

AN ACOUSTIC STUDY OF SOUNDS PRODUCTION OF CHILDREN DURING THE FIRST POSTNATAL YEAR

SPA – SPEECH PROCESING AND ACOUSTIC OF THE COMMUNICATION. PACS - 43.70.- h

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ABSTRACT

On the basis of instrumental analysis of Russian infants vocalizations at the first year of life, the dynamics of main vowel-like sounds characteristics were determined. We showed the hierarchical organization of signs, important for description different vowel-like sounds. The quality of sounds articulation defines the possibilities to use the one or other signs for description the infants' sounds. Unclear vocalization can be described on the basis of far multiple of signs. Possibilities to apply the acoustic keys, important for the analysis of vowels adult speech, increase with mastering of children's articulation skills.

Introduction

One of the general questions in areas of speech development is question about stabilizations the signs, important for descriptions and recognizes different levels of speech. Characteristic feature of speech is its efficiency and noise stability. These properties provide an opportunity of comprehension of a voice information in requirements of different noises: hums, contortions in system of communications, and also, for want of psychological and emotion states of speaking.

According our opinion, the nonverbal period can be considered as a basis for speech development. At the present moment the available experimental data and theoretical propositions allow us to consider that the development of speech is caused by the both biological determinants and environmental factors. Innate factors play more important role versus social during the early period of ontogenesis. Researches on children's preverbal and early speech development, which are carrying out in different countries [1, 2, 3], resulted in numerous data. They pointed out that by the birth infants have only linguistic ability. During the development on the background of the innate linguistic ability, related with the distinction of linguistic contracts and the successive change of vocalizations, speech-like elements and then the first words are being formed [4]. This process is caused by the increase of possibilities of articulator system and hearing aid and by the complication of neuron mechanisms of vocal and auditory development's control. On the other hand, it is caused by the influence of linguistic environment by means of imprinting and imitation. However, the question about a role of infants'

vocalizations in the making of speech production remains open in many aspects. The systematic long-term researches of formation of phonological development of Russian children are absent. Also, there is the absence of the clear criteria of features, underlying in the transition from infants sounds to speech-like elements and speech sounds. The purpose of the present study was to define signs, important for description the phonological development during the first year of life.

Method

The subjects were 18 Russian healthy infants from 3 months until 12 months of age. All acoustics sounds were recorded in different infant's conditions every three months (3, 6, 9, 12 months). They were born full-term, and their courses of development were reported to be normal and free of any specific problems relating to their vocalizations and hearing apparatus. Additionally were investigation developments of vocal-speech interaction in the five dyads of mothers and infants during the first year of babies' life. Were audio and video recorded mothers voices direct to infants (ID) and infant vocalizations during model situation mother-child interaction and during situation then infants play without their mothers. Were used the tape recorder "Pioneer" CT-W704RS, microphone-MD-59 and video camera "Panasonic"-WV-135N, microphone - model 4433. The special apparatuses (Bruel and Kjaer) were application to calibrate transparent characteristics of the audio recorder equipments. Psychosomatic status of children was estimated once per three months by a KID-scale. Firstly the all babies' vocalizations were selected. Were excluded from future analysis any noised production, vegetative and reflexive sounds. The acoustic sounds were listened by Russian-native speakers. All sounds were transcribed using the IPA symbols and SAMPA for Russian language. The temporal, spectral and formant characteristics of sounds were evaluated by means of special software Cool Edit (Syntrillium Soft. Corp.) and CSL – 4.0. In each signal the fundamental frequency (F0), value of formant frequencies (F1, F2, F3), and amplitude of corresponding formants (E0, E1, E2, E3) were measured. The signals were divided on the basis of their dynamic spectrum. In case of complex signals spectral and temporal characteristics were determined for the each of fragments distinguished on a base of sound and spectral analysis. Position of the two first formant of vowel-like sounds on two formant coordinate plot (F1/F2), and amplitudes of spectral maximum (En) in relation to amplitude of the first maximum (E0) correspondingly to fundamental frequency (En/E0) were taken in to consideration. In (F)/(En/E0) coordinates the formant frequencies value dependence on coincided values of amplitude normalized in relation to E0 were analyzed. The data were formed in the tables of "Access 7.0" program for the following statistical analysis. Mann-Whitney, Student-Newman-Keels, Kruskal-Wallis criteria defined the reliability of discrimination, with a value of significance not less than 0.05 in ANOVA program.

Results

On the basis of the instrumental analysis of infants' vowel-like sounds similarity and distinction between acoustic characteristics of vowel-like sounds and vowels of adults' speech were revealed. The vowel-like sounds of babies are characterized by high value of F0 (from 300 to 1000 Hz), great dispersion in the F1/F2 coordinate space occupying areas of different adults' vowels, formant ratio other than vowels ones. Were found that the values of F0 of infants vowel-like sounds correspond to values F1 of adult vowels [o], [u], [l], [f]. These special characteristics of infant's vowel-like sounds indicate that classical signs (as two coordinate plot) are not important for descriptions infants' vocalizations. The tendency to decrease the F0 were revealed only in infants "calm" sounds since the second half of first year of life. Our research showed that the sounds, which appearing by first ([a] and [e]-like sounds) undergo the greatest alteration during the first year of life in terms of physical characteristics (the value of fundamental frequency and spectrum maximums which we call formants by analogy with adults' speech). During the first two months of life [a] and [e]-like sounds do not differ from other sounds by their frequency characteristics. Apparently it is caused by possibilities of articulator movements and peculiarities of infant vocal tract's structure. The first differences in the characteristic of [a]-like sound caused by generation in different functional states were revealed at 3 months of age. The significant differences ($p < 0,05$) in values of the second formant are determined for vowel-like

