Research article
UDC 159.91
https://doi.org/10.21702/rpj.2023.3.9

Manifestations of Speech Defects in the Processes of Speech Perception and Inner Speaking

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Abstract

Introduction. Existing research in the field of speech disorders does not provide a systematic understanding of the relationship between brain bioelectric activity and the nature of speech disorders, characteristics of speech perception and inner speech. This study aims to compare brain activity during the perception and inner speaking of words between a group of non-language impaired subjects and a group of subjects with functional dyslalia. For the first time, an analysis and comparison of evoked potentials (EPs) of the brain in the process of speech perception and inner speaking in individuals with and without rhotacism were carried out. **Methods.** A total of 36 subjects participated in the EEG study, including 18 subjects suffering from the rhotacism speech impediment. The subjects were presented with auditory stimuli (words) spoken by a speaker with rhotacism and a speaker without sound pronunciation peculiarities. Subsequently, the study participants were asked to mentally repeat the word, maintaining the tone and pronunciation characteristics as in overt speech. **Results.** During the EEG study, the most significant differences in the EP structure were found in lead C3. **Discussion.** The differences in EP in the process of speech perception and inner speaking in subjects with and without rhotacism were analyzed. It was shown that for the task on speech perception and inner speaking of speech stimuli, there is a tendency to distinguish between defective and normative pronunciation of words by a group of individuals without speech disorders. No significant differences in EP were observed in subjects with rhotacism under the same conditions. It can be assumed that individuals with rhotacism do not perceive the difference between these pronunciation options.

Keywords

electroencephalography, inner speech, rhotacism, evoked potentials, perception, speech disorders, functional dyslalia, sound image, pronunciation defects, inner speaking

Funding

The work was supported by the Russian Science Foundation, project No. 20-18-00067.

For citation

Shevaldova, O. V., Vartanov, A. V. (2023). Manifestations of speech defects in the processes of speech perception and inner speaking. *Russian psychological journal, 20*(3), 173–187. https://doi.org/10.21702/rpj.2023.3.9

Introduction

The prevalence of speech disorders, according to various sources, varies from 5–10 % (Yagunova, 2018) to 22 % (Goulart, 2017). In recent years, there has been an increase in the number of patients with cognitive deficits and speech development disorders (Makarov, Emelina, 2017). The use of electroencephalography (EEG), magnetic resonance imaging (MRI), and computed tomography (CT) to assess the functional state of the brain has become widespread. Using these methods, in recent years, epileptiform and local pathological changes (with temporal predominance) in the brain have been discovered in children with severe speech disorders and organically caused severe mental retardation (Gamirova, Belousova, Utkuzova, & Zaikova, 2014), neuropsychological and neurolinguistic aspects of specific speech disorders (Pachalska, Jastrzębowska, Lipowska, & Pufal, 2007). A correlation has been established between temporomandibular disorders, atypical swallowing, and dyslalia (Marchesi et al., 2019).

Despite research into the diagnosis and treatment of speech disorders in children and adults, such issues as the pathogenesis of various speech disorders, the relationship between brain bioelectrical activity characteristics and speech defects and the characteristics of inner speech and perception remain unresolved. Understanding the neurophysiological mechanisms of the organization of speech activity is a necessary condition for the development and application of appropriate methods to correct speech development disorders.

Functional dyslalia

Functional dyslalia is a defect in sound pronunciation caused by a dysfunction of the cortical parts of the speech-motor and speech-auditory systems or a defect in the speech production mechanism. It is manifested by motor (distortion) or sensory (mixing, substitution) inaccuracy in the pronunciation of phonemes. Rhotacism is a form of dyslalia associated with the presence of a defect in the pronunciation of the [r] and [r'] sounds.

