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Original Article

The Influence of Neuromuscular Electrical Stimulation on the Heart Rate Variability in Healthy Subjects

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Abstract. [Purpose] The purpose of this study was to examine the effect of neuromuscular electrical stimulation (NMES) on heart rate variability (HRV). [Subjects and Methods] Ten healthy subjects participated in the study. All subjects received NMES with a pulse duration of 300 us and frequency of 30 Hz at the vastus lateralis and vastus medialis for 15 minutes. The stimulation intensity was adjusted in the range of 20 to 30 mA. HRV using a pulse oximeter was measured in the sitting position before and after NMES. [Results] After the NMES, all HRV data slightly increased, but there was no significance between before and after data. [Conclusion] We suggest that strengthening exercises using NMES may be undertaken safely.
Key words: Neuromuscular electrical stimulation, Heart rate variability, Strengthening exercise

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INTRODUCTION

Muscle strengthening exercise is effective in preventing and improving musculoskeletal and cardiovascular system problems[1)]. It increases sympathetic activity and decreases parasympathetic activity, thereby heightening the heart rate. When the exercise is finished, the sympathetic activity decreases and the parasympathetic activity increases, reducing the heart rate and returning it to normal[2)]. This type of autonomic nervous system balance plays an important role in maintaining the health of the cardiovascular system[3)].

High-intensity muscle contraction performed within a short time may affect the activity of the autonomic nervous system. In particular, resistive exercise conducted for a short time is known to decrease cardiac vagal control[4)]. Cardiac stress may be triggered by a continued increase in sympathetic activity and a simultaneous decrease in parasympathetic activity, causing health problems[5, 6)].

A physical therapist may enhance muscle strength by triggering muscle contraction through neuromuscular electrical stimulation[7)]. Muscle strengthening by NMES may affect a person's autonomic nervous system balance in a similar way to resistance exercise. Current research on electrical stimulation and autonomic nervous system balance mostly concerns transcutaneous electrical stimulation, and research on the effects of NMES on muscle strengthening and autonomic nervous system balance is insufficient[8)]. Given that there are many patients who should not be exposed to cardiac stress in a physical therapy setting, the effects of NMES on autonomic nervous system balance need to be examined. Accordingly, this study contracted the quadriceps muscle using NMES and measured the variability in the heart rate to examine the effects of NMES on autonomic nervous system balance.

SUBJECTS AND METHODS

This study included 10 healthy adult males who had no history of disease related to the cardiovascular system and autonomic nervous system (ANS) and had the same daily routines. The average age, weight, and height of the subjects were 22±2 years, 65±3.2 kg, and 164.2±4.1 cm, respectively. All the subjects signed an informed consent form, and the study was approved by the institutional review board of the Catholic University of Pusan (document number: CUPIRB-2013-012).

The temperature and humidity of the experimental room were maintained at 23 °C and 65%, respectively, outside noise was blocked, and the experimental area was enclosed with a curtain to minimize environmental influences. The experiment was conducted only between 17:00 and 18:00 PM. From 48 hours prior to the experiment, the subjects were forbidden to perform exercise, overeat, or drink alcohol. From 4 hours prior to the experiment, they were required to fast and restricted from smoking or consuming drinks containing caffeine.

They were advised to wear comfortable clothes. Prior to

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starting the NMES stimulation, they rested on a chair for 10 minutes. For NMES stimulation, a subject sat on a chair and flexed the hip joint and the knee joint at 90 degrees. The electrodes were attached to the motor points of the vastus lateralis and vastus medialis. Using an ES-420 low-frequency electrotherapy unit (ITO, Tokyo, Japan), asymmetrical biphasic rectangular wave stimulation was applied to the motor points for 15 minutes. The wave was set at a pulse width of 300 us with an on-time of 10 sec, and an off-time of 10 sec. The intensity of the stimulation was adjusted in the range of 20 to 30 mA when the subject's knee joint was fully extended.

In a sitting position, the subject's right hand was placed at the same height as the subject's heart, and a uBplus T1 pulse oximeter (LAXTHA Inc., Daejeon, Korea) was attached to the right index finger. The heart rate variability (HRV) was measured before and after NMES. The following items were analyzed: heart rate (HR), high-frequency (HF) oscillation power, low-frequency (LF) oscillation power, standard deviation of all normal R-R intervals (SDNN), total power (TP), and the HRV index. The Wilcoxon test was conducted on the obtained data with SPSS 18.0, and the significance level was set at α=0.05.

