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Original Article

Immediate Effect of Neuromuscular Electrical Stimulation on Balance and Proprioception During One-leg Standing

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Background: Neuromuscular electrical stimulation (NMES) is a physical modality used to activate skeletal muscles for strengthening. While voluntary muscle contraction (VMC) follows the progressive recruitment of motor units in order of size from small to large, NMES-induced muscle contraction occurs in a nonselective and synchronous pattern. Therefore, the outcome of muscle strengthening training using NMES-induced versus voluntary contraction might be different, which might affect balance performance.

Objects: We examined how the NMES training affected balance and proprioception.

Methods: Forty-four young adults were randomly assigned to NMES and VMC group. All participants performed one-leg standing on a force plate and sat on the Biodex (Biodex R Corp.) to measure balance and ankle proprioception, respectively. All measures were conducted before and after a training session. In NMES group, electric pads were placed on the tibialis anterior, gastrocnemius, and soleus muscles for 20 minutes. In VMC group, co-contraction of the three muscles was conducted. Outcome variables included mean distance, root mean square distance, total excursion, mean velocity, 95% confidence circle area acquired from the center of pressure data, and absolute error of dorsi/plantarflexion.

Results: None of outcome variables were associated with group ($p > 0.35$). However, all but plantarflexion error was associated with time ($p < 0.02$), and the area and mean velocity were 37.0% and 18.6% lower in post than pre in NMES group, respectively, and 48.9% and 16.7% lower in post than pre in VMC group, respectively.

Conclusion: Despite different physiology underlying the NMES-induced versus VMC, both training methods improved balance and ankle joint proprioception.

INTRODUCTION

A neuromuscular electrical stimulation (NMES) is a physical modality that uses electricity to elicit contraction of skeletal muscles for pain control [1,2], edema control [3,4], re-education of muscle functions [5-8], improving circulation [9-11], facilitating tissue healing [12-14], and/or muscle strengthening [15-17]. Because of its convenience (battery-powered and portable) and safety (the intensity of the electrical current delivered to individuals is far below harmful levels), the device has become commercially available for individuals to use at home or facilities without a clinician's supervision. In particular, the NMES is popular to enhance the outcome of muscle strengthening exercise training, and research evidence supports its benefits [18,19].

Physiologically, muscle strengthening is a result of increased muscle size (muscle mass adaptations) and improved motor unit recruitment pattern (non-muscle mass adaptions) [20]. These changes occur with repetitive contractions and relaxations of muscle fibers caused by volitional or electrical control, or both. Caggiano et al. [21] and Kamel and Yousif [22] have shown the effect of improving muscle strength when the voluntary muscle contraction (VMC) and NMES are applied independently or simultaneously. But, the VMC follows the progressive recruitment of motor units in order of size from small to large depending on the severity of a task (i.e., the magnitude of external load or perturbation) (Henneman [23]'s size principle) and the level of tibialis anterior muscle activation to maintain balance while standing increases up to 29.0% as the severity of perturbation (i.e., horizontal translation of a floor on which individuals stand on) increases from small to large [24]. Whereas, the NMES-induced muscle contraction disrespects the physiology, causing the muscle fibers to contract in a nonselective and synchronous pattern [25-28]. Therefore, muscle strengthening training with NMES might change the normal physiology of muscle contraction, leading to change in the balance maintaining strategy while standing.

Proprioception is an ability to recognize locations and movements of body segments, and is known to be a biomarker of one's postural stability. Proprioception can be measured using the Biodex equipment [29]. Chen and Qu [30] have measured the proprioception along with balance, and found that the proprioception declined when static balance decreased. Furthermore, Coelho et al. [31] have found that the proprioception improved when dynamic balance increased. Collectively, these studies suggest that the proprioception is a good biomarker of one's static and dynamic balance. Balance also can be measured with variation of the center of pressure (COP) using a force plate. Amiridis et al. [32] have applied NMES to tibiailis anterior muscle bilaterally for 4 weeks in order adults, and examined how this affected balance. They found that the NMES muscle training improved balance 50.0%. And Mignardot et al. [33] measured COP variation with NMES training on the calf muscles, resulting in a 31.5% improvement in balance. However, in both studies, activation of the two muscles of the tibialis anterior muscle and calf muscles are important to maintain balance, but only one muscle was trained, and the difference according to vision was not considered. On the other hand, clinical measures of balance concern a structured questionnaire [34] and time to finish a given task (i.e., the faster the time, the better the balance) [35], and commonly used by clinicians due to its convenient administration and interpretation. However, the clinical measures are limited to understand changes in body mechanics underlying balance maintenance. Therefore, it is necessary to compare training effects of VMC vs NMES through COP and Proprioception measures. In addition, Greve et al. [36,37] have reported that the higher the body mass index (BMI), the lower the balance in young adult males when standing on one leg, and males have higher BMI than females and need more effort to maintain their balance. Therefore, it is expected that there will be a sex difference in balance ability. Kim et al. [38] have reported that more balance control is required with eyes closed, so it is expected that there will be a difference in balance ability with or without visual input. Therefore, the purpose of this study was to investigate how the training effects were affected by gender and visual feedback.