Causes of functional dyslalia

In individuals with functional dyslalia, the structure of the peripheral speech apparatus is normal, the innervation of the articulatory muscles is not impaired, and physical hearing is preserved. The pronunciation defects are due to disruption of neurodynamic processes in the cerebral cortex. Functional dyslalia can be caused by the following two types of factors:

1. **Biological factors**. These include delays in speech and mental development and general physical exhaustion due to long-term illnesses or severe infectious pathologies. Disorders of general physical development predetermine a neurodynamic deficit that manifests itself in the weakening of subtle differentiations in the speech-auditory or speech-motor systems. Articulatory movements are unclear, speech kinesthesia is unclear, phonemic hearing is not formed.
2. **Social (pedagogical) factors**. These include cases of incorrect speech training: parents' imitation of 'babbling' pronunciation, children's assimilation of defective speech patterns of adults, excessive stammering of parents and close relatives, which children begin to mimic. Speech development is negatively affected by upbringing in a bilingual environment. In this case, the normative features of sound pronunciation for one language can be transferred to another, where they are not the norm. Among other things, the cause of dyslalia may be a delayed visit to a speech therapist or pedagogical neglect (Boltakova, 2013).

Mechanism for occurrence of dyslalia

The occurrence of functional dyslalia is associated with an imbalance of excitation and inhibition in the cortical areas of the speech-auditory and speech-motor systems of the human brain. The nature of the main defect is determined by the localization of cortical neurodynamic dysfunction. When the motor speech center (Broca's area) is damaged, motor failure occurs mainly. Firstly, the reproduction of phonemes is affected, and secondly – speech hearing. When neurodynamic disorders are localized in the sensory speech area (Wernicke's area), the ability to perceive speech sounds as linguistically significant decreases.

Early studies showed contradictory results on the relationship between speech production and auditory perception in individuals with speech disorders. Some authors suggest that the perception of sounds is a critical variable and impacts speech production (Munson, Edwards & Beckman, 2005; Nijland, 2009; Cabbage, Hogan & Carrell, 2016). Other authors argue that there is little evidence that the presence of a speech impediment causes problems in auditory speech perception (Nagao, 2012; Hearnshaw, Baker, &

Munro, 2018). Thus, recent research (Berti, Guilherme, Esperandino & de Oliveira, 2020) has confirmed the relationship between speech production and speech perception, although it is noted that speech perception does not fully reflect the process of speech production.

Given the ambiguity of previously results, it appears necessary to continue studying the relationship between speech production and perception in individuals with defects in sound pronunciation.

There is an ongoing debate about whether overt and inner speech are equally processed in the brain. Do both types of speech contain detailed articulatory information and inner speech lacks only sound production? Does inner speech contain no detailed articulatory information (Stephan, Saalbach, & Rossi, 2020)? A study (Stephan et al., 2020) has shown that the brain successfully distinguishes between overt and inner speech. By simultaneously using EEG and functional near-infrared spectroscopy (fNIRS), the authors showed that differences between overt and inner speech are explained not only by specific language and motor processes, but also by inhibitory mechanisms. In addition, recent attempts have been made to automatically decode inner speech using EEG and other non-invasive methods (Simistira, Gupta, Saini, De, & Liwicki, 2022; Nieto, Peterson, Rufiner, Kamienkowski, & Spies, 2022; Berg, Donkelaar, & Alimardani, 2021).

A study (Mehta et al., 2015) has shown the presence of generalized EEG abnormalities in children with speech impairments. Significant statistical changes in the EEG parameters have been found, characteristic of various levels of general speech underdevelopment. These changes are necessary for the differential diagnosis of moderate and severe impairments and for the prognosis of the disease (Razin'kova et al., 2019).

In a recent paper (Ballard, Etter, Shen, Monroe, & Tien, 2019), the authors demonstrated the feasibility of using EEG-based automatic speech recognition systems as a feedback tool in speech therapy for patients with aphasia. The results presented in another paper (Krishna et al., 2021) showed a first step towards demonstrating the feasibility of using non-invasive neural signals to develop a reliable speech prosthesis in real time for stroke survivors suffering from aphasia, apraxia, and dysarthria.

The processing of auditory information plays an important role in the process of inner speech. It is carried out in a number of cortical areas found in the lower bank of the lateral sulcus and adjacent to the superior temporal gyrus (Vartanov & Shevchenko, 2022). From the perspective of brain mechanisms, there is a complex system, which, on the one hand, is similar to the system of speech perception and representation of sound images, and, on the other, to the system of speech production.

