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Original Article

Chronological changes in neuromuscular cooperativeness before and after muscle fatigue loading using the silent period of the quadriceps and hamstrings in young female athletes

Sakiko Ito-Oonishi, PT, PhD[1, 2)*], Masahiro Takemura, PT, MPhty[2)],
Akihiro Kanamori, MD[2)], Yasuaki Kusumoto, PT, PhD[3)], Shumpei Miyakawa, MD, PhD[2)]

[1)] *Department of Physical Therapy, School of Health Sciences, Tokyo University of Technology: 5-23-22 Nishikamata, Ota-ku, Tokyo 144-8535, Japan*
[2)] *Faculty of Sport and Health Science, University of Tsukuba, Japan*
[3)] *Department of Physical Therapy, Fukushima Medical University School of Health Sciences, Japan*

Abstract. [Purpose] Understanding the neuromuscular cooperativeness functions when an athlete is fatigued is essential in preventing sports injuries and examining post-injury return standards. This study aimed to investigate the kinds of changes in neuromuscular cooperativeness before and after fatigue loading. [Participants and Methods] Fifteen female university athletes were examined for chronological changes in neuromuscular cooperativeness. Muscle fatigue loading was performed using BIODEX (180°/s) during knee flexion and extension exercises on one side. Surface electromyography of the rectus femoris and biceps femoris was performed on both sides before and immediately, 5 min, 10 min, and 15 min after loading. The switching silent period and pre-motor time were calculated from the electromyographic waveforms to indicate neuromuscular cooperativeness. [Results] The switching silent periods in the loading side immediately and 5 min after loading were significantly prolonged compared with that before loading. [Conclusion] Muscle fatigue loading instantaneously prolonged the switching silent period and decreased the neuromuscular cooperativeness. Furthermore, recovery generally occurred within 10 minutes after loading.

Key words: Neuromuscular cooperativeness, Switching silent period, Muscle fatigue

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INTRODUCTION

Various studies have been conducted on the neuromuscular response times. According to a study by Pope et al. on neuromuscular response time using a feedback mechanism, when a disturbance was applied to the foot, the quadriceps muscle contraction began 180 ms afterward[1)]. Furthermore, in a study by Koga et al., based on an analysis of anterior cruciate ligament (ACL) injury times, the greatest tension on the ACL occured approximately 40 ms after landing, leading to injury[2)]. Based on these findings, it may be difficult to prevent ACL and other types of injuries with responses using the feedback mechanism.

Silent period (SP) is a pause in muscular electrical activity observed in surface electromyography (sEMG) before a muscular activity is started, leading to a rapid response movement[3)]. Its appearance mechanism is such that the SP appearance preceding a voluntary movement is believed to involve efferent impulses from the cerebral cortex of the frontal lobe, cerebellum, and brain stem repression domain[4)]. Switching silent period (SSP) is a muscular electrical activity SP that

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*Corresponding author. Sakiko Ito-Oonishi (E-mail: ohnishisk@stf.teu.ac.jp)

appears in both the agonist and antagonist muscles to the point preceding the start of the muscular electrical activity of the agonist muscle when a switch movement is made as quickly as possible by the agonist muscle. Hufschmidt et al., who were the first to report on SSP, considered 10–20 ms to be the minimum time needed for the inhibition mechanism5). Furthermore, Sasaki et al. considered SSP to be the time from the disappearance of the muscular electrical discharge of the agonist muscle to the start of the muscular electrical discharge of the antagonist muscle and believed that its length reflected the quality of the change between the agonist and antagonist muscles. Using predictability controls (feed-forward functions) as indicators, they reported that these reflected neuromuscular cooperativeness functions6). This study examined neuromuscular cooperativeness functions using SSP as an indicator.

Further, in a previous study, a decline in neuromuscular cooperativeness functions was observed following an ACL reconstructive surgery7), and a similar decline was observed immediately following muscle fatigue loading in healthy adults8). It is believed that sports injuries occur easily when an athlete is fatigued. Understanding the kinds of changes in neuromuscular cooperativeness functions before and after fatigue loading is believed to be essential for preventing sports injuries and examining return standards following an injury. This study aimed to use SSP and pre-motor time (PMT) to examine the chronological changes in neuromuscular cooperativeness before and after muscular fatigue in university athletes.