MATERIALS AND METHODS

1. Subjects

Forty-four young adults (22 males and 22 females) aged between 19 and 28 participated. Participants were randomly assigned to a NMES (11 males and 11 females) and VMC group (11 males and 11 females). Demographic information on the participants is provided in Table 1. Exclusion criteria included individuals with a declined sensation, metal implants, and any other neuromuscular conditions that may cause discomfort during experiments [39]. The experimental protocol has been reviewed and approved by the Institutional Review Board at Yonsei University Mirae campus (IRB no. 1041849-202203-BM-063-03), and all participants provided a signed consent form.

2. Experimental Equipment

A biomechanical approach to assess one's balance involves an analysis of characteristics of the movement of the COP while standing [40]. While it requires a measurement device (i.e., force plate) and computational skills, the approach is considered an accurate and comprehensive measure of balance in biomechanics research as it helps explain how individuals keep their center of body mass within a base of

Table 1. Demographic information of participants

Group	Sex	Height (cm)	Mass (kg)	BMI (kg/m^2)	Age (y)
VMC	Male	173.0 ± 6.5	76.5 ± 14.0	25.4 ± 3.3	22.9 ± 2.6
VMC	Female	161.6 ± 5.9	59.3 ± 8.8	22.7 ± 3.3	22.2 ± 3.0
NMES	Male	175.0 ± 5.5	81.0 ± 19.6	26.4 ± 6.0	24.7 ± 2.8
NMES	Female	162.1 ± 3.9	57.4 ± 6.2	21.9 ± 2.5	22.4 ± 2.1

Values are presented as mean ± standard deviation. VMC, voluntary muscle contraction; NMES, neuromuscular electrical stimulation; BMI, body mass index.

support during activities [41]. During trials, ground reaction forces and moments were measured from the force plate (model OR6-7-2000; Advanced Mechanical Technology Inc., Waltham, MA, USA) at a sampling rate of 1,000 Hz and used to calculate the COP. The outcome variables were mean distance (MDIST, mm), root mean square distance (RDIST, mm), total excursion (TOTEX, mm), mean velocity (MVELO, mm/s), and 95% confidence circle area (AREA, cm^2), and the smaller these variables, the better the balance ability.

A common method to measure the proprioception includes an assessment of a joint position sense, which expressed as an absolute error in degrees between a joint (target) angle requested to stop at and individuals actually choose under a deprivation of visual inputs (the greater the error, the poorer the proprioception). Biodex System 4 Pro Dynamometer (Biodex R Corp., Shirley, NY, USA) was used to measure this ankle proprioception. Outcome variables included absolute errors, which are defined as a difference in degrees between the target angles (10° for dorsiflexion, 15° for plantar flexion) and the actual angle that participants chose. The smaller the absolute error, the better the proprioception.

3. Experimental Protocol

All participants stood looking ahead with their preferred leg on a force plate (model OR6-7-2000) for 10 seconds (Figure 1A). Trials were acquired with eyes open and eyes closed, and there was a 30 seconds rest period between trials. Participants also sat on the Biodex System 4 Pro Dynamometer to measure ankle proprioception (Figure 1B). Starting from neutral position, they were asked to stop at 10° of dorsiflexion and 15° of plantarflexion while eyes closed [29]. Three trials were acquired and averaged for data analysis. All measures were conducted before and after a training session.

