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# A SYSTEMATIC APPROACH TO THE STUDY OF EXPERIMENTAL PHONETICS

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# EKSPERIMENTAL FONETIKANI O'RGANISHDA TIZIMLI YONDASHUV

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# СИСТЕМНЫЙ ПОДХОД К ИЗУЧЕНИЮ ЭКСПЕРИМЕНТАЛЬНОЙ ФОНЕТИКИ

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**Abstract.** This article explores the application of a systematic approach in experimental phonetics, which allows for the integration of various aspects of articulation, acoustics, and speech perception to deeply understand the mechanisms of verbal communication. Based on interdisciplinary analysis, the article describes how a systematic approach can contribute to more accurate modeling and visualization of articulatory processes, improve the quality of acoustic analysis, and enhance the accuracy of perception and interpretation of speech signals. The paper presents the main methods and analyzes the relationships between articulatory and acoustic characteristics of speech, as well as their impact on perceptual processes of sound perception. The article emphasizes the importance of a systematic approach for solving complex tasks in experimental phonetics, enabling scientists to effectively integrate data from various studies and provide a more comprehensive understanding of speech processes.
**Keywords:** experimental phonetics; systematic approach; articulation; acoustics; speech perception; methods of experimental phonetics.

**Annotatsiya.** Bu maqola eksperimental fonetikaga tizimli yondashuvni qo'llashni o'rganadi, bu nutq aloqasi mexanizmlarini tushunish uchun artikulyatsiya, akustika va nutqni idrok etishning turli jihatlarini birlashtirishga imkon beradi. Maqolada fanlararo tahlilga asoslanib, tizimli yondashuv qanday qilib artikulyatsiya jarayonlarini aniqroq modellashtirish va vizualizatsiya qilish, akustik tahlil sifatini yaxshilash va nutq signallarini idrok etish va talqin qilishda aniqlikni oshirish imkonini beradi. Maqolada nutqning artikulyatsion va akustik xususiyatlari o'rtasidagi bog'liqlik, shuningdek, tovushni idrok etishning perseptiv jarayonlariga

ta’siri asosiy metodlarni taqdim etadi va tahlil qiladi. Maqolada eksperimental fonetikaning murakkab muammolarini hal qilishda tizimli yondashuvning muhimligi ta’kidlangan, bu olimlarga turli tadqiqotlar ma’lumotlarini samarali integratsiya qilish va nutq jarayonlarini to‘liqroq tushunish imkonini beradi.
**Kalit so‘zlar:** eksperimental fonetika; tizimli yondashuv; artikulyatsiya; akustika; nutqni idrok etish; eksperimental fonetika metodlari.

**Аннотация.** Эта статья исследует применение системного подхода в экспериментальной фонетике, который позволяет интегрировать различные аспекты артикуляции, акустики и восприятия речи для глубокого понимания механизмов речевого общения. Основываясь на междисциплинарном анализе, статья описывает, как системный подход может способствовать более точному моделированию и визуализации артикуляционных процессов, улучшению качества акустического анализа и повышению точности восприятия и интерпретации речевых сигналов. В работе представлены основные методы исследования артикуляционных и акустических характеристик речи и анализируются взаимосвязи между ними, а также их влияние на перцептивные процессы восприятия звуков. В статье подчеркивается важность системного подхода для решения сложных задач экспериментальной фонетики, что позволяет ученым эффективно интегрировать данные из различных исследований и обеспечивать более полное понимание речевых процессов.
**Ключевые слова:** экспериментальная фонетика; системный подход; артикуляция; акустика; восприятие речи; методы экспериментальной фонетики.

## Introduction

The study of experimental phonetics, which delves into the intricate mechanisms of human speech production, perception, and acoustic properties, is pivotal for advancing our understanding of language. The complexity of speech, encompassing everything from individual phonemes to the rhythmic flow of conversation across different languages and contexts, necessitates a comprehensive methodological framework. A systematic approach in experimental phonetics provides such a framework, allowing researchers to integrate multiple layers of phonetic analysis — from physiological to psychological aspects — to form a coherent understanding of how speech functions. The importance of a systematic approach lies in its capacity to bridge the gaps between isolated studies of articulatory motions, acoustic variations, and perceptual feedback, offering a holistic view of phonetic phenomena. This approach not only enhances the precision and depth of phonetic research but also expands its applicability to real-world issues such as language learning, speech recognition technologies, and the diagnosis and treatment of speech disorders. Furthermore, as the field of phonetics interacts increasingly with rapidly advancing areas like machine learning and big data analytics, a systematic approach facilitates the adaptation of phonetic research to these interdisciplinary interfaces. This integration is crucial for developing more

sophisticated models of speech processing and for pushing the boundaries of what computational and cognitive phonetics can achieve.

