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Original Article

Effects of simultaneous short-term neuromuscular electrical stimulation and static stretching on calf muscles

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Abstract. [Purpose] The simultaneous application of static stretching and neuromuscular electrical stimulation (NMES) to calf muscles may enhance physiological parameters in young and healthy individuals; however, the efficacy of this intervention and potential sex variation remain to be elucidated. The present study aimed to investigate these aspects. [Participants and Methods] Thirty healthy university students (15 males and 15 females) participated in this study. All participants simultaneously underwent static stretching and NMES of the calf muscles for 4 min while lying on an upright and tilted table. The mean differences in the dorsiflexion angle (DFA), finger-floor distance (FFD), and straight leg raising (SLR) angle before and after the intervention were calculated. Sex variations were assessed using a two-way analysis of variance (ANOVA). [Results] The DFA, FFD, and SLR angle exhibited significant effects on time. No significant sex variations were observed between the groups. [Conclusion] Simultaneous static stretching and NMES of the calf muscles potentially enhanced the DFA, FFD, and SLR angle in healthy university students, irrespective of sex.
Key words: Calf muscles, Neuromuscular electrical stimulation, Static stretching

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INTRODUCTION

Neuromuscular electrical stimulation (NMES) is a commonly used electrotherapy technique that induces involuntary muscle contractions through electrical currents to enhance and/or restore neuromuscular function[1]. Frequently, electrical stimulation is applied to muscle, primarily mobilizing the motor units directly beneath the electrodes in a non-physiological sequence, that is, synchronously and spatially[2]. In adult rats, concurrent passive static stretching and electrical stimulation of muscle tissue better reduced the number of sarcomeres than did passive static stretching alone[3]. A decrease in sarcomere number signifies muscle shortening[4]. In males, proprioceptive neuromuscular facilitation (PNF) stretching with NMES enhanced hamstring flexibility more than did PNF stretching without NMES[5]. Therefore, simultaneously applied passive stretching and muscle contraction may effectively ameliorate muscle shortening.

Although simultaneous application of passive tissue stretching and NMES is a promising strategy for elongating muscle tissues, two primary concerns need to be addressed. First, this intervention has only been considered in the context of

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interventions performed by practitioners. *In vivo* experiments involving only muscle stretching with machines[3], as well as studies on the efficacy of static stretching alone not involving a practitioner in healthy individuals[6], have been performed. However, the effect of the combination of practitioner independent co-application of static stretching and NMES is unclear. Second, sex differences in the efficacy of simultaneous application of static stretching and NMES is unclear. The effects of static stretching alone are greater in males than in females[7]. Our hypotheses are as follows: (1) practitioner-free static stretch and NMES applied simultaneously to calf muscles will enhance physical parameters such as flexibility and muscle strength in healthy young individuals, (2) the effect of simultaneous intervention is greater in males than in females. Toward the goal of establishing new intervention measures for improving muscle flexibility, this study to investigate the extent of the effects of simultaneous application of static stretching and NMES on physical parameters in healthy young individuals, as well as sex differences in intervention effects.

PARTICIPANTS AND METHODS

Our study comprised physically healthy university students. The exclusion criteria were as follows: (1) lower limb injury in the past 6 weeks, (2) lumbar spine pathology in the past 6 weeks, and (3) lower limb surgery in the past 6 months or major ligament surgery in the past year. The participants were recruited using bulletin boards within the university. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Review Board of International University of Health and Welfare (protocol code: #23-Io-34, date of approval: November 15, 2023). Informed consent was obtained from all participants involved in the study.

The participants were positioned on a tilt table set to stretch the calf muscles and received NMES for 4 min. The tilt table angle was set at 90°, and the ankle angle was adjusted to provide a strong but tolerable stretch sensation as reported by the participant. To apply NMES, self-adhesive electrodes measuring 5 × 9 cm were placed over the motor points of both the medial and lateral areas of the gastrocnemius muscle. NMES was administered using a low-frequency stimulator (ESPURGE; Ito Co., Ltd, Saitama, Japan) with a pulse width of 250 µs and a frequency of 50 Hz, following the method of Pérez-Bellmunt et al[5]. The stimulation time was 15 s, followed by a rest period of 45 s, for a total duration of 4 min and a total stimulation time of 60 s. The participant set the stimulation intensity to the maximum tolerable level and was encouraged to increase the intensity as much as possible.

