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Effect of Electrical Stimulation of Tongue in Rehabilitation – A Systematic Review

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Abstract Tongue is unique and each half of the tongue is represented bilaterally in brain and is being used as an effective interface to send signals to central nervous system. Tongue movements and tongue stimulation have been used in various types of rehabilitation. The purpose of this study is to review all articles related to tongue stimulation. All studies including reviews, case, cohort and experimental studies, which dealt with tongue stimulation, periglossal stimulation, or hypoglossal stimulation during the period between 1981 to 2020 were screened and a total of 41 studies comprising of 9 review articles, 30 experimental studies and 2 case reports were included for review. The methodology quality of the experimental studies has been analyzed using PEDro score and level of evidence measure. Electrical stimulation of the tongue was performed on normal subjects to find out the taste sensation and its similarity with other liquids. Hypoglossal stimulation has been found to stimulate the muscles of the tongue and it stiffens the posterior aspect of tongue and walls of the pharynx, thereby reducing the symptoms in obstructive sleep apnea. Stimulation of the muscles of the tongue also improves swallowing functions in dysphagia patients. Tongue stimulation, using a variety of devices and in combination with balance exercises, has also been used to improve balance in stroke, multiple sclerosis and spinal cord injury patients by inducing activity in cerebellum and brainstem, which process the balance networks. Tongue movements and tongue stimulation along with upper limb rehabilitation, have also been used in improving upper limb functions in stroke patients based on the principles of Hebbian theory. Thus, tongue stimulation along with targeted exercise program becomes a novel mode of therapy in inducing neuroplasticity and can be used in wide variety of patients in rehabilitation. This review will input to the clinicians and researcher for conducting further research on tongue stimulation. Further long-term follow-up studies can also be done to find out the neuroplastic changes in brain following tongue stimulation.

Keywords Tongue Stimulation, Cranial Nerve Noninvasive Neuro Modulation (CN NINM), PONS Device

1. Introduction

1.1. Tongue is Unique

The tongue is unique and has bilateral representation in the brain homunculus. The behavioral and voluntary tongue movements is controlled by corticobulbar connections which mediate between motor cortex and lower motor neurons. The cell bodies of these neurons are located bilaterally in the hypoglossal nuclei on the dorsal surface of the medulla [1].

The tongue, a muscular organ, plays a vital role in various body functions such as breathing, speaking, chewing and swallowing (Figure 1) [2, 26]. Its action also affects lower limb muscle strength and posture in addition to oral cavity. According to one line of thought, the tongue has paracrine/autocrine mechanism of action to produce different substances which interact with the whole body. Connections with the tongue should be considered to enhance patient rehabilitation programs to get better therapeutic results [2].

1.2. Tongue Stimulation

Tongue can be used as a useful link for sending electrical signals to the central nervous system, for example, sensory substitution in blind or balance-impaired individuals. Tongue stimulation along with vestibular training improved balance in vestibular disorder patients which was sustained even after the final stimulation session. In 2001, Schwartz et al. [3] demonstrated the successful use of hypoglossal nerve stimulation in small cohort of sleep apnea patients to reduce sleep apnea.

Neurorehabilitation therapists use multiple therapeutic techniques to help the patient improve either by helping the patient relearn and improve previous skills or by compensating with alternative techniques or by providing assistive technologies that may be temporary or permanently used. A related specialty, neuromodulation, effects the central nervous system with the use of electrical current or medications. Neuromodulation interventions such as spinal cord stimulators, baclofen pumps, deep brain stimulators and transcranial magnetic stimulation are commonly used [4].

The basic principles of Cranial-Nerve Non-Invasive Neuromodulation (CN-NINM) technology is to access brain networks through stimulation of cranial nerves which are present in tongue, and it is used in conditions such as headache, tinnitus [5], sleep disorders and depression. It is noteworthy that the principles and corresponding therapeutic regimens are already successfully implemented on various neurological conditions where there are problems in balance, gait disorders, eye movement control, speech and cognitive functions [6, 7].