Thus, the systematic approach in experimental phonetics not only serves as a robust analytical strategy but also propels the field forward, making it integral to both theoretical explorations and practical applications in the study of human speech. This article aims to explore the foundations, methodologies, and implications of adopting a systematic approach in experimental phonetics, underscoring its significance in advancing our comprehension of the complex dynamics of spoken language.

Although experimental phonetics was established a long time ago, it continues to attract interest among linguists. This interest is bolstered by the precision and effectiveness of experimental methods in phonetic research. Experiments enable the discovery of subtle details that even researchers with good hearing might not recognize.

One of the key advantages of experimental phonetics lies in its ability to study not only individual sounds but also their interactions with each other. Even Ferdinand de Saussure emphasized in his works that analyzing sounds in isolation from each other is unacceptable. He noted, “Phonology, trying to establish its key principles based on isolated sounds, goes against common sense. When it encounters the dualism of sound combinations, it proves ineffective. To understand the processes in sound combinations, it is necessary to develop a phonology that would allow these sound combinations to be viewed as algebraic equations” (16, 87). “In general, it should be emphasized that without experimental study of the speech chain, it is difficult to draw specific conclusions about the phonetic characteristics of a language” (19, 6).

Experimental phonetics is engaged in the study of the acoustic and physiological properties of speech sounds, applying instrumental methods to individual languages as well as entire language families. With the development of this discipline, phonetics has become one of the most precise sciences of language. Thanks to these methods, scientists have been able to study the characteristics of speech sounds and signals in detail, as well as analyze human intonation in various emotional states. Subsequently, these approaches have laid the foundation for the development of psycholinguistics, speech recognition technologies, forensic phonetics, and other specialized fields. Experimental phonetics is defined as “a set of instrumental methods for analyzing the sound composition of speech” (1, 497).

Experimental phonetics analyzes the phonetic sounds of speech under non-standard conditions. Often, depending on the research objectives, an isolated recording of each sound is required. However, with the advancement of computer technology, it has become possible to analyze sounds within the context of individual speech fragments. This approach allows for the study of sounds both in isolation and in their interaction with other sounds. A systematic approach can significantly enrich the understanding and methods used in experimental phonetics. The systematic approach is a methodology that involves analyzing research objects as unified, holistic systems comprised of interconnected elements. The principles of interdependence of system components, their hierarchy,

and the system's ability to self-regulate and adapt underpin this approach. It allows for the examination of research objects in their dynamics, interactions, and development. Using a systematic approach, phonetic systems can be analyzed as complete structures, where each sound (or its absence) affects the functioning of the system as a whole. This deepens the understanding of the mechanisms of interaction between various articulatory and acoustic phenomena in speech (10, 149). Phonetics, as a system, can be broken down into subsystems and elements, ranging from the level of the respiratory apparatus to the nuances of articulation and acoustics. This principle helps to systematize research, making it deeper and more multifaceted (4, 203). The systematic approach enables the integration of various methodologies and data—from articulatory to acoustic and perceptual measurements — creating a comprehensive view of phonetic phenomena (9, 327). Within the framework of a systematic approach, computer modeling can be used to simulate phonetic processes, allowing for the testing of various hypotheses and predicting the behavior of the system when certain parameters are changed (17, 206). A systematic approach in phonetics often requires knowledge and methods from other fields, such as biophysics, electronics, and psycholinguistics, which facilitates the development of a complex and multidisciplinary approach in research (6, 145).

The systematic approach in science enables the study of complex objects through the analysis of interactions and dependencies between their parts. The fundamental principles of the systematic approach include integrity, hierarchy, and goal setting. Applying these principles to experimental phonetics can lead to a deeper understanding of the dynamics and structure of human speech sounds. Integrity implies that the system as a whole possesses properties that cannot be fully understood by examining its parts separately. In the context of phonetics, this means that the sound system of a language (phonology) and methods of articulation (phonetics) should be studied not only through individual sounds but also through their interaction in the speech stream.