Since inner speech can be considered as a derivative form of overt (sound) speech, it is reasonable to expect that impairments of overt speech can also manifest themselves in inner speech. However, on the other hand, since sound production itself is not required in inner speech, it would seem that pronunciation defects should not manifest themselves in the mental image of sounds. This contradiction represents **the main problem** of this study. Its relevance and scientific importance are not so much related to the area of speech therapy and defectology, but to the field of neurophysiology. At present, there is no complete systemic understanding of the brain mechanisms of inner speech. The relationship of these processes and the nature of the speech defect has not been virtually studied (this is the **object of this study**). The corresponding manifestations of bioelectrical activity using EP have not been described, which is the **subject of this study.**

This study aims to use EEG data to construct and compare evoked brain potentials in the process of perception and inner pronunciation (mental repetition) of words (pronounced normally and by a speaker with rhotacism) by a group of subjects with rhotacism and a group of subjects with normative pronunciation.

Methods

Subjects

A total of 36 subjects participated in the study (18 women and 18 men aged 22–38 years), including 15 subjects (6 women and 9 men) with a peculiarity of sound pronunciation in the form of rhotacism. The subjects had higher education. All subjects had no history of mental illness, and also signed a voluntary informed consent to participate in the experiment, approved by the ethics committee of the Faculty of Psychology, Lomonosov Moscow State University, No. 6, 2020.

Equipment

The BrainSys software (BrainWin) was used to record and edit the EEG to exclude artifacts. Registration of electrical activity of the brain was carried out monopolarly, using the Neuro-KM 19-channel electroencephalograph (Statokin company, Russia). The electrodes were placed according to the international 10–20 system. The Presentation software (version 18.0 from Neurobehavioral Systems, Inc.) was used to present the stimuli. Average evoked potentials (EPs) and the corresponding 95 % confidence intervals were calculated for each stimulus.

Stimuli

1. Raketa – a meaningful word with the control letter [r] at the beginning.
2. R'aketa – a significant word pronounced by a speaker with rhotacism.
3. Biblioteka – a neutral word that does not contain the control letter [r];
4. Kur'er – a meaningful word with a control letter [r] in the middle of the word before the soft sign and at the end of the word.
5. Ograda – a meaningful word with the control letter [r] in the middle of the word before the vowel.

These stimuli were presented in audio format. In the audio presentation, recordings of a female voice were used to present these words without additional sounds, noises, and the possibility to form phrases and sentences.

Experimental procedure

The stimuli were presented in a random order, each 50 times. The total sequence of presentations consisted of 250 stimuli. The duration of the experiment was about 25 minutes. The beginning of inner speaking was indicated by a special signal (short sound). Auditory stimuli were presented through headphones. During the experiment, subjects had their eyes closed.

Data analysis

To exclude artifacts, the visual analysis of the EEG was performed using the Brainsys software (BrainWin). As a result of automatic sorting of EEG segments by stimulus numbers and averaging of EP fragments in the interval of 200 ms before the stimulus and 500 ms after its presentation, 5 EPs were obtained for the perception of stimuli and 5 EPs for their inner speaking for each of 19 leads for the two studied groups of subjects. For all EPs, 95 % confidence interval estimates were obtained, which were further used to determine the significant differences between them.

Results

For each of the studied groups of subjects (groups of subjects with and without rhotacism), averaged EPs were obtained during perception and during inner speaking of each of the presented words with an estimate of 95 % confidence interval, which made it possible to assess the reliability of differences in the amplitude of the corresponding peaks. In most leads, no significant differences were found between the groups of subjects for any of the word stimuli. However, subtle but significant changes in bioelectrical activity were detected for some conditions in lead C3. The perception task is characterized by virtually complete coincidence of evoked potentials in shape for both groups of subjects for all stimuli. In lead C3 there was a slight difference in the amplitude and shape of the EP for the words 'biblioteka' and 'kur'er'; the presence of an N450 peak was also characteristic when the word 'biblioteka' was perceived by a group of subjects with rhotacism (Figure 1).

