Effect of surface neuromuscular electrical stimulation on labial and lingual muscles in healthy volunteers

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Neuromuscular electrical stimulation (NMES) may have potential as a treatment for muscle weakness as it may improve strength when applied to the orofacial muscles. However, before incorporating this procedure into clinical practice, research is needed to investigate its effects on lingual and facial muscles of speech and mastication. The aim of this study was to determine what effect(s) submental and labial NMES would have on lingual and labial muscle strength in healthy participants. Fourteen healthy adults (27–49 years old) were assigned to two groups (treatment and control). A pretreatment and post-treatment test using the Iowa Oral Performance Instrument was used to measure the strength of labial and lingual muscles in both groups. Participants in the treatment group received labial and submental NMES while performing a structured labial, buccal, and lingual exercise program. In contrast, participants in the control group completed the same oral motor exercise program without stimulation. Results: On comparing the total change in labial and lingual strength between the two groups, an increase in total labial strength was found in the treatment group compared with the control group. However, the control group showed an increase in total lingual strength compared with the treatment group. Results for all measurements were not statistically significant. This study concluded that NMES may be a promising modality to combine with labial and buccal exercises for improvement of muscle strength. *International Journal of Rehabilitation Research* **40:119–126**

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Introduction

Neuromuscular electrical stimulation (NMES) is a treatment that uses a small electrical current to activate nerves innervating muscles affected by paralysis resulting from spinal cord injury, head injury, stroke, and other neurological disorders (Kahn, 1987; Sheffler and Chae, 2007). NMES is delivered to muscles as a waveform of electrical current through electrodes. The application of NMES causes muscles to contract as if they were exercising.

NMES approaches are generally used in patients who have intact peripheral and motor-neuron systems, but who are unable to activate their musculature for volitional functions such as eating or speaking. Current clinical application of NMES is limited to neurologic impairments that involve the upper and lower motor neuron such as what might occur because of spinal cord injury, stroke, brain injury, multiple sclerosis, and cerebral palsy (Sheffler and Chae, 2007) that result in muscle paresis (weakness) or paralysis.

The effects of NMES, as a modality, have been investigated in several areas related to the orofacial region, although not extensively. The effect of NMES applied lingually on airway patency has been investigated in patients with obstructive sleep apnea (Miki *et al.*, 1989; Mezzanotte *et al.*, 1992; Isono *et al.*, 1999; Oliven *et al.*, 2001; Randerath *et al.*, 2006). In these studies, different approaches to applying electrical pulses to the lingual muscles were investigated using the following: (a) intramuscular NMES (Decker *et al.*, 1993; Oliven *et al.*, 2001; Hu *et al.*, 2008; Oliven *et al.*, 2009), (b) submental surface NMES (Decker *et al.*, 1993; Guilleminault *et al.*, 1995; Yang *et al.*, 2000; Steier *et al.*, 2011), (c) lingual surface NMES (Schnall *et al.*, 1995; Isono *et al.*, 1999), and (d) Sublingual NMES (Oliven *et al.*, 2001). The aim of these studies was to explore the effect of NMES in maintaining an open airway in patients with obstructive sleep apnea. The airway is typically obstructed in patients with sleep apnea because of pharyngeal and lingual muscle weaknesses (Remmers *et al.*, 1978; Oliven *et al.*, 2003); thus, stimulation of the genioglossus muscle (Oliven *et al.*, 2003) moves the tongue superiorly and anteriorly, which leads to opening of the airway. Although these studies focused on the single time effect in relation to obstructive sleep apnea, they showed that surface electrical stimulation can be utilized safely to stimulate extrinsic lingual muscles. As extrinsic lingual muscles weakness may cause articulation and swallowing difficulty, it is

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imperative to investigate the effect of NMES of such muscles in relation to speech and swallowing.

Another area of investigation has been the effect of electrical stimulation on the facial muscles. The facial muscles are superficial and can be easily targeted by electrical stimulation. However, few studies to date have investigated the effects of NMES on facial muscles, in general, and muscles of speech production and swallowing specifically. In a study that targeted the zygomatic major muscle, Kavanagh *et al.* (2012) concluded that following a 12-week course of facial NMES, the thickness of the muscle was increased as measured by ultrasound and there were subjective improvements in facial characteristics.