PARTICIPANTS AND METHODS

The participants of this study were six female university club soccer players and nine female university club regulation tennis players, forming a total of 15 participants, none of whom had a history of serious lower limb orthopedic conditions (height, 161.8 ± 9.7 cm; weight, 55.2 ± 7.2 kg; age, 20.4 ± 1.4 years). This study was approved by the Research Ethics Committee at the University of Tsukuba Graduate School of Comprehensive Human Sciences (No. 27-117). Informed consent of the participants was obtained following a complete written and oral explanation of the test contents.

The sEMG measuring device used was the sEMG MR3 myo MUSCLE Master (EM-701; Noraxon, Scottsdale, AZ, USA), and the myoelectric probe used was the earth-integrated model EMG probe TeleMyo Direct Transmission System (EM-801; Noraxon) (sampling frequency, 1,500 Hz). The data was captured on a DELL PC with blue sensors (M-00-S/50). Before attaching the electrodes, the surface of the skin was treated with alcohol antiseptic cotton, and skin impedance was brought below 5 KΩ. EMG derivation was performed using the bipolar induction method, and the distance between electrodes was set at 2 cm. The muscles measured were the rectus femoris (RF) and biceps femoris (BF); the electrodes were positioned along the center of the line connecting the anterior superior iliac spine to the patella for the RF and the two-thirds peripheral area of the line connecting the rear knee joint and the greater trochanter for the BF.

Measurements were taken using the following methods, conducted by Sasaki et al.9) and Hiragami et al10).

After 1 min in the resting decubitus position, EMG waveforms were measured for 5 s when the amplitude stabilized. This allowed for the calculation of an average electric potential in the resting decubitus position for each muscle. The average electric potential was taken as the average rectified value of the 3 s of the stabilized amplitude of the 5 s measured.

The maximum electric potential, which was taken as the absolute value of the 3 s of the stabilized amplitude of the 5 s measured, was calculated by measuring the EMG of each muscle for 5 s, when the amplitude stabilized during 10 s in a one-leg standing position with the sole on the ground.

The participants were asked to start from a one-leg standing position with the knee bent 30° and jump as quickly and as high as possible immediately after a photic stimulation, without bending the knee further or having the arms or upper body recoil (the jump task). A light was used for the photic stimulation and placed at eye level 2.0 m in front of the participant. A thorough practice was conducted in advance to prevent learning from affecting the jump task. The participants were asked to complete the jump task five times for each leg, and EMG was measured for the jump task before, immediately after, 5 min after, 10 min after, and 15 min after muscle fatigue loading.

The Biodex System 2 (Biodex Medical Systems, Shirley, NY, USA) was used for the muscle fatigue loading, wherein the participants were asked to do a flexion and extension exercise five times continuously at an angular velocity of 180°/s, during which their maximum muscle strength was measured. Then, they were asked to continue bending and stretching the knee until the RF was recorded as being 50% below the maximum muscle strength for three repetitions continuously, achieving muscle fatigue loading.

The sEMG data measured by the TeleMyo Direct Transmission System (Noraxon) were imported to a myo RESEARCH XP (EM-129M; Noraxon) and analyzed after the waveforms were rectified into full waves. PMT and SP were calculated using the following methods. PMT was taken as the RF from the photic stimulation up to the point in time surpassing maximum electric potential in the one-leg standing position or RF-on. SSP was taken from the point in time of RF-off or the point at which it went below the average electric potential of the RF in the resting decubitus position, up to BF-on, or the point in time at which the BF surpassed the maximum electric potential in the one-leg standing position.

To compare the progress before and after for the muscle fatigue loading side and the non-loading side, a two-way analysis of variance was conducted, and a multiple comparison test was conducted using the Bonferroni post-hoc test for items considered to have significance. $P<0.05$ was considered significant. The SPSS (version 21; IBM, Armonk, NY, USA) was used for statistical analyses.

RESULTS

As a result of two-way ANOVA, main effects were observed in the muscle fatigue loading factor and post-load time factor in SSP, and the interaction was confirmed ($p<0.05$). No main effect was observed in PMT for any of the factors. The SSP in the loading side immediately after loading and 5 min after loading was significantly prolonged compared with that before loading ($p<0.05$). No significant differences were observed before and after loading on the non-loading side for SSP (Table 1).