Figure 1

Comparison of EPs between groups of subjects with and without rhotacism during word perception

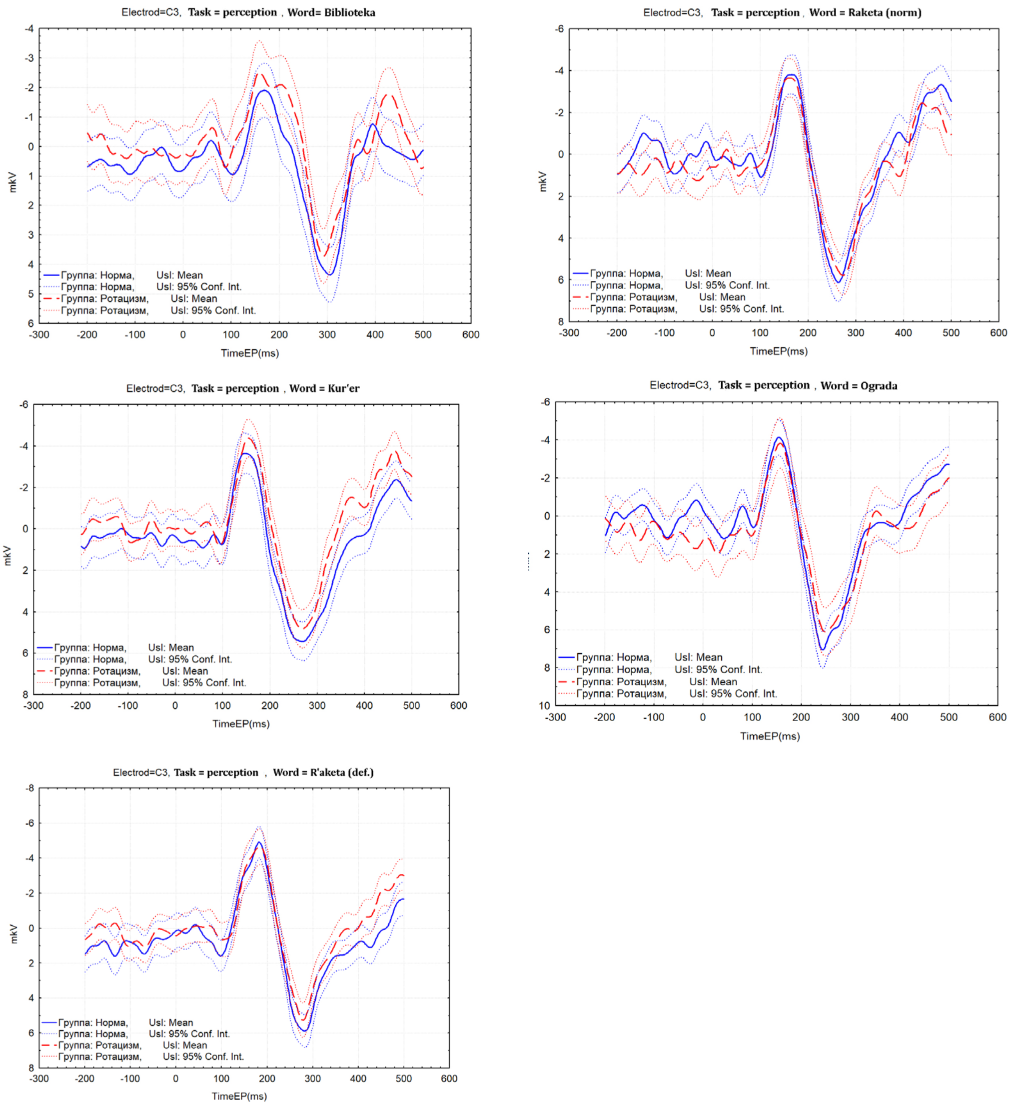


Figure 2

Comparison of EPs between groups of subjects with and without rhotacism during internal pronunciation of words