The application of integrity in phonetics allows researchers to explore how changes in one sound affect other sounds and the overall perception of speech. This understanding is crucial for the development of speech recognition and synthesis technologies, where precise modeling of such interactions is critically important (7, 95). Hierarchy implies that systems can be decomposed into subsystems, which in turn can contain even smaller subsystems. In phonetics, this can be represented by division into levels: sounds, syllables, words, phrases, sentences, and so forth. Each level has its own rules and characteristics, but at the same time, is connected with other levels (3, 118). This principle allows for the systematic analysis of articulatory and acoustic features of speech, taking into account how the properties of one level affect the properties of another. For example, changes in articulation at the syllable level can lead to changes in the sound of individual phonemes (8, 245). Goal setting means that the behavior of the system is directed towards achieving a specific goal or set of goals. In phonetics, goals can vary from practical (e.g., effective communication) to more abstract scientific tasks (e.g., understanding the mechanisms of speech production and perception). This

principle helps to formulate hypotheses and design experiments aimed at investigating specific phonetic phenomena, such as the influence of emotions on intonation or changes in pronunciation under the influence of sociolinguistic factors (13, 137).

The systematic approach in experimental phonetics allows for the integration of various levels of analysis — from the physiology of articulation to the perceptual and sociolinguistic aspects of language. Below are several specific studies demonstrating how a systematic approach contributes to a deep understanding of phonetic processes:

In their work, Browman and Goldstein proposed an approach to articulatory phonology, which represents phonetic processes as interactions between articulatory gestures. This approach for the first time allowed the systematic study of how various articulatory movements are coordinated to produce phonemes. This research demonstrated the importance of considering the phonetic system as a complex of interacting subsystems (3, 92).

Stevens used a systematic approach to study the acoustic properties of speech. In particular, his work on the theory of quantal phonetics introduced models that explain how changes in articulation affect the acoustic characteristics of sounds, which in turn affects speech perception (17, 270). This approach showed how the physical properties of the vocal tract are related to the psychological perception of sounds, providing a holistic understanding of the speech reproduction process.

James Emil Fledge developed a model illustrating how adults learn a second language and how it affects their native language. In his works, a systematic approach was used to analyze the interaction of the first and second languages in articulation, which helped identify the mechanisms of adaptation of the speech apparatus in bilingualism (5, 198). This research highlighted how speech motor systems can adapt and reorganize when learning a new language.

## Experimental methods for studying articulation, acoustics, and sound perception, and the interrelationship between different aspects of the phonetic system

Articulation: Electromagnetic articulography tracks the movement of small sensors attached to the articulators (such as the tongue, lips, and jaw) to record their movements in space and time during speech. This provides a dynamic representation of articulatory processes. Ultrasound diagnostics use high-frequency sound waves to visualize articulatory movements, especially of the tongue, providing important data on the mechanics of speech.

Acoustics: Acoustic analysis, using software such as Praat, analyzes sound waves recorded during speech to measure parameters such as formants, intensity, fundamental frequency, and temporal characteristics. Aerodynamic testing, methods such as measuring airflow and pressure in the vocal tract, help understand how various sounds are produced, including plosive and fricative consonants.

Sound Perception: Perceptual tests, experiments in which participants perform tasks to recognize, discriminate, or evaluate sounds or

words. These tests assess how different acoustic parameters affect speech perception. Functional magnetic resonance imaging (fMRI) allows for the visualization of active brain areas during tasks related to speech perception, while EEG tracks the brain's electrical activity associated with processing audio signals.

Data Integration from Different Studies: Integrating data from different studies helps create a more comprehensive and systematic understanding of speech processes. For example, correlating data from articulatory movements (EMA, ultrasound) with acoustic characteristics of sounds (Praat) and perceptual responses to them (perceptual tests, fMRI, EEG) allows for the development of hypotheses about the connections between physical speech production and its perception. This multimodal information is crucial for understanding and treating speech disorders, developing speech recognition technologies, and improving foreign language teaching methodologies.

Self-observation without the use of instruments. Self-observation can target both muscular sense data and auditory data. In self-observation, a mirror is used (to determine the position of the lips, mouth aperture), a candle (to observe the flow of the air stream), and a laryngoscope (a medical device used for examining the palate, uvula, and larynx). All experiments are conducted repeatedly, as fixing muscular movements and auditory impressions requires some training. Despite its simplicity, this method has its drawbacks:

1. Not all speech organs can be studied
2. To research the articulation of any sound, it needs to be repeated many times.