The objective of this review is to find out the use of tongue stimulation in various types of rehabilitation and its effectiveness.

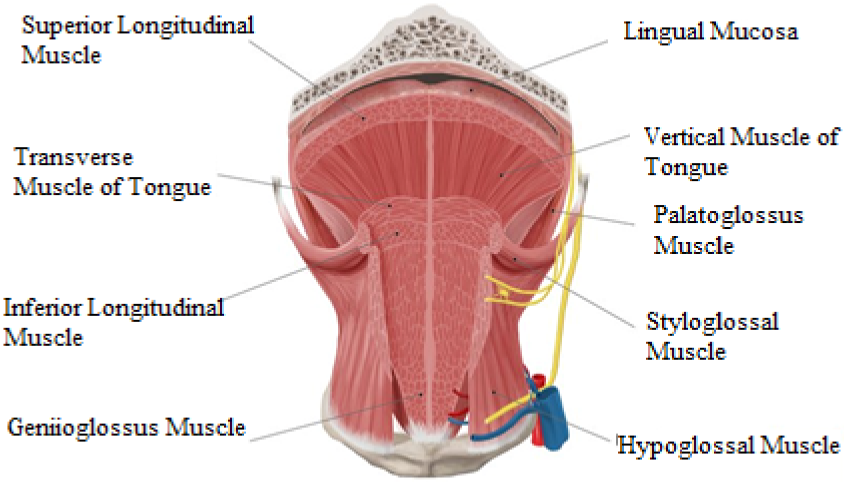

Figure 1. Muscles of the Tongue (source: www.kenhub.com)

2. Material and Methods

2.1. Inclusion and Exclusion Criteria

All studies published during the period between 1981 and 2020 including case studies, cohort studies, experimental studies, and reviews, which were dealing with tongue stimulation had been included in the study. Studies done on animal subjects and studies where only abstracts available were excluded for the review.

2.2. Search Strategy

A total of 1014 peer reviewed journal articles, reports, book chapters published during the period between 1981 and 2020 were reviewed and collated from major databases such as PubMed, EMBASE, The Cochrane Library, and Scopus. Key words included were “tongue stimulation,” “hypoglossal stimulation,” and “periglossal stimulation.” Only 41 articles, which met the inclusion and exclusion criteria, were taken for final data analysis.

2.3. Data Extraction and Synthesis

The included papers were critically evaluated using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, formerly QUOROM) Statement. The PRISMA Statement provides an evidence-based 27-item checklist (eg, on objectives, methodology, and limitations) for reporting in systematic review. All information related to tongue stimulation, periglossal stimulation, and hypoglossal stimulation was extracted from 41 articles. Information related to use of tongue stimulation on different categories of the patients, its benefits, any adverse events, and physiology behind the outcome were analyzed.

3. Results

We have included 41 studies for review after screening for relevance of the study article and excluding the articles which do not meet the inclusion and exclusion criteria, (Refer Table 1). We found that several studies have been done on tongue stimulation in various subjects – normal as well as on disease conditions. The studies were done on normal subjects, balance impaired patients, multiple sclerosis, spinal cord injury and stroke patients to find out the effect of tongue stimulation on taste quality, pharyngeal cross-sectional area, balance and motor recovery (Table 2 and Table 3). Methodology quality of the study has been analyzed using PEDro Score and Level of Evidence measure. Experimental studies with PEDro score $\geq$ 4 have been taken for analysis and discussion.