A limited number of studies have investigated the application of NMES within the facial palsy population (Cronin and Steenerson, 2003; Hyvarinen *et al.*, 2008; Alakram and Puckree, 2011), although controversial. In a retrospective case review of patients with facial paralysis who received NMES, the investigators concluded that all patient groups made significant improvements in function with improved symmetry on the basis of dual-channel electromyographic readings as well as increased facial movement on the basis of percentages of movement measured in the study (Cronin and Steenerson, 2003). In another study that targeted participants with chronic facial nerve paralysis with sensory-level NMES, a significant improvement was observed in the upper branch of the facial nerve motor action potential distal latency – improvement of one grade on the House–Brackmann scale – on the affected side in all patients and some patients also reported a subjective improvement (Hyvarinen *et al.*, 2008). Another study investigated the NMES as a treatment approach for Bell's palsy in the acute phase of the disorder in conjunction with other modalities (i.e. heat, massage, exercises). The results of the study showed that the effects of electrical stimulation, as used in that study, were found to be clinically, but not statistically significant (Alakram and Puckree, 2011).

To date, no published studies have examined the effect of NMES on the strength of muscles that are involved in speech articulation and the oral phase of swallowing – such as labial (i.e. the orbicularis oris, levator labii superioris, levator labii superioris alaeque nasi, levator anguli oris, zygomaticus minor, zygomaticus major, risorius, depressor anguli oris, depressor labii inferioris, and mentalis) and jaw (i.e. buccinator and masseter) muscles – despite the fact that many of these muscles can be targeted easily by surface NMES.

Lingual and facial muscles of mastication and expression are important for communication and swallowing. Speech-language pathologists as well as orofacial myologists are in need of modalities that aid the treatment of muscular paresis. NMES is a modality that is used commonly in the physical therapy and occupational therapy fields for the treatment of several motor and sensory muscular disorders including muscular weakness (Kahn, 1987; Binder-Macleod *et al.*, 1995; Binder-Macleod and Lee, 1997; Sheffler and Chae, 2007; Doucet *et al.*, 2012).

NMES has been shown to have good potential as a treatment modality for muscle weakness (Randerath *et al.*, 2006; Sheffler and Chae, 2007). Theoretically, this positive effect should translate into improved strength when applied to the orofacial muscles. However, before it can be incorporated into clinical practice, research is needed to investigate its effects on lingual, labial, and buccal weakness.

The present study was carried out to explore the effects of NMES on labial and lingual muscles to determine whether such a procedure provides an additional modality for improving labial and lingual strength. NMES has been reported to increase muscular mass, strength, and endurance of both normally and abnormally innervated skeletal muscles in a range of pathological conditions (Hainaut and Duchateau, 1992).

The following questions were proposed for this study: (I) What effects does surface submental NMES have on lingual strength in healthy participants?; (II) What effects does labial surface neuromuscular electrical stimulation have on labial strength in healthy participants?; (III) What effects do oromotor exercises have on labial and lingual muscle strength in healthy participants?

Methods

Participants

Approval of the Howard University Review Board was obtained for this study. All participants signed a written consent form to participate in this study. Table 1 presents the demographics of the participants.

Participants completed a medical screening form before participating in the study. All participants fulfilled the eligibility criteria that included the absence of neurological, phonological, psychiatric, speech, or swallowing disorders. Individuals who also had cardiac irregularities or a history of rheumatic fever were excluded from this study.

