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Original Article

# Effects of simultaneous neuromuscular electrical stimulation and static stretching on flexibility and strength: a randomized controlled trial

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**Abstract.** [Purpose] This study aimed to determine the effects of simultaneous neuromuscular electrical stimulation (NMES) and static stretching on flexibility and muscle strength. [Participants and Methods] A randomized controlled trial was conducted with 96 healthy university students equally assigned to either a simultaneous NMES and static stretching group (Group S) or an NMES-only group (Group C). The gastrocnemius muscle was the target of both NMES and static stretching. Ankle dorsiflexion angle (DFA), forward flexion distance (FFD), and ankle plantar flexor strength (PFS) were measured before and directly following intervention. Outcomes in the two groups were evaluated using two-way analysis of variance. [Results] A significant time effect was observed for both DFA and FFD, whereas a significant interaction effect was observed for FFD only. Improvements in DFA were similar between the groups; however, improvements in FFD were significantly greater in Group S. PFS showed no significant interaction between the group and the time factor. [Conclusion] Our findings suggest that simultaneous intervention enhances flexibility. Despite targeting the gastrocnemius muscle, the observed improvement in hamstring flexibility may have been because of fascial connections. These findings support the efficacy and safety of NMES combined with static stretching for increasing flexibility.

**Key words:** Neuromuscular electrical stimulation, Dorsiflexion angle, Forward flexion distance

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## INTRODUCTION

Neuromuscular electrical stimulation (NMES) employs external electrical stimuli to induce muscle contractions, widely applide to enhance muscle strength and re-educate muscle activity. Numerous studies have demonstrated the efficacy of NMES in augmenting muscle strength and preventing muscle atrophy[1]. However, the individual effects of NMES on muscle strength and flexibility remain unclear. Static stretching is a technique that involves maintaining a muscle in a lengthened position for a specific duration, which improves flexibility. Various studies have reported the effectiveness of static stretching in enhancing joint range of motion (ROM) and flexibility[2]. Nonetheless, the impact of static stretching on muscle strength is inconsistent, with some research suggesting potential muscle strength reduction[3], whereas other studies indicate negligible effects[4]. Simultaneous NMES and static stretching can synergize the benefits of both methods and effectively improve

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muscle strength and flexibility. However, research on the combined effects of NMES and static stretching is limited, with insufficient evidence regarding their efficacy and optimal combination. Existing studies have predominantly focused on single intervention methods and lack a comprehensive examination of the synergistic effects of their combinations. This study aimed to clarify the immediate effects of simultaneous NMES and static stretching on flexibility and muscle strength. Specifically, a randomized controlled trial was conducted with healthy university students who were randomly assigned to a group receiving simultaneous NMES and static stretching (Group S) or a group receiving only NMES (Group C), with pre- and post-intervention comparisons. This study sought to provide new insights into the combined effects of NMES and static stretching on flexibility and muscle strength, contributing to optimizing intervention strategies in physiotherapy and sports training. Therefore, this study aimed to establish a foundation for practical applications and potential implementation in clinical and athletic settings by clarifying the effects of simultaneous NMES and static stretching.

## PARTICIPANTS AND METHODS

A randomized parallel-group clinical trial was conducted to elucidate the effects of simultaneous NMES and static stretching on flexibility and muscle strength. Ninety-six healthy university students (48 males, 48 females; mean age 21.3 years) were recruited as participants. Using G-power 3.1.9.4 version (Heinrich-Heine-Universität, Düsseldorf, Germany), effect size=0.58[5)], αlevel=0.05, and power=0.8, the required appropriate sample size was calculated to be 96. Physically active individuals, who exercised at least once a week, were included in the study. The exclusion criteria were based on the previous research by Igawa et al.[6)]: (1) lower limb injuries within the past six weeks, (2) lumbar spine conditions within the past six weeks (e.g., known lumbar spine conditions restricting ROM, previous lumbar spine surgery, and known lumbar-sacral physical disabilities affecting ROM and function), and (3) lower limb surgery within the past six months or major ligament surgery within the past year. Participants were recruited via bulletin board notices at the university. This research was conducted at a private medical university in the Kanto area of Japan. The participants received written and verbal explanations prior to the study and provided written informed consent. This study was approved by the ethics committee of the International University of Health and Welfare, and all research procedures were carried out in accordance with the Helsinki Declaration (No. 23-Io-34; institutional date, 2023/11/15).