Table 1. Study Characteristics

SNo	Type of Study	Number of Studies included
1	Case Studies	2
2	Experimental Studies	30
3.	Reviews	9

Table 2. Tongue Stimulation in Various Conditions

S.No.	AUTHORS (YEAR)	STUDY PROTOCOL	NUMBER OF SUBJECTS	OUTCOME MEASURES	RESULTS AND CONCLUSION	Level of Evidence	Quality / PEDro score
1.	Tyler S. Allison et. al. (2020) [7].	Fungiform papillae number and distribution were determined for 15 subjects and they were given electrotactile stimulation (ETS).	15	Perceived number of stimuli and perceived intensity.	Electrotactile discrimination ability of the tongue is associated with the presence of specific connective tissue structures	2b	Fair PEDro Score = 5
2.	Armand V. Cardello et al (1981) [8].	Four subjects underwent chemical, electrical, and tactile stimulation of single human taste papillae.	4	Taste quality	Proportion of salty responses were significantly lesser for tactile stimulation than for electrical stimulation	3b	Fair PEDro Score = 4
3.	S. Isono et. al. (1999) [9].	Seven OSA patients underwent tongue stimulation (pulse width of 0.2 ms, frequency of 100 Hz, duration of two-three seconds)	7	Pharyngeal cross-sectional area	Electrical stimulation of the tongue stiffens the airway wall behind the tongue in patients with obstructive sleep apnea.	3b	Good PEDro Score = 6
4.	Harry T. Lawless et. al. (2005) [10].	A series of three experiments investigated the nature of metallic taste reports after stimulation with metallic salt solution, metals and electric currents.	10, 23, 78	Taste sensation	Two distinct mechanisms for evaluation of metallic taste reports, one dependent upon retronasal smell and a second mediated by oral chemoreceptors.	2b,	Good PEDro Score = 6
5.	Y.P. Danilov (2007) [11].	Subjects with peripheral or central vestibular loss were trained with the Brain Port balance device	28	Computerized Dynamic Posturography (CDP) using the Sensory Organization Test (SOT), Dynamic Gait Index (DGI), Activities-specific Balance Confidence Scale (ABC), and Dizziness Handicap Inventory (DHI)	All subjects showed improved performance than the conventional vestibular therapy.	2b	Good PEDro Score = 6
6.	Cecil A. Lozano et al. (2009) [12].	Eight healthy subjects underwent electrotactile stimulation of the tongue:	8	Intensity perception, discrimination and cross-modality estimation	The sensory system and bioelectrical properties of the tongue allow reliable and stable transmission of electrotactile stimulation intensity information	3b	Good PEDro Score = 6
7.	Kazuma Aoyama et al. (2017) [13].	Eight male participants underwent galvanic tongue stimulation to find out the effect of galvanic stimulation on bitter and sweet tasting electrolyte and nonelectrolyte.	8	Taste sensation	Galvanic Tongue Stimulation Inhibits Five Basic Tastes Induced by Aqueous Electrolyte Solutions.	3b	Good PEDro Score = 6
8.	Joel Moritz Jr et al. (2017) [14].	Twenty five healthy subjects underwent tongue stimulation.	25	Perceived Intensity and Discrimination Ability	Stimulation of the most anterior and medial tongue resulted in the highest perceived intensity and the best discrimination ability. Most subjects were able to perceive and discriminate electrotactile stimulation better on one side of the tongue, and perception was affected by the orientation of stimulating electrodes.	2b	Good PEDro Score = 7
9.	Zack Frehlick et al (2019) [15].	Twenty subjects underwent translingual neurostimulation for 20 minutes	20	EEG changes	The initial findings of EEG changes in resting brain activity were reported after a single 20-min session of PoNS. While both high and low frequency PoNS dosage levels produced significant changes in alpha and theta wave activity, HF stimulation showed differential dosage effects.	1b	Good PEDro Score = 7