DISCUSSION

In this study, SSP was prolonged on the loading side immediately after loading, and PMT did not change over time. This was consistent with the result of a previous study8), indicating that muscle fatigue loading might immediately reduce neuromuscular coordination. Based on this, SSP is considered to better reflect the changes in neuromuscular coordination after muscle fatigue than PMT.

Regarding the causes of fatigue, various studies conducted in the past have put forth "central nervous system fatigue", which occurs in the nerves of the cerebrum or intraspinal synapses11), and "peripheral fatigue", which occurs in the motor nerve fibers, neuromuscular junctions, and muscle fibers themselves12). In this study, because the smooth transmission of stimuli in the neuromuscular junction was inhibited by the muscle fatigue loading, some influence may have been given to the muscle electrical discharge of the RF and BF. However, it was believed that SSP reflects the quality of motor control functions in the upper central nervous system13). Moreover, it was observed that prolonged SSP was due solely to the effects of mental fatigue loading8). The fatigue in muscle operation occurred in the mutual influence of central nervous system factors and peripheral factors14), and fatigue should be understood with consideration of central nervous system effects because the sense of fatigue and the mobilization of motor units are controlled by the central nervous system15). However, in this study, the participants were not surveyed on their subjective degree of fatigue, and their level of sense of fatigue was not examined. In addition, it was unclear as to which part of the brain the muscle fatigue affected. In the future, we believe examining which areas of the brain affect SSP during mental and muscle fatigue loadings will be necessary. Furthermore, in the previous study8), SSP was significantly prolonged immediately after loading for both the loading and non-loading sides; however, in this study, significant prolongation was only observed on the loading side. The healthy individuals of the previous study may have experienced fatigue more intensely after muscle fatigue loading than the university club athletes of the present study because the sense of fatigue with regard to muscle fatigue loading differed depending on the fitness levels of the participants.

In this study, SSP was significantly prolonged immediately after, 5 min after, and 10 min after muscle fatigue loading compared with that before fatigue loading. The period immediately following fatigue loading, in particular, showed approximately 45 ms of prolongation in average SSP values.

In the existing literature on muscle response after muscle fatigue, it was reported that the response time for before and after standing movements16) and before and after an ankle dorsal flexion exercise17) had a significant delay and recovered to rest levels 8 min later. Although the task behavior was different, this study also obtained largely similar results that suggested the recovery of neuromuscular cooperativeness within approximately 10 min.

This study had some limitations. First, it was unable to examine how recovery times changed depending on differences in the quantity of muscle fatigue loading. Second, it was unable to examine how the neuromuscular cooperativeness recovery process changed in cases of post-ACL reconstructive surgery, post-leg-injury, or other lower limb injury cases.

In conclusion, muscle fatigue loading instantaneously prolonged SSP and decreased neuromuscular cooperativeness. Furthermore, recovery generally occurred within 10 min. In the future, we believe it will be necessary to study the effects of changes in load quantity and compare groups of participants with lower limb injuries with groups of healthy individuals as well as increase the number of participants.

Table 1. SSP and PMT averages in the loading and non-loading sides

	Loading or Non-loading side	Before	After	After 5 min	After 10 min	After 15 min
SSP (ms)	Loading side (Mean ± SD)	42.7 ± 8.7	87.7 ± 61.6†	75.1 ± 47.0††	60.7 ± 41.3	58.0 ± 39.9
	Non-loading side (Mean ± SD)	43.8 ± 17.1	58.8 ± 20.4	49.0 ± 13.3	48.5 ± 15.7	53.7 ± 17.4
PMT (ms)	Loading side (Mean ± SD)	224.2 ± 65.9	238.7 ± 64.4	242.8 ± 62.6	238.5 ± 58.4	242.5 ± 56.2
	Non-loading side (Mean ± SD)	251.9 ± 71.7	247.1 ± 62.3	253.3 ± 59.7	243.2 ± 63.5	254.7 ± 48.0

Data are expressed as mean ± SE: n=15. SSP: switching silent period; PMT: pre-motor time.
SSP for the loading side immediately after loading (†$p<0.05$) and 5 min after loading (††$p<0.05$) was significantly high compared with that before loading. †: Before vs. After ††: Before vs. After 5 min.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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