GraphPad Software (GraphPad Software Inc., La Jolla, CA, USA) was used for randomization and a researcher blinded to the participants' attributes prepared the allocation schedule. A 1:1 block randomization stratified by sex was performed. Allocation concealment was ensured through central registration. An independent researcher, who was not involved in creating the allocation schedule, sequentially assigned the participants to groups.

Participants assigned to the simultaneous NMES and static stretching group (Group S) had to stand on a tilt table to stretch their calf muscles and received electrical stimulation for 4 minutes. Electrical stimulation was applied to the motor point. Participants assigned to the NMES-only group (Group C) received electrical stimulation of the calf muscles in the supine position. NMES was administered using a low-frequency stimulator (ESPURGE; Ito Co., Ltd, Saitama, Japan), set at a pulse width of 250 µs and a frequency of 50 Hz, with 15 s of stimulation and 45 s of rest, for a total of 4 minutes (cumulative stimulation time of 60 s) according to Pérez-Bellmunt et al.'s method[7)]. The stimulation intensity was set to the maximum tolerable level for each participant with encouragement to increase the intensity as much as possible.

The primary outcome measures were dorsiflexion angle (DFA) and forward flexion distance (FFD). DFA was measured using a digital inclinometer smartphone application (iPhone 13 mini, iOS16.7.1, Apple, Cupertino, CA, USA). The participants were instructed to tilt their legs forward without lifting the soles of their feet from the floor, and the examiner measured the DFA using a smartphone fixed to the center of the ventral side of the lower leg. This method has high intra-rater reliability, as our group previously reported[8)]. The DFA, measured using a smartphone, was the maximum forward tilt angle of the leg when the floor was set at 0°. Therefore, a smaller DFA value indicates a larger ankle dorsiflexion ROM. FFD was measured using a digital forward flexor (T.K.K.540; Takei Machinery Industry, Niigata, Japan). Ankle plantar flexor strength (PFS) was measured using a fixation belt in the setting position as a secondary outcome measure[8, 9)]. PFS was measured using a manual muscle strength-measuring device (Mobie, Sakai Medical Co., Ltd., Tokyo, Japan). These outcome measures were reassessed immediately after intervention. A blinded researcher performed all measurements.

Changes in outcomes between the two groups were compared using an independent t-test. A mixed-model two-way analysis of variance (ANOVA) with group and time factors was performed to compare the data between the two groups. All statistical analyses were conducted using SPSS Statistics Ver.27 (IBM Corp., Armonk, NY, USA), with the significance level set at $p<0.05$.

## RESULTS

The mean age was 21.7 ± 1.0 years in the intervention group (24 men, 24 women) and 21.4 ± 0.8 years in the control group (24 men, 24 women). Table 1 presents the participants' demographic information. All participants received the assigned intervention and participated in post-intervention outcome measurements. A two-way ANOVA showed a main effect of the time factor on the DFA but no significant interaction between the group and the time factor. FFD showed a main effect of the time factor and interaction (Table 2). PFS showed neither a main effect nor an interaction. Although the difference in DFA between the two groups was not significant, a significant difference was observed in the change in the FFD (Table 3). No adverse events were observed in either of the groups.

## DISCUSSION

This study aimed to address the knowledge gap on the effects of simultaneous NMES and static stretching on muscle strength and flexibility. As highlighted in the introduction section, there is a lack of evidence regarding the simultaneous effects of NMES and static stretching. We evaluated the changes in DFA, PFS, and FFD among healthy university students subjected to simultaneous NMES and static stretching interventions versus NMES alone.

Our findings demonstrated a significant main effect of time on DFA but no significant interaction between group and time; this suggests that although NMES alone may enhance muscle flexibility, the addition of static stretching does not significantly contribute to further improvement in DFA. In contrast, for the FFD, a significant main effect of time and a significant interaction were observed. This indicates that Group S exhibited a significantly greater improvement in flexibility than Group C,

**Table 1.** Participant's demographic data

| | Group S (n=48) | Group C (n=48) |
|---|---|---|
| Age, years | 21.7 ± 0.8 | 21.4 ± 0.8 |
| Gender, n (%) | | |
| Male | 24 (50.0) | 24 (50.0) |
| Female | 24 (50.0) | 24 (50.0) |
| Height, cm | 165.0 ± 9.7 | 164.3 ± 8.3 |
| Weight, kg | 59.5 ± 11.7 | 61.0 ± 13.2 |
| BMI, kg/m$^2$ | 21.7 ± 2.8 | 22.5 ± 3.7 |

Mean ± standard deviation. *p<0.05.
Group S: receiving simultaneous neuromuscular electrical stimulation (NMES) and static stretching; Group C: receiving only NMES.
BMI: body mass index.