Table 3. Tongue Stimulation in Neurological Conditions

S.No.	AUTHORS (YEAR)	STUDY PROTOCOL	NUMBER OF PARTICIPANTS	OUTCOME MEASURES	RESULTS AND CONCLUSION	LEVEL OF EVIDENCE	PedRO Score
1.	Wildenberg J C, et al (2011) [19].	Balance impaired subjects underwent cranial nerve noninvasive neuromodulation (CN-NINM) for 20 minutes for five days.	12, 9	Functional MRI And Postural Sway	CN-NINM may induce neuromodulation and improve balance by increasing activity within the dorsal pons. ($p<0.01$)	2b	Fair PEDro Score = 5
2.	Wildenberg J C, et al. (2011) [17].	Balance impaired subjects received tongue stimulations, 19 sessions (over the period of ten days) wherein the subject stood as stable as possible with their feet together and eyes closed.	9, 9	Functional MRI and sensory organization testing(SOT)	Six of the eight balance-impaired subjects had improved SOT composite scores after CNNINM stimulation.	2b	Fair PEDro Score = 5
3.	Joe C. Wildenberg et al (2013) [18].	Twelve Balance impaired individuals were given tongue stimulation for 5 days (9 sessions) and compared with nine normal subjects.	12, 9	MRI – GLM analysis	Balance impaired individual had decreased response of the primary visual cortex to visual stimuli and increased connection between visual cortex and motion sensitive area, which was corrected by tongue stimulation	2b	Fair PEDro Score = 5
4.	Mitchell E Tyler et al (2014) [20].	Chronic Multiple Sclerosis patients underwent 14 weeks of balance training along with tongue stimulation.	20	Dynamic Gait Index	Tongue Stimulation improves balance in multiple sclerosis patients.	1b	Good Quality PEDRO score = 9
5.	Brittany Mei Young (2014) [21].	Subjects underwent15 two-hour sessions of intervention using an electroencephalogram- guided brain computer interface device, which incorporated tongue stimulation, visual display, and functional electrical stimulation as feedback. These BCI therapy sessions were scheduled over the course of up to six weeks with no more than three sessions per week.	16	Functional MRI, Action Research Arm Test (ARAT), 9-Hole Peg Test (9-HPT), and Hand function domains of Stroke Impact Scale (SIS) and Activities of Daily Living (ADL).	The correlations observed between changes in FC measures and changes in behavioral outcomes indicate that both adaptive and maladaptive changes in FC may develop with this therapy and also suggest a brain-behavior relationship that may be stimulated by the neuromodulatory component of BCI therapy.	2b	Good PEDro Score = 6
6.	Brittany Young et al. (2015) [22].	Stroke subjects with upper limb impairment underwent training with Brain-Computer Interface with tongue stimulation.	16	ARAT, SIS, FMRI, Nine- hole peg test	It was found that improvement in stroke impact scale score were directly responsive to BCI therapy dose and intensity correlated positively with increased SIS Strength ($p \leq 0.05$), although no direct relationships were identified with 9-HPT or ARAT scores.	2b	Good PEDro Score = 6

Table 3 Continued

7.	Brittany Mei Young (2016) [23].	Stroke patients with upper extremity motor impairment underwent training with Brain-Computer Interface with tongue stimulation.	19	Nine Hole Peg Test (9-HPT), Action Research Arm Test (ARAT), Stroke Impact Scale (SIS), and DTI scans.	Increases in contralesional corticospinal tract (CST) functional anisotropy (FA) were correlated with improvements in 9 Hole Peg Test while increases in aFA correlated with improvements in Action Research Arm Test but with worsening 9-HPT performance; changes in transcallosal motor fibers positively correlated with those in the contralesional CST.	1b	Good PEDro Score = 7
8.	Gabriel Leonard et al (2017) [24].	Multiple Sclerosis patients (Seven in active and seven in sham stimulation group) received intensive physical therapy and working memory training for fourteen weeks. [10]	14	Functional MRI, sensory organization tests (SOT), motor performance measures, and neuropsychological assessment	Active group showed improvement in SOT. PoNS stimulation can enhance motor performance and working memory while driving neuroplasticity	1b	Excellent PEDro Score = 9
9.	Rosaleena Mohanty et al (2018) [25].	Chronic-stage stroke subjects exhibiting persistent upper-extremity motor deficits received the therapeutic intervention using a closed-loop neurofeedback BCI device for three weeks.	20	Functional MRI, Action Research Arm Test, Nine-Hole Peg Test, and Barthel Index as well as subjective measures including the Stroke Impact Scale	Rehabilitative therapies have enabled recovery even at the chronic stage of stroke	1b	Good PEDro Score = 7.
10.	Rosaleena Mohanty et al (2018) [26].	Chronic stroke patients with residual upper-extremity motor impairment received neuromodulatory training using a closed-loop neurofeedback BCI device.	12	Functional MRI	A higher number of strengthening functional changes in comparison to the ones weakening between pre- and post-therapy suggests a greater overall positive impact of BCI intervention on stroke recovery at a whole-brain level	2b	Good PEDro Score = 7
11.	Alexander B. Remsik et al (2019) [27].	Stroke survivors, presenting with persistent upper limb impairment, received a maximum of 18–30 hours of intervention with a new electroencephalogram-based BCI-driven functional electrical stimulator (EEGBCI-FES) device.	21	NIHSS, Barthel, Grip Strength, 9 HPT, MMSE, ARAT	BCI intervention may be an effective way of addressing the upper extremity recovery in stroke patients and studying neuromechanical coupling with motor outputs.	1b	Good PEDro Score = 7

