were not changed even after the surprised landing before the application of the vibration stimulation, but that of the RF enhanced significantly as compared with other 2 types of normal landings in the present study.

In contrast, the prolonged vibration stimulation significantly enhanced the MLRs of the VL and the BF only after the surprised landing even though no alternation of the MLR of the VL and the BF in both normal landings were found even after the application of prolonged vibration stimulation. These results suggested that neurological alternations leaded by the prolonged vibration stimulation have no effect on landings accomplished by accurate feedforwarded information from brain based on visual estimation. However, only when discrepancy was recognized between the feedforward from brain and feedback from the proprioceptors in the lower limbs, the MLRs of the VL and BF were enhanced.

The fluctuations existed in the MLR might be reasonable. The rational why the MLR was affected by the surprised landing protocol has been explained by the previous study [10]. According to the previous study examined the neural changes caused by surprised landing, the afferent signal to the brain would be evoked when they contact a false floor and it would take a minimum of 30ms to reach brain. Then, a minimum of 15ms would be necessary to send modified signal down from the brain to the spine [10].

In present study, whereas, the enhancement of the MLRs of the VL and the BF was not found in normal condition without vibration although the MLRs of those were enhanced by the surprised landing in vibrated condition. There are two possible explanations for this for this result. First, the MLRs of the VL and the BF in the normal condition without vibration stimulation would be inhibited via some kind of neural modulation. Second, some kinds of neural facilitation were occurred in the MLR of these muscles after prolonged vibration. Since MacDonagh and colleague reported that the MLR were preferentially used after surprised landing because of the inability to use preprogram build upped in brain [10), the first explanation would be more reasonable than the second.

Even though the MLR of both the VL and the BF were enhanced by the prolonged vibration stimulation only after the surprised landing, the mechanism of the enhancement of these muscles must not be coincidence. If the Ia afferent attenuation which were supposed to be induced by the prolonged vibration stimulation were only the neural changes [19, 20), the reflex of the BF could be enhanced but must not be in the VL. This is because Ia afferent attenuation could enhance reflex activity of antagonists via deactivation of Ia inhibitory interneurons, but inhibit activities of homonymous muscles [21). In present study, therefore, the enhancement of the MLR activities of the BF after surprised landing could be leaded by deactivation of Ia inhibitory interneuron caused by prolonged vibration to the quadriceps. In the vibration protocol used in the present study, whereas, vibration stimulation was applied to infrapatellar tendon in which Golgi tendon organs existed. Therefore, the prolonged vibration protocol used in present study could lead neurological changes in Ib afferents [22-25). Indeed, the prolonged vibration stimulation could also inhibit Ib afferent in the same manner as Ia afferernt such as neurotransmitter depletion, increment of threshold, and presynaptic inhibition. If so, disinhibition leaded via Ib afferents could associate with the enhancement of the MLR activities of the VL. In contrast to Ia interneuron, reflex pathway via Ib inhibitory interneuron could affect to homonymous muscle. Indeed, the disinhibition associated with the Ib interneuron was known to be modulated by both afferents from proprioceptors in peripheral structures such as skin, tendon and joint, and efferent signals from brain [26). Furthermore, modulation of Ib interneurons were ruled by the neural mechanism which is called on state-dependent reflex reversal [26). Ib interneurons could lead either inhibition or disinhibition of homonymous muscles depended on activity level of the homonymous muscles and loaded condition [26). Efferent from brain to Ib interneurons play an important role to switch the functions either inhibition or disinhibition of homonymous muscles [26). However, we cannot identify the function of brain in present study. Further studies would be needed to examine the function of brain during surprised landing in the state affected by vibration stimulation.

Conclusion

The brains of the subjects after receiving the prolonged vibration stimulation were supposed to recognize less afferents were sent from proprioceptors after the application of the prolonged vibration stimulation. Since the vibration protocol of the present study would induce persistent neural alternations, therefore, their brains would be able to recognize afferents to brain were attenuated in advance of performing surprised landings. If the attenuated afferents from proprioceptors to their brain could be a trigger to enhance the MLR via disinhibited Ib interneuron, the mechanism of the enhancement of the MLR via the attenuated afferents from proprioceptors to their brain might work as a preparatory mechanism in case startle events were imposed to them. In other words, in advance, a human brain might produce neurophysiological state in which the MLR could easily be enhanced via disinhibited Ib interneurons as a compensatory strategy to prepare startle events.

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