Table 1 Participants' characteristics

	Control group	Treatment group
N	6	8
Age		
Range	27–44	30–49
Mean (SD)	34.7 (6.74)	36.24 (5.75)
Sex	Four male Two female	Seven male One female

Procedures

Assessment of labial and lingual muscular strength

The strength of labial and lingual muscles was measured using the Iowa Oral Performance Instrument (IOPI) (Iowa Oral Performance Instrument; IOPI Medical, Redmond, Washington, USA). Three measurements were obtained at the beginning of the study to establish a baseline and again at the completion of the last session to monitor and quantify progress. All measurements were taken by a certified speech language pathologist or a doctoral speech language pathology student who was trained in the use of the IOPI before all treatment sessions began. The following IOPI bulb placements were used: (a) labial placements (bilabial medial, bilabial lateral, and lateral buccal dental placements) and (b) lingual placements (frontal lingual alveolar and dorsal lingual palatal placements). These placements assessed the same muscles that were targeted by oral motor exercises as well as NMES. Each participant was asked to place the bulb and squeeze it as hard as possible for about 2 s. Three measures were recorded for each placement.

Neuromuscular electrical stimulation device and electrodes

The AMPCARE ES (AMPCARE ES; Restorative Medical Inc., Brandenburg, Kentucky, USA) NMES unit was used for surface stimulation application. The electrical stimulation unit provided two channels of bipolar electrical stimulation. The following fixed waveform specifications were used in the study: a symmetrical biphasic waveform, 50 μs phase duration, and a frequency of 30 Hz.

For submental electrical stimulation, AMPCARE E series surface reusable electrodes (AMPCARE; Restorative Medical Inc.) were used. Columbia 600 Electrodes (Columbia Scientific LLC, Portland, Oregon, USA) were used for the application of electrical stimulation to the patients' lips. These are single-patient use surface electrodes. A self-adherent bandaging tape (3M Vetrap bandaging tape; 3M Center, St Paul, Minnesota, USA; 3 mol/l) was fitted over the electrodes to maintain good skin contact.

Treatment protocol

For the treatment group, the skin in the submental and labial regions was cleaned with alcohol and wiped with a TENS Clean-Cote Skin Wipe (Medtronic Parkway, Minneapolis, USA) to increase adherence of the electrodes to the skin (Uni-Patch Model UP220; Tyco). All male participants were also clean-shaven to allow optimum electrode adherence. Each participant was familiarized with the sensations to expect from the electrodes to prepare them for the actual electrical stimulation. Then, each electrode pair was placed on the skin and the electrical stimulation was presented, with the stimulation intensity gradually increasing until the participant experienced a tingling sensation. To achieve motor-level stimulation, the intensity level was increased gradually until the participants indicated that the sensation level was becoming uncomfortable. Next, the stimulation intensity was increased until the participant reported that it was at the maximum tolerance level. The stimulation was set at the participant's maximum stimulation tolerance level for each placement. After 5 min of stimulation, the participants were asked whether they felt any pain or whether they could tolerate further stimulation. The intensity of stimulation was adjusted according to their response. This maximum tolerance level in each session was recorded for the two electrode placements. Each session lasted 30 min with a duty cycle of 5 : 25 (5 s on and 25 s off).

Oral motor exercise protocol

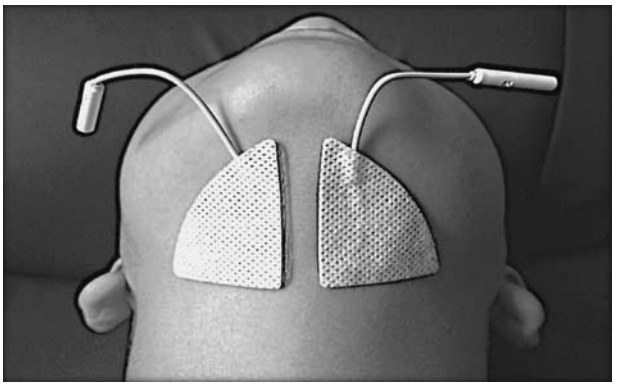
All participants in the treatment group performed a structured oral motor exercise (OME) program targeting specific labial, buccal, and lingual muscles in conjunction with the NMES. The exercises were performed while the stimulation was on. Participants received three sessions per week over 4 weeks. Participants in the control group only performed the same oral motor exercise program three times per week over 4 weeks (a total of 12 sessions).

These exercises targeted the same muscles that were targeted by NMES. These exercises are used frequently in the treatment of orofacial weaknesses that leads to articulation and swallowing problems in children. These exercises are also used in adults who develop orofacial weakness as a result of neurologic impairment such as cerebrovascular accidents and Parkinson's disease.