4. Discussions

Tongue stimulation has been used in wide variety of conditions due to specific characteristics of the tongue. The effects of tongue stimulation in different conditions and its benefits are discussed in detail

Tongue and its Characteristics

Tongue has a unique and rich innervation pattern with trigeminal, facial, glossopharyngeal, vagus and hypoglossal nerves. It is rich in sensory, mechanic and taste receptors and has a minimum two-point discrimination threshold, which ranges around 0.5-1 mm for mechanical stimulation and 0.25 – 0.5 mm for electrotactile stimulation [6, 28].

The tongue is an optimal site for electrotactile display. It is highly flexible and very sensitive to touch, both in spatial acuity and pressure sensitivity. It has a huge representation in the brain like that of the hands, the primary human organ for exploration by touch. The lips, palate and oral mucosa are also very sensitive to touch and have been explored as sites for electrotactile display [29]. There is significant electrotactile percept inhomogeneity on the tongue, and offers indirect evidence of the effects of the type of innervations and wide differences in both densities and distributions of tactile fibers in the tongue [30].

Chorda tympani (CT) and glossopharyngeal (IXth) nerves transmit taste information from anterior and posterior tongue to brainstem where they synapse with second order neurons in the rostral nucleus of solitary tract (rNST) [31].

Tongue Stimulation in Normal Subjects

Galvanic tongue stimulation (GTS) induces metallic or electric taste (Stevens et al, 2008). This fact was first discovered by Sulzer in the eighteenth century [13]. Fungiform papillae density is associated with increased discrimination ability for electrical stimuli [7].

The sensory system of the tongue can effectively convey electrical stimuli despite a very minimal practice and when information transfer is limited [18]. Due to technical difficulty in stimulating the tongue, researchers have developed special instruments to prove the neural mechanisms for somatosensory processing. In the somatotopic representation in cerebral cortex, the face and oral regions as well as the hand area occupied larger regions (Penfield and Boldrey, 1937), indicating an important role in the human somatosensory system [32].

Tongue Stimulation in Obstructive Sleep Apnea (OSA)

The pathophysiology of obstructive sleep apnea is characterized by multiple patterns of upper airway collapse. Most sleep apnea patients have airway collapse at multiple levels at the levels of the velum, oropharynx, tongue base, and epiglottis. At all levels, complete or partial anteroposterior collapse is the most common pattern [3].

Hypoglossal nerve stimulation results in improvement in sleep apnea without awakening the patient by decreasing the collapsibility of the pharynx and thereby increasing the airflow [33]. Thus it is a safe and beneficial treatment for CPAP refractory OSA. It is also associated with greater patient compliance, and it significantly improves the quality of sleep [34]. Tongue Stimulation stiffens the airway wall in sleep apnea patients [9].

It is important to note that CN-NINM is a platform that consist of various technologies which influences the central nervous system, primarily, through vagal and trigeminal cranial nerves. NEMOS, Cefaly, NeuroSigma, and SIMPATOCOR are examples of other technologies within the CN-NINM canon. Translingual neurostimulation is one of the new methods of stimulation in this platform [6].