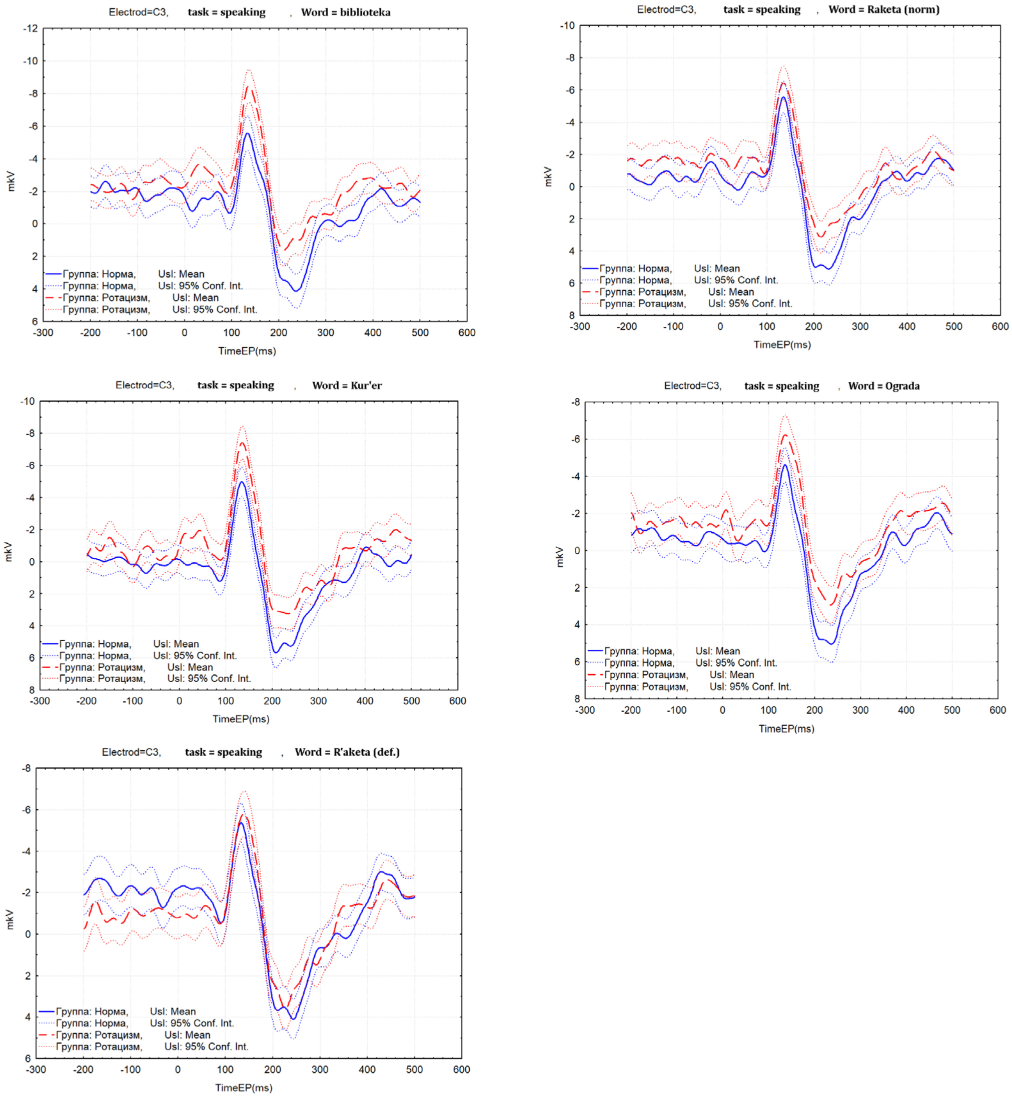
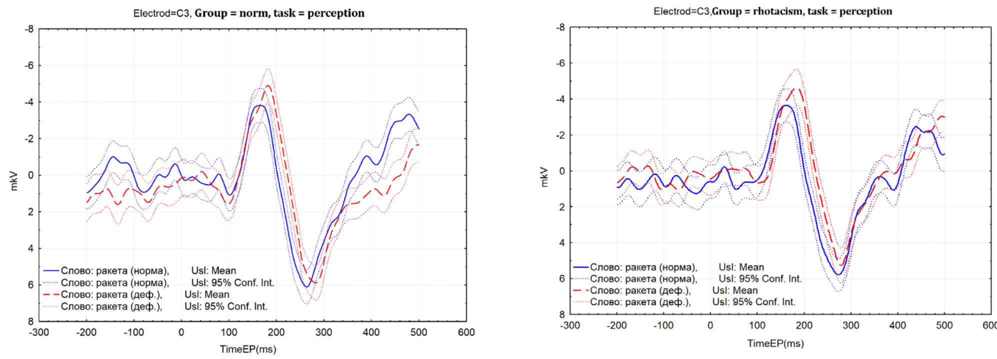


Figure 3 additionally shows a comparison of EP in lead C3 for the task of perceiving the words 'raketa', pronounced by a speaker without speech defects ('raketa' normal) and 'r'aketa', pronounced by a speaker with rhotacism ('raketa' (def.)). The presence of a shift in EP latency to the right is characteristic of the perception of a stimulus spoken by a speaker with a diction defect for both groups of subjects (Figure 3).

