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AUTOMATION POSSIBILITIES FOR ELECTROSTIMULATION OF THE TONGUE - A COMPUTATIONAL APPROACH

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Abstarct: *The aim of this study is to assess the extent to which current developments in the area of tongue electrostimulation automation provide a basis for the development of a new group of clinical and technological solutions. Scientists and engineers can contribute to the development of effective, safe, and widely applicable tongue electrostimulation technologies with diverse applications in healthcare and consumer products.*

Keywords: *electrostimulation, oral language, paralysis, speech*

Możliwości automatyzacji elektrostymulacji języka – podejście obliczeniowe

Streszczenie: *Celem pracy jest ocena, w jakim stopniu obecny rozwój automatyzacji elektrostymulacji języka stanowi podstawę do opracowania nowej grupy rozwiązań klinicznych i technologicznych. Naukowcy i inżynierowie mogą przyczynić się do rozwoju skutecznych, bezpiecznych i szeroko stosowanych technologii elektrostymulacji języka o różnorodnych zastosowaniach w opiece zdrowotnej i produktach konsumenckich.*

Słowa kluczowe: *elektrostymulacja, język jama ustna, porażenia, mowa*

1. INTRODUCTION

New research in the area of electrostimulation is gradually providing more and more information on how stimulation of particular them nerves can contribute to the treatment of various conditions [1]. A prospective study of electrostimulation of the motor homunculus in 100 patients showed the need to update the human motor homunculus and its correlation with the somatosensory homunculus using a similar brain mapping technique [2]. The area of the face, particularly the oral cavity and tongue, is a particular area of research here. In addition, it appears that taste and lingual somatosensory function can be damaged after middle ear surgery, with recovery occurring more rapidly in paediatric patients than in adult patients [3]. Investigating and measuring the effects of electrostimulation on orofacial muscles, chewing, breathing and swallowing functions in people with Down syndrome showed statistically significant differences between before and after electrostimulation in terms of:

- the appearance of the cheeks (their flaccidity, flexion),
- tongue mobility,
- muscle activity when performing stomatognathic functions (breathing, lip behaviour, biting and grinding food. Functional increases in chewing, breathing and swallowing performance have been observed [4].

During electro-stimulation, lower average positive intensity thresholds were observed for the hand (2.39 mA) and tongue (2.60 mA) than the intensities required to elicit sensations in other parts of the body [5].

Complaints of taste disorders and tongue numbness are frequently observed in the middle ear surgery group, but objective assessment of somatosensory changes of the tongue and taste function is necessary here. Post-operative thresholds of sensitivity of the tympanic cords nerve (CTN) to touch on the operated side were significantly higher than pre-operative thresholds. Tongue sensory nerve thresholds here correlated with the tongue numbness symptom. CTN dysfunction occurred after surgery, even when the CTN was preserved. The improvement of somatosensory symptoms of the tongue after surgery occurred much earlier than the taste disorder and sensory thresholds returned to baseline values with the resolution of symptoms [6].

Transcutaneous electrical nerve stimulation (TENS) used alone or in combination with lingual trills helps to close the glottis and improved comfort during phonation. TENS combined with lingual trills results in improved voice quality [7].

Interestingly, an electrostimulation device (Tongue Display Unit with a 12 × 12 electrode array) can be used in gaze substitution (e.g. for navigating blind people), so stimulation of the tongue provides sufficient precision of sensation to control the movement path [8].

But when the electrostimulation signal is applied continuously, the receptors of the affected area may become saturated and the patient may temporarily lose sensitivity to the information thus transmitted. As a countermeasure to this effect, the use of stochastic saccades on the signal applied to a 12x12 matrix is proposed, which gives a reduction in the saturation of the touch receptors on the tongue [9]. The use of a moderate level of sparking improves the perception of the direction of lines drawn on the matrix and shortens the reaction time [10]. This phenomenon can be used in electrostimulation for tongue function therapy.

It was necessary to develop clinical tests to:
- measuring trigeminal nerve sensitivity on the tongue,
- objectively assessing changes in trigeminal sensitivity in the oral cavity and the ability to taste after damage to the cricothyroid nerve (CTN).

In patients with a severed CTN, postoperative thresholds on the operated side were significantly higher than preoperative thresholds in the electrostimulator test, 2-point discrimination test and electrogustometer (EGM). In patients with manipulated but not dissected CTN, postoperative thresholds were significantly higher than preoperative thresholds in the electrostimulator test and EGM. Patients with manipulated but not cut CTN and abnormal EGM postoperative thresholds showed that postoperative thresholds were significantly higher than preoperative thresholds in all tests. The electrostimulator test was most useful for objectively assessing small changes in trigeminal sensation. CTN function affects both taste and trigeminal sensation of the tongue [11].

New rehabilitation methods (training programmes, subglottic nerve stimulation) for the treatment of obstructive sleep apnoea syndrome (OSAS) are currently being modified. among others, towards electrostimulation of the genioglossus muscle, which can support conventional treatment or can be an alternative for patients with poor compliance with CPAP therapy, mandibular advancement devices or insufficient surgical results [12].

Further development and evaluation of a feedback system to prevent pressure ulcers in paraplegic patients should be conducted. [13].

An innovative health strategy involves the use of computers and sensory substitution using the tongue to compensate for the loss of sensation in the buttocks area in people with paraplegia [14].

Daily submandibular electrical stimulation (dSE) of the suprahyoid muscles is used to prevent the tongue from retracting into the lower airway during sleep. By placing stimulating electrodes inside and outside the oral cavity, the recruitment of stimulated muscle fibers at low current intensity was improved. A significant effect of electrical stimulation on suprahyoid muscle strength was initially demonstrated in healthy volunteers compared to placebo-treated volunteers [15]. Modern sleep medicine is an interdisciplinary field that requires cooperation with various specialists to address the ailments of our patients. [16], moreover, dSE can prevent apnea episodes caused by the tongue falling into the throat during sleep. [17].