Tongue Stimulation in Balance Impairments

Tongue stimulation has been used in various types of patients with sensory driven balance deficits: vestibular disorders, sensorimotor neuropathy, traumatic brain injury, stroke, ataxia, parkinsonism patients and older adults. [37]. Optic flow activated the right vestibular nucleus, the right superior colliculus and many structures in cerebellum. Comparison of these patterns of activation before and after tongue stimulation showed that there was increased activation within trigeminal nucleus and alteration in activation in cerebellum [17].

The effect of added simultaneous task on the motor activity of tongue and hand was similar for slower movement, whereas for rapid movements, tongue speed was maintained but hand movements were degraded [35].

Anatomical and functional communication between the vestibular and adjacent trigeminal nuclei might be enhanced by the tongue stimulation which allows for the visual motor information in the vestibular nuclei to stimulate the trigeminal. This alternate communicative pathway between the vestibular and visual system could be the probable reason for improvements in postural stability [17].

There was significant signal increase in sensorimotor area, supplementary motor cortex, operculum, thalamus, insular and cerebellum after tongue stimulation. [1]. Thus, tongue stimulation has been used to improve balance in various types of neurological disorders: multiple sclerosis, spinal cord injury [33], head injury, vestibular disorders, cerebral palsy, ataxia, depression [36], and stroke.

The intact sensory channels, (e. g. proprioception, visual), provide feedback to central nervous system about the body motion and sensory augmentation training will make the patient depend on these intact sensory systems. Moreover, cognition, sixth sense (Brain interprets sensory training as new sensory channel), context specific adaption and combined volitional and non-volitional responses contributed to improvement in balance. Thus, cognition and sensory retraining are the 2 mechanisms responsible for improving balance [37].

Tongue Stimulation in Stroke Patients

Persistent motor functional loss in the upper extremity is more common after cerebrovascular accident which makes the patient dependent on activities of daily living. [27]. Brain computer interface therapy has been developed along with tongue stimulation for improving motor functions in stroke patients [4, 21. 25, 26, 39. 41]. Brittany Young et al. tested on one volunteer and found that there was significant improvement in ARAT scores and Stroke impact scale scores [22].

Alexander B. Remsik et al. [40] did a randomized controlled trial on 21 cerebrovascular accident patients with persistent upper extremity impairment. They received a maximum of 18-30 hours of therapeutic interventions with novel electroencephalogram-based brain computer interface driven functional electrical stimulation device (EEG – BCI – FES). The results showed that there is significant improvement in grip strength and action research arm test [27]. Tongue stimulation has been used to improve balance and improve hand functions in stroke patients.

Tongue Stimulation and its Safety

Tongue stimulation has been safely used in wide categories of patients, although, minor and temporary adverse events have been reported, which includes pain, tongue abrasion, mild headache, or discomfort. Tongue abrasion has been remedied with reprogramming the device and using tooth guard [6, 34]. However, hardly any study has been done to find out the effect of tongue stimulation on hemodynamic parameters

5. Conclusions and Suggestions

Tongue stimulation has been used in wide variety of patients safely and effectively. It has been found that stimulation of tongue resulted in improvement of functions pertaining to tongue and associated muscles in dysphagia and obstructive sleep apnea patients. Also, stimulation of nerves innervating tongue resulted in synaptic changes in brainstem and improved balance in balance impaired conditions. Based on Hebbian theory, tongue stimulation or tongue movements along with upper limb training induced neuroplasticity and thereby improvement in upper limb functions. Tongue stimulation results in complex interaction among vestibular, trigeminal and solitary nuclei, where co-modulation and convergence of vestibular, visual, visceral and nociceptive signal results in behavioral and subjective improvement in various functions. Although, a number of devices have been designed for providing tongue stimulation, pros and cons of these devices needs to be investigated. Also randomized controlled studies, to find out the effect of tongue stimulation on motor recovery in neurological patients, needs to be done. Further research also needs to be done on the effect of tongue stimulation on cardiopulmonary parameters.

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Conflict of Interest

None declared.

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