Somatic methods (related to the use of devices, instruments, and apparatus):

1. Palatography — registering the contact area of the tongue with the palatal arch when pronouncing various phonemes. For this purpose, an artificial palate is prepared on a model of the upper jaw from various materials: plastic, glass, wax, celluloid. The surface of the plate facing the tongue is covered with black lacquer or dusted with an indifferent powder (talc, but not confectioner's sugar, which can cause hypersalivation), introduced into the oral cavity of the subject and pressed against the palate. The subject pronounces the suggested sound. At this time, the tongue touches the corresponding areas of the palate, leaving prints. The plate is then removed from the mouth and the prints are studied.

2. Photopalatography — obtaining photographs of the "artificial palate" with the tongue prints obtained after palatography. For this purpose, the "artificial palate" is placed on a model of the upper jaw. Photostatic photography technique is used to reproduce identical images before the start of orthodontic treatment, during the process, after its completion, and after speech therapy training. On the negatoscope, a scheme is traced on tracing paper. Then, identical palatograms are compared, and the results are analyzed.

Advantages of radiography:

— Wide availability of the method and ease of conducting research;
— No special preparation of the patient is required;
— Relatively low cost of the study;

— Images can be used for consultation with another specialist or in another institution.

Disadvantages of radiography:

— "Frozen" image — difficulty in assessing organ function;

— Presence of ionizing radiation, which can have harmful effects on the studied organism.

This method can also include radiophotography, as a combination of microphotography and radiography.

3. Microphotography — photographing the articulation of organs located inside, using a miniature camera. This method can also include cinematography, as an accompaniment to photography with synchronized sound recording.

4. Tomography — a non-destructive method of layered investigation of the internal structure of an object by multiple transillumination in various intersecting directions, allowing imaging not through and through, but at a specified depth.

Electroacoustic methods:

These methods allow obtaining visual schemes of sound. There are many such methods, here are the main ones:

— Kymography — this technique involves directly recording articulatory movements of the larynx, mouth, and nose on a moving paper tape using pens connected to what directly contacts the articulating organs of the subject. Kymography allows breaking down the articulation of the speech apparatus into nasal, oral, and laryngeal.

— Oscillography — allows converting oscillatory movements of the air into electrical ones, which are then transmitted to an oscilloscope, transforming the signal into digital form and representing it as a zigzag line — an oscillogram.

— Spectrography — in this method, the air stream is also converted into an electrical signal, which passes through the filters of the spectrograph. This allows obtaining a spectral picture of speech sounds.

Modern computer technology allows obtaining various acoustic characteristics of sounds, for example, information about intensity, changes in the fundamental tone in a word, phrase, or larger segments of speech.

## A systematic approach in speech analysis and synthesis, in working with big data, and in using machine learning for phonetic analysis

The systematic approach in experimental phonetics significantly expands the possibilities for speech analysis and synthesis, big data processing, and the application of machine learning for phonetic analysis. To demonstrate this, let's consider the following case study, which integrates data and methods from various sources and research areas.

In speech analysis, a systematic approach can include articulatory, acoustic, and perceptual data to create a more accurate model of the speech process. For speech synthesis, such models help in creating artificial speech that sounds more natural to the human ear. Using articulatory synthesizers that mimic the movements of the human speech apparatus can

improve the quality of synthesized speech, making it more understandable and natural (11, 246).

Phonetic analysis often requires processing and analyzing large volumes of data, including audio recordings, transcriptions, and annotations. A systematic approach allows for the integration and analysis of these disparate data using big data methods to identify patterns and trends in speech data. Using technologies such as Hadoop and Spark for distributed processing of audio data can significantly speed up the preprocessing and analysis of large data sets (20, 178).

Machine learning offers powerful tools for speech analysis, especially when it comes to classification, pattern recognition, and prediction. Integrating machine learning into a systematic approach allows for the creation of models that can be trained on complex data, including articulatory, acoustic, and perceptual aspects of speech. Using deep neural networks for emotion recognition in speech or for automatic speech recognition (ASR) allows systems to train on large volumes of data and achieve high accuracy in speech recognition and interpretation (12, 67).

Integrating various methods and approaches within systematic phonetics allows for a more complete understanding and modeling of speech processes, which is important both for theoretical research and practical applications. Such an approach enhances the accuracy and efficiency of modern phonetic research and technologies.