RESULTS

After the NMES stimulation, the heart rate, LF, HF, SDNN, TP, and HRV index all slightly increased, but the increases were not significant (Table 1).

Table 1. Comparison of HRV between beforeand after the intervention

	Before NMES	After NMES
HR (bpm)	73.3±2.3	73.6±2.6
LF (ms^2)	6.4±0.1	6.8±0.2
HF (ms^2)	5.8±0.2	6±0.2
SDNN (ms)	47.2±4.1	55.1±5
TP (ms^2)	7.3±0.1	7.7±0.1
HRV index	13±0.8	14.3±1.1

All data represents the mean±SE

DISCUSSION

Pulse oximeters process biological signals in a safe and precise way and monitor them on a real-time basis[9]. They are also noninvasive and efficient in evaluating the ANS[10]. This study measured the HRV using a pulse oximeter, and consistent data with a small standard error were obtained.

Strengthening exercise may affect the activities of the ANS by increasing sympathetic and decreasing parasympathetic activity[2]. This study attempted to apply NMES training similar to strengthening exercise to the subjects. We used a 30 Hz biphasic pulse, which may trigger tetanic contractions, with an on-time of 10 sec and an off-time of 10 sec. Therefore, the duty cycle was 50%. The pulse duration, which greatly affects the formation of quadriceps strength, was set at 300 µsec[11, 12]. The knee joint was fully extended in a sitting position. The intensity of the stimulation was adjusted continuously to maintain full extension during the on-time between a minimum of 25 mA and a maximum of 35 mA. Muscle fatigue was not observed in the subjects during the experiment.

The electrical stimulation slightly increased the LF oscillations and the HF oscillations, reflecting the activity of the sympathetic and the parasympathetic nerves, respectively. However, the increases were not significant. The rates of the subjects heart showed almost no change. Thus, the muscle strengthening exercise using NMES did not affect the sympathetic or parasympathetic nervous systems. After the application of NMES, the SDNN, reflecting the ability to resist stress, and the TP, reflecting the ability to adjust the ANS, slightly increased. However, these changes were not significant. NMES did not influence the stress resistance ability or the ability to adjust the ANS. The HRV index also slightly increased, but the increase was not significant. The NMES did not affect the HRV index. The above results show that NMES can potentially be used as a safe muscle strengthening tool.

However, electrical stimulation may modulate the activity of the sympathetic and the parasympathetic nerves. Stein et al.[8] asserted that 10 Hz of electrical stimulation to the paravertebral ganglionar region may decrease the LF and increase the HF and that 100 Hz of electrical stimulation may increase the LF and decrease the HF. The present study used 60 Hz, which is a relatively high frequency, but the results were not consistent with those of Stein et al[8]. In several studies, changes in sympathetic tone have been observed as a result of spinal cord electrical stmulation[13–15]. Hsin et al.[16] reported that electrical stimulation at the nuchal region may increase sympathetic tone and decrease parasympathetic activity. Because the paravertebral regions are important sites of an anatomical autonomic organization, electrical stimulation can easily influence the autonomic nervous system[17, 18].

Wong et al.[19] applied electrical stimulation to acupuncture points of the hand and forearm and observed increased activity of the sympathetic nervous system. The sympathetic activity slightly increased in the present study, but the increase was not significant. Although the physiological mechanism has not yet been discovered, acupuncture points are known to affect the autonomic nervous system. Syuu et al.[20] reported that electrical stimulation of the neiguan point of the forearm flap may influence cardiovascular function. The discord between the results of this study and the other studies is likely due to the differences in the areas where the electrical stimulation was applied. In the previous studies, the electrodes were attached to the paravertebral ganglionar region or the acupuncture point, whereas they were attached to the motor points in the present study. The quadriceps muscle strengthening exercise using NMES did not change the balance of the ANS. This finding suggests that NMES may be safely applied to those who have diseases that affect the ANS. Future research to examine long-term NMES in a large number of subjects with diverse diseases who are undergoing long-term NMES is considered necessary.

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