Electrode placement

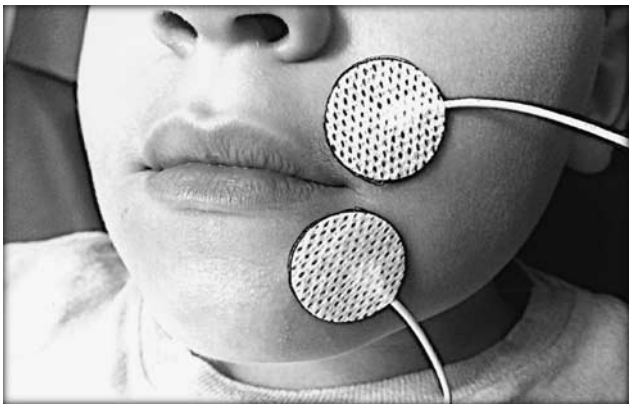
To target extrinsic lingual muscles, two electrodes were placed submentally between the hyoid bone and the chin (Fig. 1). The goal was to target the genioglossus and

Fig. 1



Submental electrodes' placements.

Fig. 2



Labial electrodes' placements.

hyoglossus muscles with NMES and/or OME. Labial muscles were targeted by placing a pair of labial electrodes – one in the superior lateral corner and the other in the inferior lateral position of the lips (Fig. 2). The goal was to target the orbicularis oris, buccinator, risorius, levator anguli oris, and depressor anguli oris with NMES and/or OME.

Data analysis

Labial and lingual IOPI measurements were compared before and after 12 sessions of NMES to analyze changes in muscular strength. For labial strength measurement, three bulb placements were used: bilabial medial, bilabial lateral and lateral buccal dental positions. For lingual strength measurement, two bulb placements were used: frontal lingual alveolar and dorsal lingual palatal placements. Three measurements at each location were performed. The mean for each position was then calculated. The difference in means between pretests and post-tests for each placement was then calculated to determine the change in muscular strength following the 12 sessions of treatment.

To determine whether the changes were significant, paired sample *t*-tests were computed. Independent-sample *t*-tests were used to assess the differences between the treatment and the control group. Differences were considered significant when the probability (P) of a type I error was 0.05 or less ($P < 0.05$).

Results

Participants

Sixteen volunteers initially consented to participate in the study. Two participants withdrew from the study because of logistical challenges. Fourteen participants completed the study. Table 1 presents the demographics of the participants.

Table 2 Intensity levels of neuromuscular electrical stimulation

	Submental stimulation MTL	Labial stimulation MTL
Total number of sessions	96	96
NMES stimulation intensity		
Range (mA)	39.20–88.20	29.40–78.40
Mean (SD)	65.99 mA (15.39)	55.33 mA (13.29)

MTL, maximum tolerance level; NMES, neuromuscular electrical stimulation.

All the participants in the treatment group could tolerate the NMES for all 12 sessions for a total of 96 NMES treatments. Table 2 presents the results for the amount of NMES tolerated by participants.

Labial strength measurements

To evaluate whether surface NMES applied to labial muscles had positive effects on labial strength in healthy participants, IOPI measures of the lateral labial, medial labial, and lateral buccal dental bulb placements were obtained. Tables 3–5 and Figs 3–5 present the results of the total difference in the means of these measures.

Lingual strength measurements

To evaluate whether surface NMES applied in the submental area had positive effects on lingual strength in healthy participants, IOPI measures of the frontal lingual alveolar and dorsal lingual palatal bulb placements were obtained. Tables 6 and 7 and Figs 6 and 7 present the results of the total difference in the means of these measures.

On comparing the total change in labial and lingual strength between the two groups, it was noted that there was an increase in the total labial measurement in the treatment group, whereas the control group had relatively increased measurements in the total lingual strength. The treatment group showed a slight decrease in lingual strength. Figure 8 shows this difference.