In NMES group, electric pads (Klug; Daily & Co, Seoul, Korea) were placed on the motor point of tibialis anterior, gastrocnemius, and soleus muscles for a 20-minute muscle contraction (1.6–34.3 Hz with Blue mode) (Figure 2A). The VMC group conducted isometric exercise by holding the calf muscles and the tibialis anterior muscle simultaneously for 20 seconds and resting for 60 seconds while bending the knees and maintaining dorsiflexion in the sitting position (Figure 2B). They repeated this exercise 5 times.

4. Data Analysis

COP data were filtered through a fourth-order zero phase Butterworth low-pass digital filter with a 5-Hz cut-off frequency. The first and the last one seconds were discarded and the middle 8-second COP data were used to calculate outcome

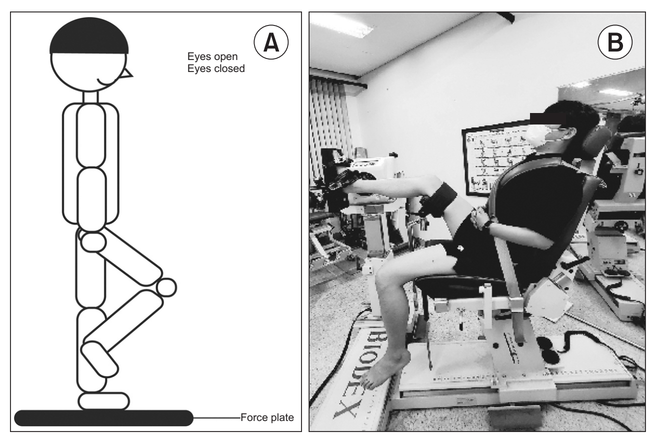

Figure 1. (A) One-leg standing with eyes open or closed. (B) Ankle proprioception measure on the Biodex (Biodex R Corp.).

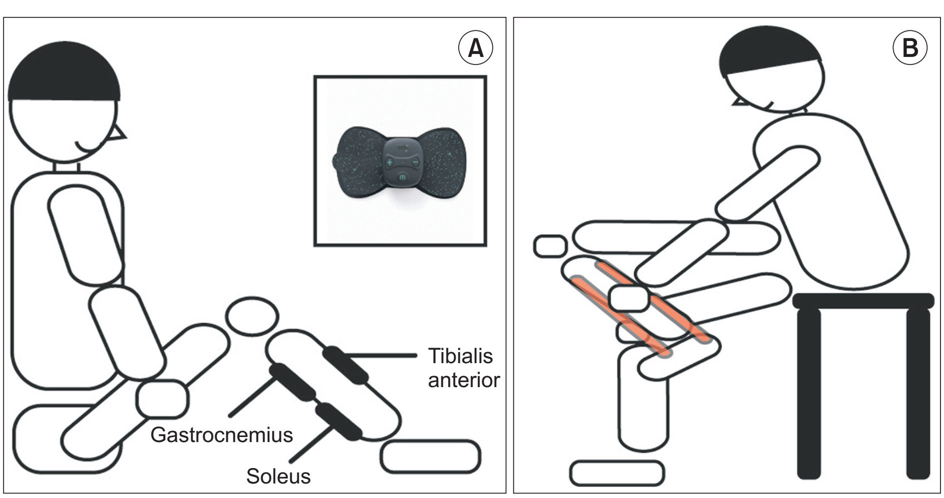

Figure 2. Schematics of the (a) neuromuscular electrical stimulation intervention, and (b) voluntary muscle contraction intervention.

variables suggested by Prieto et al. [42]. All outcome variables were computed using a customized Matlab routine (Matlab R2019a; MathWorks, Natick, MA, USA).

For statistical analysis, Mixed ANOVA was used for statistical analysis with a significance level of α = 0.05, using a SPSS version 21.0 (IBM Co., Armonk, NY, USA), and within-subject factors of COP were vision, gender, and time (pre vs post), and between-subject factors were NMES and VMC. And within-subject factors of proprioception were gender, time (pre vs post), and between-subject factors were NMES and VMC.

RESULTS

None of outcome variables of the COP and proprioception were associated with group ($p > 0.35$) (Tables 2, 3).