Figure 3

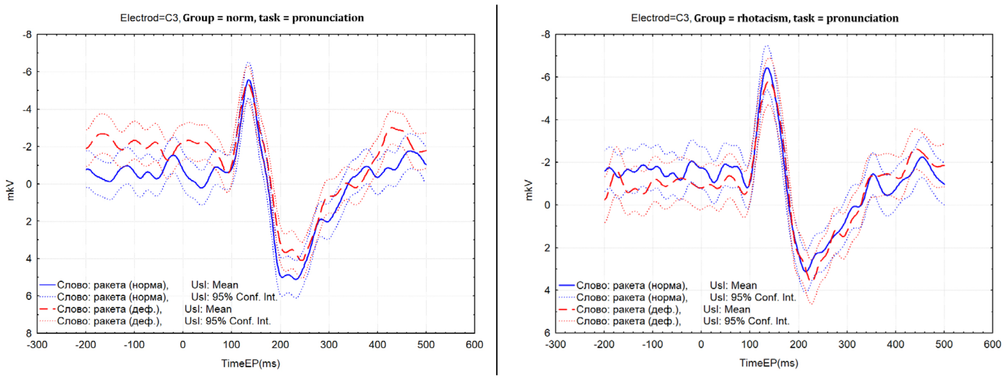
Comparison of EPs between groups of subjects with and without rhotacism when perceiving the word 'raketa', pronounced by a speaker with rhotacism and a speaker without speech defects



Pronunciation of the same stimuli is characterized by virtually complete coincidence of EP shapes, amplitudes, and latencies in lead C3 for both groups (Figure 4).

Figure 4

Comparison of EPs between groups of subjects with and without rhotacism during inner speaking of the word 'raketa' pronounced by a speaker with rhotacism and a speaker without speech defects



Discussion

The neurophysiology of severe speech disorders is presumably caused by organic factors due to perinatal hypoxic damage to the central nervous system. The mechanisms of moderate and mild speech impairments are determined by the discoordination of the processes of excitation and inhibition of certain brain structures (Razinkova et al., 2019), which undoubtedly affects changes in the overall EEG pattern. Such speech disorders are mainly associated with structural abnormalities of the left inferior frontal lobe. Thus, it has been shown that biofeedback, developed on the basis of EEG signals in leads O2, O1, C3, C4, F3, F4, F7, F8, effectively helps in correcting speech disorders (Jayawickrama & Thelijjagoda, 2020).

The results of this study demonstrate that the largest and only differences in EP between groups of subjects with and without rhotacism were found only in lead C3.

The model of language analysis (Emelina, Makarov, & Gasanov, 2019), based on numerous neurophysiological studies of the process of language analysis (Frisch, Hahne & Friederici, 2004; Friederici, 2011; Yurchenko, 2017), suggests the existence of a three-stage model of processing linguistic information in the brain. At the first stage (time interval 100-300 ms), syntactic analysis is carried out; it is determined to which part of speech a particular word belongs and whether it can be included in the semantic configuration of the sentence. In the range of 120–200 ms, the early left anterior negativity (ELAN) (Hahne & Friederici, 2002; Frisch et al., 2004; Friederici, 2011), can be observed, which determines the correct recognition of the sound stimulus and the correlation with a memory pattern. At the second stage (300–500 ms), lexical-semantic information is processed and the meaning of the received information is integrated into the context. In this range, the left anterior negativity (LAN) can be observed (Gunter, Friederici & Schriefers, 2000; Sabourin & Stowe, 2004), which characterizes the perception of stimuli with morphosyntactic anomalies, which result in difficulties in assigning thematic roles. At the third stage (from 500 ms), all types of information are combined. In the presence of syntactic and sometimes semantic anomalies, the P600 effect occurs, which most likely characterizes the stage of reanalysis of the received information.