In patients with tongue pain, electrostimulation of the tongue pain zones was performed: a current of 45 mkA was applied for 10-20 min, with the current power regulated by the patients themselves, trying to obtain a slight stinging sensation, and each therapeutic session consisted of 10-12 exposures. High effectiveness was demonstrated compared to traditional methods (novocaine blockade, analgesics, etc.), and improvement was observed already after the first exposure, a significant reduction in the pain syndrome was observed after treatment in all patients (100% of cases compared to 74% in the control group) [18].

In patients with xerostomia, significant improvement in swallowing difficulties and tongue burning has been observed, but the response to therapy is not evenly distributed over time [19].

Electrodiagnostics of functional and neuromuscular disorders of the small muscles of the organ producing voice and speech is difficult due to the hidden anatomical situation. However, it enables electromyography of the larynx, palate and tongue during voluntary muscle contraction, as well as neuromyography after electrostimulation of the afferent nerve, especially cranial nerve X, as well as reflex myography after electrostimulation of the contralateral nerve [20].

Distribution of interneuronal connections between analyzers. ensures the implementation of conditioned effector movement (including in a cat), occurring in both situations with the participation of the same effector organ (tongue) and determines the nature of a specific adaptive reaction. [21,22].

The aim of this study is to assess the extent to which current developments in the area of tongue electrostimulation automation provide a basis for the development of a new group of clinical and technological solutions.

2. RESEARCH GAPS

Despite aformentioned significant progress in electrostimulation of the tongue, there are still several research gaps. Identifying and addressing them can contribute to a more comprehensive understanding and application of tongue electrostimulation. Some research gaps include:

- mechanisms of action, i.e. underlying neural and physiological mechanisms through which tongue electrostimulation affects e.g. taste perceptron, pathways and neurotransmitters involved in the precision and effectiveness of such stimulation;
- dose-response relationships for optimizing the intensity, frequency, and duration of tongue electrostimulation, including determining the minimum effective dose and potential saturation effects;
- long-term effects of repeated tongue electrostimulation;
- individual variability;
- clinical validation in specific clinical contexts, such as taste disorders, obesity management, or rehabilitation following oral surgeries;
- standardized protocos including within integrated multinensory approach;
- effect on taste, food preferences and consumption (e.g. diet ary chi ces in obesity treatment).

Research gaps can be observed beyond various applications in health care, but also, for example, in culinary research.

3. COMPUTATIONAL APPROACH

To date, none known working biocybernetic models for electrostimulation of tongue have been developed. They should involve the development of theoretical frameworks that integrate principles of biology, cybernetics, and control systems to understand and predict the responses of the tongue to electrical stimulation. Key aspects of biocybernetic models relevant to electrostimulation of the tongue are following:

- neurophysiological foundations;
- considering the conductivity of tongue tissues, the placement of electrodes, and how electrical currents propagate through neural structures;
- dose-response relationships between the characteristics of electrical stimulation (amplitude, frequency, and duration) and the resulting neural or perceptual responses
- neural adaptation and plasticity, e.g. to stimulated taster;
- closed-loop control systems with real-time feedback (based on the user's responses or/and desired outcomes).
- factors contributing to individual variability (e.g., anatomical differences, genetic variations, baseline taste sensitivity);
- explanation and predicting the outcomes of tongue electrostimulation in clinical applications in various conditions;
- real-time imaging data, such as functional magnetic resonance imaging (fMRI) or electroencephalography (EEG);

Comprehensive understanding of the complex interactions between electrical stimulation and tongue physiology, ultimately enhances the design and effectiveness of electrostimulation devices and applications.

4. DISCUSSION

Researchers use deep learning for modeling tasks on small data sets, often relying on decomposition and convolutional neural networks (CNN), a type of deep learning that is particularly effective at classifying images while ensuring repeatability. AI allows both the automation of human tasks (view recognition, image segmentation, assessment of standardized structural and functional parameters of the heart) and advanced identification of patterns in image data (discovering new associations, phenotypes, predicting results and supporting clinical decisions) [23-25].

4.1. Limitations

Limitations associated with the automation possibilities for electrostimulation of the tongue include:

- limited understanding of underying neural mechanisms;
- different sensitivities and responses to electrical stimulation in individual patiens;.

- taste perception complexity and its dynamic nature (influence of mood, food context, and overall health);
- electrode placement precision;
- safety concerns.

4.2. Directions for further research

Further studies on electrostimulation of the tongue can contribute to advancing our understanding of its mechanisms, applications, and potential benefits, especially in rehabilitation. Directions for future research in this area are following:

- the neural mechanisms underlying tongue electrostimulation, exploring how electrical signals influence taste perception, sensory processing, and neural plasticity;
- individual differences in response to tongue electrostimulation (influence of age, gender, genetic variations, and sensory thresholds);
- research on clinical applications of tongue electrostimulation, including rehabilitation for individuals with taste disorders, sensory augmentation for those with impairments, and therapeutic interventions for conditions like obesity or diabetes, takinh into consideration optimization or use hybrid approach [26-29];
- establish commonly accepted standards and safety parameters for tongue electrostimulation;
- develop advanced automation and control systems for tongue electrostimulation based on artificial intelligence algorithms to optimize stimulation patterns based on real-time feedback, adapting to individual preferences and responses [30-33].

5. CONCLUSIONS

Scientists and engineers can contribute to the development of effective, safe, and widely applicable tongue electrostimulation technologies with diverse applications in healthcare and consumer products.

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