## Methodology of experimental research in phonetics using a systematic approach

Using a systematic approach in formulating hypotheses and designing experiments in phonetics allows for the integration of various levels of analysis and disciplines, ensuring a deep understanding of speech processes. This approach requires meticulous planning at every stage of the experimental process, from hypothesis formulation to data analysis and interpretation. Within a systematic approach, a hypothesis must consider the interrelationship between different components of the system. For example, a hypothesis might state: “Changes in the articulation of the sounds (p) and (b) affect the acoustic characteristics and perceptual perception of these sounds in bilinguals”. This hypothesis takes into account the interaction of articulatory and acoustic changes and their impact on perception. An experiment within a systematic approach should be multidisciplinary and multifaceted:

1. Experiment Design — should be developed to study the interaction between different levels of the system (articulation, acoustics, perception).

2. Data Collection Methods — use methods such as EMA for articulation, acoustic analysis for acoustics, and perceptual tests for evaluating perception.

3. Study Participants — selection should align with the goals of the hypothesis, for example, bilinguals who speak specific languages.

Data collection should be organized in such a way as to enable comprehensive analysis: standardizing data collection procedures to ensure data comparability across all experimental modules and obtaining a

sufficient volume of data for statistical significance of results. Data analysis in a systematic approach requires the use of statistical and analytical methods that can handle complex and multilevel data: multimodal analysis — integrating data from various sources for overall analysis, and statistical modeling — such as multilevel modeling or structural equation modeling to analyze the relationships between system components. Interpretation must consider the multifaceted nature of the data and the interrelationship between different levels of analysis: ensuring that interpretation aligns with the research goals — results should be interpreted within the context of the original hypothesis and theoretical framework. Recognizing limitations and suggestions — acknowledging the limitations of current research and proposing directions for further studies.

A systematic approach in phonetic research allows for a comprehensive evaluation of how various elements of the speech system interact with each other and provides a methodological foundation for creating more complex and informative experimental designs. A systematic approach in experimental phonetics represents an integrative methodology that allows researchers to analyze the interaction between various components of the speech process: from articulation and acoustics to perception and cognitive processing of sounds. This approach offers opportunities for a deeper understanding of speech mechanisms, however, it also includes a number of potential difficulties and limitations.

Integrating data from different disciplines: Phonetics is traditionally divided into articulatory, acoustic, and auditory phonetics. A systematic approach allows these directions to be combined to gain a more complete understanding of how sounds are produced, perceived, and processed. Such an approach can demonstrate how changes in articulation affect acoustic characteristics and how this is perceived by listeners.

Modeling dynamic processes: Speech communication is a dynamic process in which sounds constantly change and interact with each other. A systematic approach allows for modeling these changes, providing tools for a better understanding of processes such as coarticulation and assimilation.

Research on interlingual interactions: In conditions of bilingualism, a systematic approach can help investigate how two or more languages interact within the same speech apparatus, affecting each other at the articulatory and acoustic levels.

Complexity of data collection and analysis: A systematic approach requires the collection of a large volume of various types of data (e.g., articulatory data, acoustic recordings, perceptual assessments). Analyzing such a volume of information requires significant resources and high expertise, as well as powerful analytical tools for data processing.

Interdisciplinary challenges: Integrating knowledge and methods from different disciplines may lead to difficulties in understanding and applying concepts that may be unfamiliar to specialists from related fields. This requires the development of common theoretical frameworks and methodological approaches that would be understandable and acceptable to all research participants.

Potential methodological limitations: Opportunities for experimental manipulation and control over experimental variables may be limited. Interaction between different levels of the speech process can lead to ambiguities in the interpretation of results, especially when attempting to isolate the influence of one factor from others.

## Conclusion

In conclusion, adopting a systematic approach in experimental phonetics significantly enhances our ability to dissect and understand the multifaceted nature of human speech. This article has explored how such an approach integrates various levels of analysis, from articulatory mechanics to perceptual dynamics and acoustic features, thereby providing a more nuanced understanding of phonetic phenomena. The integration of diverse methodologies and data sources under a single systematic framework ensures that phonetic research is both comprehensive and coherent. It has been examined how a systematic approach facilitates the use of advanced technologies like machine learning and big data analytics, which are crucial for modern phonetic studies. These tools allow for the handling of large datasets and complex variable interactions, which traditional methods might not effectively address. Moreover, the ability to integrate findings from different research areas—such as cognitive science, linguistics, and computer science—under a systematic umbrella enriches the explanatory power and applicability of phonetic research.

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