This work shows that, for a perception task, there is a tendency to distinguish normal pronunciation of the word 'raketa' from defective pronunciation at late latency (400–500 ms) in the group of subjects without speech impediments. This probably indicates a LAN effect. For the group with rhotacism, EPs at this latency do not differ, which may indicate that subjects with rhotacism do not perceive the difference between these pronunciation options at the level of speech perception.

During the process of inner speaking, there is also a tendency to distinguish between two variants of pronunciation of the word 'raketa' by the group of subjects without speech defects at a latency of 250 ms. Repeating the word 'r'aketa' after a speaker with rhotacism, subjects without the speech defect try to recognize the stimulus and correlate it with an existing memory pattern, which is accompanied by the ELAN effect. In the group of subjects with rhotacism, such EP differences are not observed. In other words, both variants of the word 'raketa' are repeated in the same way. We should note that, according to the subjective oral report of subjects with rhotacism, they also have a defect in the pronunciation of the letters r and r' in their inner speech.

Noteworthy is the fact that the amplitude of the N150 EP decreases during inner speaking of all words in the group of subjects without speech disorders. According to Risto Näätänen's model of speech production (Näätänen, 1998), this can be explained by the process of ignoring the deviant stimulus. We should note that the N150 amplitude is lower in the normal group only during inner speaking (during perception, no difference is observed). Therefore, we can assume that in subjects with rhotacism, inhibition during the generation of sound images during internal pronunciation is not sufficiently developed. In other words, a pronunciation defect may be associated with an insufficiently correct construction of the inner sound image. Thus, they cannot properly adjust articulation according to the sound standard and do not see their own defect.

EP similarity for perception and pronunciation in the normal group indicates that the same sound image appears in pronunciation and perception, or indicates involuntary pronunciation in perception.

Conclusion

1. The largest and only differences in EPs between the groups of subjects with and without rhotacism were found only in lead C3.
2. For a perception task there is a tendency to distinguish between normal and defective pronunciation of the word 'raketa' (at a late latency of 400–500 ms) in the group of subjects without speech impediments. This probably indicates the LAN effect, which characterizes the perception of stimuli with morphosyntactic anomalies. In the group of subjects with rhotacism, such differences in EP are not observed.
3. In the process of inner speaking, there is also a tendency to distinguish between two variants of pronunciation of the word 'raketa' (at a latency of 250 ms) in the group of subjects without speech defects, which may indicate the ELAN effect, which determines the correct recognition of the sound stimulus and its correlation with the memory pattern. In subjects with rhotacism, no differences in EPs were observed when the same stimuli were presented.
4. During inner speaking of all words, the amplitude of the N150 EP differs in the groups with and without rhotacism (it is higher in the group of subjects). For the perception task, no differences in EP were observed in both groups of subjects. In subjects with rhotacism, inhibition is probably not sufficiently developed to produce a sound image during internal pronunciation. A pronunciation defect may be associated with an insufficiently correct construction of the internal sound image, which impedes correct adjustment of articulation according to the sound standard.

Based on this, we can draw the following main conclusions:

1. The only differences in EPs between the groups of subjects with and without rhotacism were found in lead C3;
2. When individuals without speech impediments perceive a word spoken by a speaker with rhotacism, late left anterior negativity is observed, which characterizes the perception of stimuli with morphosyntactic anomalies.

3. When mentally repeating a word pronounced by a speaker with rhotacism, in the group of subjects without diction defects, early left anterior negativity is observed, which determines the correct recognition of the sound stimulus and its correlation with the memory pattern.

4. In subjects with rhotacism, inhibition is not sufficiently developed when producing sound images during inner speaking.

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Received: December 11, 2022
Revision received: March 28, 2023
Accepted: June 08, 2023

Author Contribution

Ol'ga Vladimirovna Shevaldova – conducted empirical research, analyzed and interpreted the results, worked with sources, contributed to the overview part of the article.

Aleksandr Valentinovich Vartanov – developed the research concept, analyzed the results, critically revised the content of the manuscript.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.