Statistical analyses

On reviewing the measured data, differences were noted between the treatment and control groups in all measurements. To identify whether these results were

Table 3 Total difference in the mean lateral labial measurements performed by the Iowa Oral Performance Instrument

Control group		Tx group	
Participant no.	Mean IOPI measurement (kPa)	Participant no.	Mean IOPI measurement (kPa)
1	−1	9	−2
2	−1	10	1
3	0	11	3
4	0	12	3
5	1	13	5
6	0	14	−3
		15	1
		16	0
Mean	−0.17	Mean	+1.00

IOPI, Iowa Oral Performance Instrument.

Table 4 Total difference in the mean medial labial measurements performed by the Iowa Oral Performance Instrument

Control group		Tx group	
Participant no.	Mean IOPI measurement (kPa)	Participant no.	Mean IOPI measurement (kPa)
1	−1	9	0
2	0	10	3
3	2	11	1
4	0	12	5
5	0	13	7
6	0	14	−3
		15	3
		16	−3
Mean	+0.167	Mean	+1.63

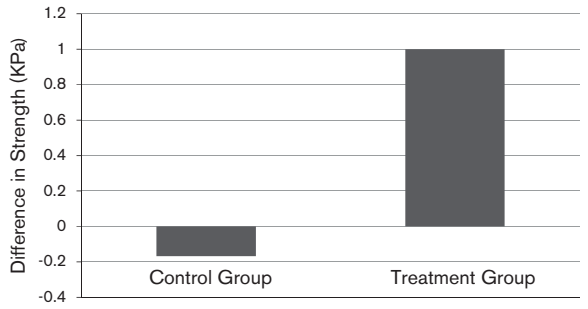
IOPI, Iowa Oral Performance Instrument.

Table 5 Total difference in the mean lateral buccal dental measurements performed by the Iowa Oral Performance Instrument

Control group		Tx group	
Participant no.	Mean IOPI measurement (kPa)	Participant no.	Mean IOPI measurement (kPa)
1	0	9	0
2	0	10	2
3	1	11	1
4	1	12	8
5	1	13	1
6	1	14	−5
		15	1
		16	−2
Mean	0.67	Mean	0.75

IOPI, Iowa Oral Performance Instrument.

Fig. 3

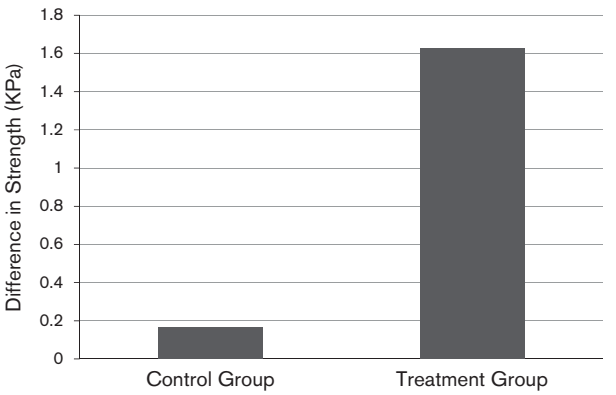


Comparison of the total Difference in the mean lateral labial measurements.

significant, independent-sample *t*-tests were run. Table 8 presents the results of these analyses. Results for all measurements were not statistically significant. Differences were considered significant when the probability (*P*) of a type I error was 0.05 or less ($P < 0.05$).

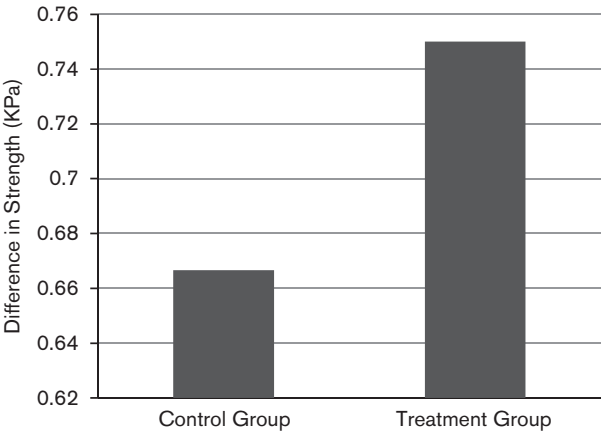
Although no statistically significant differences were noted between the treatment group and the control

Fig. 4



Comparison of the total difference in the mean medial labial measurements.

