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Neuromuscular fatigue induced by wearable small size electrical stimulation device

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1 Introduction

Electrical Muscle Stimulation (EMS) has been used in clinical settings for a long time in fields like nursing care and rehabilitation as an alternate means of exercise for people who cannot move of their own volition. In recent years, electrical muscle stimulation has come to be widely used by even healthy individuals to improve their lack of exercise or to maintain and/or improve their health. We anticipate that in the future it will be used both in everyday life and for voluntary exercise. Further, a significant training effect (increase in maximum muscle strength) has been reported by adding EMS to normal resistance training and jump training. [1] In addition, a new form of exercise has been proposed in which EMS would induce a specific metabolic response by incorporating EMS into aerobic exercise. [2] However, most of the EMS devices on the market have a lot of cables between the EMS device and the person exercising; this is because the unit itself, the controller and electrodes are separate, as well as due to the need for a power supply. If the unit and the controller are large, it is difficult to use them during activities in everyday life or during different exercises, so we anticipate the development of EMS devices that miniaturise and integrate the unit, controller and electrodes. And because it is important to make the device wearable, such as by using batteries for the power supply, in order to eliminate restrictions on the person exercising, a concern is that this will decrease the muscle output induced by the lower strength of the stimulation.

2 Purpose

The aim is to evaluate the characteristics of muscle fatigue associated with muscle contractions induced by an EMS device that has been miniaturised and made wearable.

3 Method

The research has the approval of an “Ethics Review on Research using Human Subjects” at Chukyo University (Application No. 2014-001) Further the content of measurements was explained to subjects ahead of time, their informed consent obtained in writing and the experiment conducted. The subjects were 12 males (ages: 21.4 ±1 year; height: 173.0 cm ±7.0 cm; Weight: 62.0 ± 5.8 kg; BMI: 20.7 ± 1.5). The test site was the bicep, which was measured to evaluate the muscle fatigue due to electrical stimulation and voluntary movement.

① Measurement of maximum muscle strength (MVC-PRE)

The right arm of the subject was measured with the arm fixed at a joint angle of 120 degrees (interior angle) using an isometric elbow joint flexion strength measurement device (made by VINE).

② Measurement of surface EMG median frequency (MF-PRE)

Using an electromyograph (EM-272, made by Noraxon), a surface EMG was taken with twin leads proximal to the bicep muscle while it was exhibiting submaximal muscle strength (maintaining 50% of MVC for 3 seconds) and was recorded (AB-611J, made by Nihon Kohden).

③ Exercise load

"Electrical stimulation trial"

An electrical skeletal-muscle stimulation device (made by MTG) was attached proximally to the bicep muscle, which was stimulated electrically for approximately 20 minutes while held with an elastic band. The maximum stimulation subjects could withstand was specified, which was the maximum stimulation strength of the device (40V). The stimulation frequency was at 20 Hz, which was applied continuously with 3 seconds of contraction interspersed with 2 seconds of rest.

"Voluntary movement trial"

Voluntary movement at the same level as that induced by electrical stimulation was specified, so voluntary movement (isometric elbow joint flexion movement) that exhibited the muscle strength of about 12% of maximum muscle strength was conducted for approximately 20 minutes, with 3 seconds of contraction interspersed with 2 seconds of rest.

④ Measurement (MVC-POST) of maximum muscle strength after the application of load to the muscle was made in the same way as「①」

⑤ Measurement (MF-POST) of surface EMG median frequency after the application of load to the muscle was made in the same way as 「②」

Based on the results of the foregoing, the rates of change of maximum muscle strength (MVC-POST/MVC-PRE) and that of EMG median frequency (MF-POST/MF-PRE) before and after application of load to the muscle were calculated.

4 Results

The rates of change of maximum muscle strength (MVC-POST/MVC-PRE) were 71.9% ± 5% for the electrical stimulation trial and 93.2% ± 4.2% under the voluntary movement trial, so maximum muscle strength under the electrical stimulation trial dropped significantly more ($p<0.05$).

The rates of change (MF-POST/MF-PRE) of EMG median frequency during exhibition of submaximal muscle strength were 87.0±15.7% for the electrical stimulation trial and 105.5±9.2% under the voluntary movement trial, so it dropped significantly more under the electrical stimulation trial ($p<0.05$).

5 Discussion

Because a drop in maximum muscle strength is an indication of muscle fatigue, despite the muscle output being similar, the results we obtained suggest that muscle fatigue is accelerated more by electrical stimulation than by voluntary movement.

The drop in EMG median frequency is well-known to reflect fatigue, especially peripherally (muscle itself). A drop in the median frequency was not observed with voluntary movement in this study. This fact points to the possibility that almost no peripheral fatigue was induced by voluntary movement during the 20 minutes provided.

By contrast, a drop in the median frequency was observed under electrical stimulation, despite it being such low-intensity exercise. From an electrophysiological standpoint, this supports the possibility that electrical stimulation gives rise to greater fatigue than voluntary movement suggested from the drop in maximum muscle strength.

We can also confirm this from the fact that almost no fatigue is produced when voluntary movement is at the level of 10% of maximum muscle strength. Despite such an extremely low

level of intensity in muscle output, we obtained a result that reflects that electrical stimulation gives rise to fatigue. It is thought that this is due to different motor units and/or muscle fibres being mobilised during voluntary movement versus electrical stimulation.
According to the principle of size, under voluntary movement, muscle fibres are mobilised in order, starting from the low-tension muscle fibres (so-called slow-twitch muscle) that are not readily fatigued by low-intensity exercise. On the other hand, high-tension muscle fibres (so-called fast-twitch muscle) that do fatigue easily are basically only mobilised during high-intensity exercise. It is known that electrical stimulation of skeletal muscles, the motor neurons that control them, or both, mobilises motor units randomly, which does not follow this principle of size. [3] [4]
In other words, fast-twitch muscles that are not mobilised under low-intensity voluntary movement are mobilized under electrical stimulation, even if the muscle output is low-intensity.
As was observed during this study, even though under low-intensity voluntary movement is mobilised, fatigue is not produced, the low intensity movement is what caused an increase in fatigue under electrical stimulation.
From the foregoing results, the inference is that the wearable EMS device used in the study can induce specific muscular fatigue via EMS.

References

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