**Table 2.** Group differences in treatment effects

| | | Baseline | Immediate after | Group | Time | Interaction |
|---|---|---|---|---|---|---|
| DFA, deg | Group S | 39.1 ± 5.6 | 36.7 ± 5.1 | | * | |
| | Group C | 39.9 ± 7.2 | 37.5 ± 6.3 | | | |
| FFD, cm | Group S | −0.4 ± 8.2 | 2.2 ± 8.2 | | * | * |
| | Group C | 1.6 ± 9.9 | 3.2 ± 9.6 | | | |
| PFS, Nm/kg | Group S | 1.27 ± 0.45 | 1.29 ± 0.44 | | | |
| | Group C | 1.25 ± 0.42 | 1.25 ± 0.48 | | | |

Mean ± standard deviation. *p<0.05.
Two-way ANOVA was used to evaluate the difference between males and females in intervention effect.
Group S: receiving simultaneous neuromuscular electrical stimulation (NMES) and static stretching; Group C: receiving only NMES.
DFA: dorsiflexion angle; FFD: forward flexion distance; PFS: plantar flexor strength; ANOVA: analysis of variance.

**Table 3.** Change of participants' physical parameters.

| | Group S | Group C | Mean difference | 95% CI | | p-value |
|---|---|---|---|---|---|---|
| | | | | Lower | Upper | |
| DFA, deg | −2.4 ± 3.2 | −2.3 ± 3.2 | −0.02 | −1.31 | 1.27 | |
| FFD, cm | 2.6 ± 2.1 | 1.6 ± 1.9 | 1.04 | 0.22 | 1.85 | * |
| PFS, Nm/kg | 0.025 ± 0.261 | −0.006 ± 0.324 | 0.031 | −0.088 | 0.151 | |

Mean ± standard deviation. *p<0.05.
An independent t-test. was used to compare males and females.
Group S: receiving simultaneous neuromuscular electrical stimulation (NMES) and static stretching; Group C: receiving only NMES.
DFA: dorsiflexion angle; FFD: forward flexion distance; PFS: plantar flexor strength; CI: confidence interval.

demonstrating the effectiveness of adding static stretching to NMES for enhancing FFD. FFD serves as a measure of hamstring flexibility[10]. Although our intervention targeted the gastrocnemius, the observed improvement in hamstring flexibility could be attributed to the myofascial connection between the gastrocnemius and hamstrings, known as the Superficial Back Line[11]. Previous studies have reported that myofascial interventions can have remote effects, suggesting that stretching of the gastrocnemius may indirectly facilitate hamstring stretching through myofascial linkage[6, 8, 12]. Therefore, simultaneous NMES and static stretching might improve flexibility in both the targeted muscle and muscles further away.

The neurophysiological background of flexibility improvement with NMES includes the following. Previous studies have reported that NMES of the calf muscles alleviates pain through both the peripheral and central nervous systems[13, 14]. Another study has shown that the pain threshold increases immediately after NMES[13]. Additionally, muscle relaxation can be achieved through the Ib inhibition mechanism[15–17].

These findings are consistent with the existing literature, which underscores the benefits of static stretching in improving flexibility. Behm et al. demonstrated the flexibility-enhancing effects of static stretching, which are consistent with our results[2]. Additionally, Simic et al. suggested that the effect of static stretching on muscle strength was limited, which corresponds to our DFA findings[4]. However, contrary to the findings suggesting that static stretching may induce some degree of muscle strength reduction, as Kay et al. demonstrated, this study did not observe any decline in muscle strength and, thus, confirmed its safety[3].

Our findings suggest that the combination of NMES and static stretching is effective in improving flexibility; however, further research is required. Future research should explore different intervention durations and frequencies to assess the long-term effects. Only healthy university students participated in this study; therefore, the results may not be generalizable to athletes or patients, and the impact across various age groups and levels of physical activity should be investigated. In addition, differences in body position between the two groups could have affected the results. Our results suggest that simultaneous NMES and static stretching are effective and safe interventions to improve flexibility (FFD). The additional effect of static stretching on DFA improvement was limited; however, the significant enhancement in FFD underscores the efficacy of the combined intervention.


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## *Conflict of interest*

The authors declare no conflict of interest.

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