The primary outcome was the dorsiflexion angle (DFA). The DFA was measured using a digital inclinometer smartphone (iPhone 13 mini, iOS16.7.1) fixed to the midline of the anterior aspect of the lower leg. This method has high intrarater reliability as previously reported by our group[8]. Participants were instructed to keep the sole of their foot on the floor and lean their lower leg forward while the smartphone measured the DFA. The DFA measured by the smartphone was considered as the maximum dorsiflexion angle, with the floor as 0°.

The secondary outcomes were straight leg raising (SLR) angle, finger-floor distance (FFD), and plantar flexor strength (PFS). The SLR angle was measured using the same digital inclinometer smartphone application as used for the DFA measurement. Participants lay in a supine position with the smartphone fixed at the midline of the lower leg. Before lifting the lower leg, the inclinometer was calibrated to 0°, and the maximum angle of leg elevation was measured. FFD and PFS were measured using a digital flexibility testing device (T.K.K.5403; Takei Scientific Instruments, Tokyo, Japan) and handheld dynamometer (Mobie MT-100; Sakai Medical Co., Ltd, Tokyo, Japan), respectively. All physical parameters were measured by a single physical therapist blinded to the intervention.

The results were presented as mean ± standard deviation. The sample size calculation was based on data from preliminary measurements conducted on eight participants (4 males and 4 females). G*Power 3.1.9.4 (Heinrich Heine University, Düsseldorf, Germany) was employed for power analysis. Demographic information for the male and female groups was compared using Student's t-test. Differences in physical parameters before and after intervention were expressed as mean (95% CI). Sex differences in the intervention effects were evaluated using two-way ANOVA with time and group as factors. Statistical analysis was performed using SPSS Statistics ver. 27 (IBM, Armonk, NY, USA). A p-value <0.05 was considered statistically significant.

RESULTS

The results of an a priori power analysis indicated that the total sample size for the study was 30 participants (two-tailed effect size d=0.62, type I error probability=0.05, power [1- type II error probability]=0.9). Accordingly, the study included 15 males and 15 females, all of whom met the eligibility criteria. The participants' demographic information is presented in Table 1. Height and weight were significantly greater in the male vs. female group ($p<0.01$ and $p<0.01$, respectively), whereas age and body mass index did not differ significantly.

Participants received 4 minutes of static stretching and NMES for calf muscles on a tilt table. The physical parameters of the participants before and after simultaneously applied static stretching and NMES are presented in Table 2. The intervention increased the DFA by 2.17° (95% confidence interval [CI]: 0.99–3.34), FFD by 2.70 cm (CI: 1.98–3.42), SLR angle by 3.97° (CI: 2.22–5.71), and PFS by 0.002 Nm/kg (CI: −0.105–0.108).

The results of a two-way analysis of variance revealed no interaction effects for DFA, FFD, or SLR angle; however, a significant main effect of time factor was observed (p<0.01) (Table 3). Although there were no significant interaction effects for PFS, a significant main effect was observed for group factor (p<0.01).

DISCUSSION

This study aimed to evaluate the effects of simultaneous application of static stretching and NMES on the physical parameters of healthy university students; the calf muscles were specifically targeted, and potential sex differences were investigated. Our findings showed that simultaneous application improved DFA, FFD, and SLR scores. In addition, contrary to the hypothesis, significant sex differences were not detected in the intervention effects. The efficacy of static stretching alone in improving the DFA has been substantiated in numerous studies[9–11]. In the present study, the DFA had increased by 2.17° (95% CI: 0.99–3.34) after 4 min of simultaneous stretching and NMES of the calf muscles. In our previous report, the minimal detectable change in the DFA measured using a smartphone was 1.4°[8]. Thus, the change in the DFA resulting from the simultaneous stimulation may signify improvement beyond measurement error. According to a previous review[12], the weighted mean difference in the DFA before vs. after static stretching for 15–30 min is 3.03° (95% CI: 0.31–5.75). Thus, the

Table 1. Participant's demographic data

	Male (n=15)	Female (n=15)
Age, years	21.6 ± 0.8	21.3 ± 0.8
Height, cm	170.5 ± 6.2	156.5 ± 8.3**
Weight, kg	64.0 ± 9.2	52.4 ± 8.3**
BMI, kg/m^2	21.9 ± 2.4	21.4 ± 3.7

Mean ± standard deviation. **p<0.01.
Student's t-test was used to compare males and females.
BMI: body mass index.