All outcome variables of the COP were associated with time ($p < 0.02$) (Table 2), and the area and mean velocity were 37.0% and 18.6% lower in post than pre in NMES group, respectively 25.4 ± 17.8 cm^2 versus 40.3 ± 40.4 cm^2; 96.0 ± 31.7 mm/s versus 117.7 ± 48.1 mm/s, and 48.9% and 16.7% lower in post than pre in VMC group, respectively 18.3 ± 9.4 cm^2 versus 35.8 ± 45.4 cm^2; 80.4 ± 24.4 mm/s versus 95.9 ± 28.6 mm/s. Furthermore, the dorsiflexion error was associated with time ($F = 4.413$, $p = 0.042$), and the error was 3.6% and 35.3% lower in post than pre in NMES and VMC group, respectively 2.7° ± 2.2° versus 2.8° ± 1.9°; 2.2° ± 0.9° versus 3.4° ± 1.8° (Table 3).

All outcome variables of the COP were associated with vision ($p < 0.05$) (Table 2), and the area and mean velocity were 198.8% and 118.2% greater in eyes closed than eyes open, respectively 25.4 ± 17.8 cm^2 versus 7.6 ± 3.3 cm^2; 96.0 ± 31.7 mm/s versus 44.2 ± 14.3 mm/s.

All outcome variables of the COP were associated with sex ($p < 0.05$) (Table 2), and the area and mean velocity were 78.9% and 45.5% greater in males than females, respectively 25.4 ± 17.8 cm^2 versus 14.2 ± 5.5 cm^2; 96 ± 32 mm/s versus 66 ± 15 mm/s. However, none of outcome variables of proprioception were associated with sex ($p > 0.05$) (Table 3).

DISCUSSION

The purpose of this study was to compare effects on balance performance of VMC versus NMES-induced muscle contraction training. We found that both training methods improved balance up to 48.9%. This result agrees well with previous find-

Table 2. Values of outcome variables of balance

	NMES								VMC								p-value			
	Male				Female				Male				Female							
	EC		EO		EC		EO		EC		EO		EC		EO					
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Group	Sex	Vision	Time
MDIST[a] (mm)	17.4 ± 6.8	15.1 ± 4.1	7.9 ± 1.4	8.4 ± 2.0	12.3 ± 2.9	11.4 ± 2.2	6.8 ± 1.4	6.5 ± 1.1	15.6 ± 5.6	12.8 ± 2.8	8.4 ± 1.8	7.2 ± 1.6	12.8 ± 3.0	12.5 ± 3.2	6.7 ± 1.9	6.9 ± 1.0	0.552	0.001*	0.000*	0.003*
RDIST[b] (mm)	19.7 ± 8.1	16.6 ± 4.7	8.9 ± 1.6	9.3 ± 2.1	13.8 ± 3.3	12.7 ± 2.4	7.7 ± 1.5	7.4 ± 1.2	12.6 ± 6.8	14.3 ± 3.1	9.4 ± 2.0	8.1 ± 1.7	14.3 ± 3.4	14.0 ± 3.6	7.6 ± 2.1	7.6 ± 1.2	0.555	0.001*	0.000*	0.002*
MVELO[c] (mm/s)	117.7 ± 48.1	96.0 ± 31.7	49.5 ± 11.8	44.2 ± 14.3	79.8 ± 16.3	66.1 ± 14.6	32.5 ± 7.9	30.4 ± 8.3	95.9 ± 28.6	80.4 ± 24.4	43.2 ± 11.3	40.6 ± 7.3	87.2 ± 19.1	77.0 ± 21.0	37.7 ± 6.5	34.0 ± 7.3	0.541	0.000*	0.000*	0.000*
TOTEX[d] (mm)	941.2 ± 385.0	529.0 ± 117.1	395.7 ± 94.3	353.8 ± 114.3	638.7 ± 130.1	529.0 ± 117.1	259.8 ± 63.0	243.4 ± 66.2	767.2 ± 229.0	643.5 ± 195.4	345.2 ± 90.6	325.0 ± 121.0	697.5 ± 152.4	615.6 ± 168.0	301.9 ± 52.0	271.8 ± 58.5	0.541	0.000*	0.000*	0.000*
AREA[e] (cm^2)	40.3 ± 40.4	25.4 ± 17.8	7.0 ± 2.4	7.6 ± 3.3	17.0 ± 8.7	14.2 ± 5.5	5.2 ± 2.2	4.9 ± 2.0	35.8 ± 45.4	18.3 ± 9.4	7.7 ± 3.1	5.8 ± 2.2	18.2 ± 9.5	17.5 ± 10.2	5.3 ± 3.5	5.2 ± 1.7	0.743	0.012*	0.000*	0.021*