Fig. 5



Comparison of the total difference in the mean lateral buccal dental measurements.

Table 6 Total difference in the mean frontal lingual alveolar measurements performed by the Iowa Oral Performance Instrument

Control group		Tx group	
Participant no.	Mean IOPI measurement (kPa)	Participant no.	Mean IOPI measurement (kPa)
1	1	9	0
2	5	10	0
3	−1	11	1
4	0	12	0
5	0	13	2
6	1	14	−3
		15	1
		16	1
Mean	1	Mean	0.25

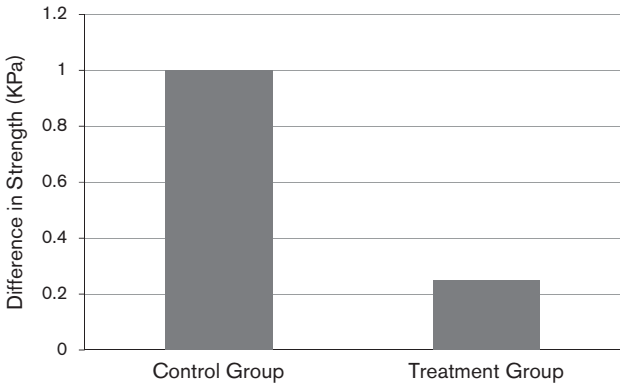
IOPI, Iowa Oral Performance Instrument.

Table 7 Total difference in the mean dorsal lingual palatal measurements performed by the Iowa Oral Performance Instrument

Control group		Tx group	
Participant no.	Mean IOPI measurement (kPa)	Participant no.	Mean IOPI measurement (kPa)
1	1	9	−2
2	1	10	2
3	−2	11	−1
4	1	12	4
5	−1	13	−2
6	1	14	0
		15	1
		16	0
Mean	0.167	Mean	0.25

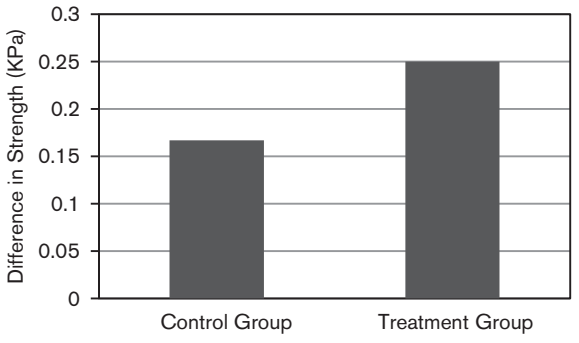
IOPI, Iowa Oral Performance Instrument.

Fig. 6



Comparison of the total difference in the mean frontal lingual alveolar measurements.

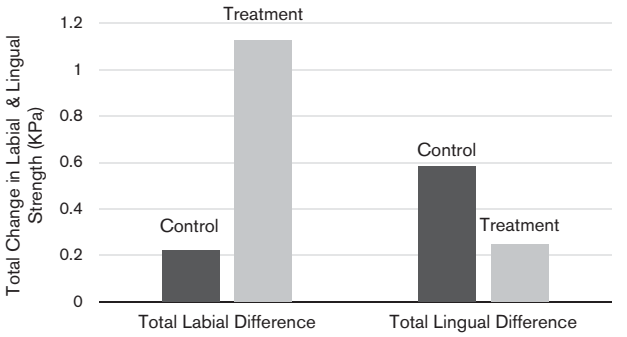
Fig. 7



Comparison of the total difference in the mean dorsal lingual palatal measurements.

group, a question arose as to whether the treatment group showed significant changes for the different IOPI measurements. To determine whether these differences were significant, paired-sample *t*-tests were run for each

Fig. 8



Comparison of the total change in labial and lingual strength between the two groups.

measurement. Table 9 shows these results. Results for all measurements were not significant.