Table 2. Change of participants' physical parameters

	Pre	Post	Mean difference	95% CI	
				Lower	Upper
DFA, degrees	38.4 ± 5.5	36.3 ± 5.3	2.17	0.99	3.34
FFD, cm	−0.8 ± 8.5	1.9 ± 8.8	2.70	1.98	3.42
SLR, degrees	66.3 ± 14.8	70.2 ± 14.7	3.97	2.22	5.71
PFS, Nm/kg	1.20 ± 0.50	1.20 ± 0.47	0.002	−0.105	0.108

Mean ± standard deviation.
DFA: dorsiflexion angle; FFD: finger-floor distance; SLR: straight leg raising; PFS: plantar flexor strength; 95% CI: 95% confidence interval.

Table 3. Sex differences in treatment effects

		Pre	Post	Main effect		Interaction
				Time	Group	
DFA, degrees	Male	39.2 ± 5.4	36.5 ± 4.6	**		
	Female	37.7 ± 5.7	36.0 ± 6.0			
FFD, cm	Male	−0.9 ± 7.6	1.4 ± 7.1	**		
	Female	−0.7 ± 9.7	2.3 ± 10.4			
SLR, degrees	Male	62.9 ± 13.1	66.5 ± 11.2	**		
	Female	69.7 ± 16.0	74.0 ± 17.0			
PFS, Nm/kg	Male	1.57 ± 0.39	1.44 ± 0.42		**	**
	Female	0.84 ± 0.30	0.97 ± 0.41			

Mean ± standard deviation. **p<0.01.
Two-way ANOVA was used to evaluate the difference between males and females in intervention effect.
DFA: dorsiflexion angle; FFD: finger-floor distance; SLR: straight leg raising; PFS: plantar flexor strength; ANOVA: analysis of variance.

effects of 4 min of static stretching and NMES may be equivalent to those of 15–30 min of static stretching alone. From the perspective of human and time resources, our intervention method may provide greater benefits.

Broadly, there are two benefits of adding NMES to static stretching. First, NMES can inhibit muscle stretching pain. Previous studies have shown that NMES of the calf muscles relieves pain through both the peripheral and central nervous systems[13, 14)] and that the pain threshold increases immediately following NMES[13)]. By combining static stretching with NMES, participants can expand their DFA in a state where the stretching pain of the calf muscles is suppressed. Second, NMES can achieve muscle tension relaxation via short-latency autogenic (Ib) inhibition. This effect has been demonstrated in patients with neurological disorders such as stroke and spinal cord injuries, as well as in healthy individuals[15–19)]. Ib inhibition occurs when Golgi tendon organs transmit the tension generated during muscle contraction or stretching to the spinal cord via Ib fibers originating from these organs. The transmitted information is then relayed to α motor neurons via inhibitory interneurons, resulting in the suppression of muscle tension[20)]. This may explain how NMES effectively elongates muscles in a short period of time.

Several studies have shown that static stretching alone decreases muscle strength and performance by inhibiting the central nervous system or reducing tendon stiffness[21, 22)]. Our results, however, did not show a decrease in PFS after simultaneously applied static stretching and NMES, thus indicating that the dual intervention has fewer adverse events than does static stretching alone. Intriguingly, our intervention favorably affected the SLR angle and FFD. One possible explanation for this is the significant continuity of the fascia between the posterior aspect of the hamstring and gastrocnemius muscles[23)]. The role of the fascia in the transmission of biomechanical forces between adjacent regions of the body has been described[24, 25)]. Therefore, the continuity, overlap, and compartmentalization of muscle tissue by the fascia may account for the beneficial effects on the dual intervention on hamstring flexibility.

Although our study suggests the potential effectiveness of the simultaneous application on the physical parameters of healthy university students, it has several limitations. First, owing to the lack of a control group with either NMES or static stretching in this study, causality between the simultaneous application and outcomes cannot be proven. Therefore, future randomized controlled trials are needed. Second, our interpretation of the extent of the intervention effects requires further statistical analysis. Equivalence and non-inferiority between simultaneous application and static stretching alone should be assessed by setting equivalence/non-inferiority margins based on previous findings and using a statistical approach. Finally, because this study targeted university students from a single institution, external validity is uncertain. Therefore, future research with larger-sized, more diverse cohorts is warranted.

Our results suggest that simultaneous application of static stretching and NMES of the gastrocnemius muscle enhanced several physical parameters in healthy university students. The effects of this intervention should be further investigated in randomized controlled trials with a control group to provide more detailed insights.

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Conflict of interest

The authors declare no conflict of interest.

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