Values are presented as mean ± standard deviation. NMES, neuromuscular electrical stimulation; VMC, voluntary muscle contraction; EC, eyes closed; EO, eyes open. [a]mean distance, [b]root mean square distance, [c]mean velocity, [d]total excursion, and [e]95% confidence circle area. *$p < 0.05$.

Table 3. Values of outcome variables of proprioception with closed eyes

Measure	NMES				VMC				p-value		
	Male		Female		Male		Female				
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Group	Sex	Time
Dorsiflexion error (°)	2.8 ± 1.9	2.7 ± 2.2	4.3 ± 2.0	2.9 ± 1.7	3.4 ± 1.8	2.2 ± 0.9	3.9 ± 2.1	2.3 ± 1.7	0.579	0.209	0.005*
Plantarflexion error (°)	3.1 ± 2.6	3.8 ± 2.6	4.7 ± 2.2	3.5 ± 2.0	3.3 ± 1.7	3.8 ± 1.9	6.7 ± 4.1	4.4 ± 2.8	0.354	0.052	0.051

Values are presented as mean ± standard deviation. NMES, neuromuscular electrical stimulation; VMC, voluntary muscle contraction. *p < 0.05.

ings. Amiridis et al. [32] and Mignardot et al. [33] used a force plate to measure COP variations while standing and found that medio/lateral (M/L) COP displacement improved 50.0% and the Limit of stability improved 31.5%, after NMES training. Acaröz Candan et al. [43] have used a clinical measure to assess balance, and found that there is 6.0% increase of balance with NMES training of quadriceps muscles. Our finding suggests that, despite the physiological differences in muscle contraction between NMES and VMC, NMES training improves balance similarly to VMC, which rejects our hypothesis that the NMES might change the normal physiology of muscle contraction, leading to change in the balance maintaining strategy while standing. This may suggest that changes (if exist) of motor unit recruitment pattern did not significantly affect the balance ability. Our results also confirmed that there was a difference in balance between males and females. This agrees well with Greve et al. [37], and this may be due to the greater BMI in male than female.

Another purpose of this study was to discuss, if possible, a potential mechanism of changes in balance performance with changes in ankle joint proprioception. We found that the absolute error decreased up to 35.3% in dorsiflexion, which may explain the improved standing balance. However, proprioception was not improved in plantar flexion, requiring further investigations on the relationship between ankle joint proprioception and balance performance.

Our results confirm a well-established notion that visual inputs are critical in standing balance. We found that the one-leg standing balance performance declined with deprivation of visual inputs, and individuals swayed faster over the larger area while balancing, which observed by several other researchers [44,45]. Our results also confirm that there exists no sexual difference in ankle proprioception following muscle strengthening training, suggested by Collins et al. [46] and Li et al. [47].

Our results should be interpreted in lights of limitations. First, we only included young adults, and the results might not be applied to older adults, particularly individuals at high risk of a fall. Second, we only examined and compared training effects immediately after interventions, and the results might differ with a longer intervention period. Future studies addressing these limitations are warranted.

In summary, despite different physiology underlying the NMES-induced versus VMC, the NMES muscle training improves one's standing balance just like what the voluntary training does. Our results provide insights on safety and benefits of NMES application.

CONCLUSIONS

Differences in immediate training effect of NMES versus VMC in balance performance have not been found, and clinicians may have more options to improve patients' standing balance. However, future studies should investigate long-term effects of the NMES training.

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CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conceptualization: JJ, WJC. Data curation: JJ, WJC. Formal analysis: JJ, WJC. Funding acquisition: JJ, WJC. Investigation: JJ, WJC. Methodology: JJ, WJC. Project administration: JJ, WJC. Resources: JJ, WJC. Software: JJ, WJC. Supervision: JJ, WJC. Validation: JJ, WJC. Visualization: JJ, WJC. Writing - original draft: JJ, WJC. Writing - review & editing: JJ, WJC.

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