Discussion

The aim of this study was to determine the effects of surface NMES on submental and labial regions in healthy adults. The major effect of this stimulation protocol was a slight increase in labial strength as measured by IOPI placements. When this stimulation protocol was applied submentally, it had no effect on lingual strength as measured by IOPI placements. However, these measures were not found to be statistically significant.

Facial placement that targeted labial and buccal muscles presented positive changes in IOPI measurements, whereas submental placement did not produce changes in lingual IOPI measurements. In addition, the treatment group receiving the NMES showed greater positive changes than the control group that engaged only in oromotor exercises, although these differences were not significant. The greater positive NMES effect on labial muscles could be attributed to the fact that labial and buccal muscles are superficial and are easily targeted by surface NMES. However, extrinsic lingual muscles are deep muscles and lie behind many muscles including the anterior belly of the digastric, mylohyoid, and geniohyoid muscles. In addition, the presence of superficial fat in the submental region could prevent the electrical stimulation from reaching the targeted extrinsic lingual muscles.

Another reason that may have contributed toward the lack of a significant NMES effect on lingual strength in this study is the phase duration. In this study, the stimulation was fixed at 50 μs phase duration. However, according to Doucet *et al.* (2012), when attempting to target secondary tissue layers, longer phase durations penetrate more deeply into subcutaneous tissue. The problem with longer phase duration is that it causes more discomfort and can even produce pain. Thus, introduction of longer

Table 8 Independent-sample *t*-test for control group versus treatment group measurements

	Lateral labial	Medial labial	Lateral buccal	Frontal lingual alveolar	Dorsal lingual palatal
Mean difference (SD) (kPa)	1.125 (0.990)[a]	1.250 (1.456)[a]	0.250 (1.333)[a]	1.125 (0.811)[a]	0.125 (0.839)[a]
t	1.136	0.858	0.188	1.386	0.149
d.f.	14	14	7.585	13.496	11.214
P	0.275	0.405	0.856	0.188	0.884

Table 9 Paired-sample *t*-test comparing the different labial and lingual measurements in the treatment group

	Lateral labial pre vs. post	Medial labial pre vs. post	Lateral buccal dental pre vs. post	Frontal lingual alveolar pre vs. post	Dorsal lingual palatal pre vs. post
Mean difference (kPa)	1.0	1.375	0.750	−0.125	0.25
t	1.058	0.973	0.574	−0.243	0.344
d.f.	7	7	7	7	7
P	0.0.325	0.0.363	0.584	0.815	0.0.741

phase durations in the head and neck area should be evaluated carefully in future studies.

Lingual IOPI measurements showed that NMES, in conjunction with oral motor exercises, did not produce any significant changes in either group. A possible explanation might be that participants who had submental NMES may have been distracted by the submental discomfort and grabbing sensations that caused them not to optimally perform the lingual exercises.

Limitations

This study has several limitations. The sample size was small. The study included only fourteen participants. This relatively small number of participants could have led to the lack of significance in the results of this study. Perhaps, if this study were to be replicated with a larger sample size, it would yield significant findings.

The second limitation was lack of randomization. Randomization is very crucial to research design to generate causality between independent and dependent variables. However, because of patients' and participants' accessibility challenges, randomization is difficult to achieve.

Another limitation was that IOPI measurements were always taken in a fixed sequence. This may have caused muscle fatigue in labial and lingual muscles. Thus, a randomized sequence of bulb placements would have controlled for this possible confounding variable.

Directions for future research

This study showed that submental NMES did not have any significant effects on lingual measurements. However, direct NMES to the lips produced some positive effects. A future study utilizing a larger group of participants to evaluate labial surface NMES is recommended. However, to target lingual muscles, direct sublingual electrodes may produce positive effects.

Despite these limitations, the results of this study are beneficial as a first step in developing an understanding of the effects of surface NMES on facial and lingual muscles. Some positive changes were found, although they were not statistically significant. Yet, the treatment group did show greater positive changes compared with the control group, indicating some positive changes in muscle strength when NMES is applied along with oral muscle exercises. However, before such a tool is used clinically, an improved understanding of its effects should be gained in the presence of specific types of labial and lingual weaknesses.

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Conflicts of interest

There are no conflicts of interest.

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