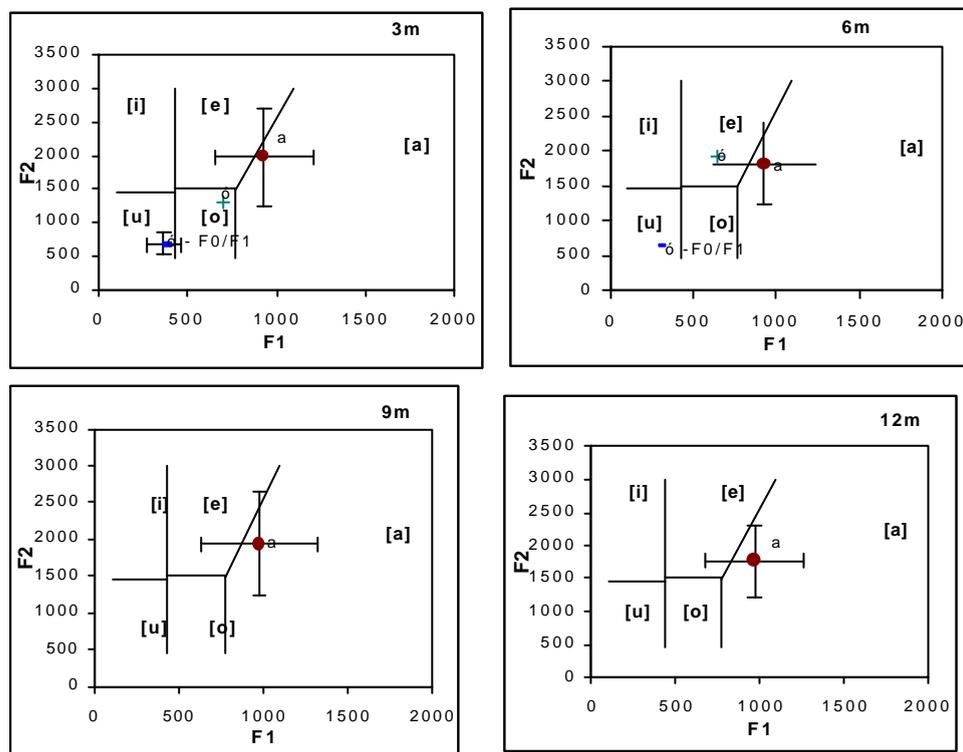
sound [a] in cry and in "calm" vocalizations, which were produced by infants at 3 months of age during contact with mother. Since the 6 months of life the differences ($p < 0,001$) in values of the second formant of sounds [a] and [e] appeared. By the 9th month there are the differences ($p < 0,05$) in values of the first formants of [o] and [u]-like sounds. Obtained data show, that in a course of [a] and [e]-vowel-like sounds distinguished features (two formant coordinate plot) used for the description of correspondent vowels of adult speech, can be taken in a consideration. At the same time, the parameters which are the basis for the distinguishing of [o], [u]; [i], [f]-vowel-like infants sounds within the first year of life differ from one of coincided vowels. In this way, absolute values of formants, as maximums in signal spectrum [5], cannot be applied at all for the description of phonetic quality of sounds. According to the theory of differential signs [6], the relative values of formants (sum, difference and attitude) are more informative characteristics for vowels description. Also, the difference between formant ($F_2 - F_1$ and $F_3 - F_2$) can be used for the description of American infants vowel-like sounds /i, u, a, æ as more significant feature versus two coordinate plot [7]. Therefore, we used supplementary signs for description of infants vowel-like sounds. As next parameters, we applied the attitude of corresponded spectral maximums amplitude to the level of fundamental frequency. It was shown [8,9], that the one of most informative characteristic was the ratio between mainly energetically expressed spectral maximum in vowel-like sounds [a], [e] and [f] of infants during the first half-year of life. The significance of amplitude ratio between the formants has already been shown [10] for adults' vowel speech. We showed, that the important feature for recognition of [a] and [e]-vowel-like sounds is a ratio of two first formants (F_1, F_2). For the description of [o] and [u]-vowel-like ratio between F_0 and F_1 is significant, for [i] and [f]-vowel-like sounds the ratio between F_0 and F_2 is important. However, these signs can be applied not at all for the description [i] and [f]-vowel-like sounds and [a] and [e] vowel-like utterance in "calm" condition. As a next, we used the complex signs: ratio between relative values of mainly energetically expressed spectra maximums and value of a difference between these spectral maximums (different for various vowel-like sounds). This feature is more important for recognition [o] and [u]-vowel-like and [i] and [f]-vowel-like sounds.

The present data mean, that association of infants vowel-like sounds with the appropriate categories of Russian vowels realized on the basis of feature set. Take into account supposition about existence of parallel system of signs and description of speech with help of formant and strip structure [see, 11], we can think that the quality of sounds articulation defines the possibilities to use the one or other signs for description of the infants' sounds. Unclear infants vocalization can be described on the basis of far multiple of signs. Possibilities to apply the acoustic keys, important for the description of vowels adult speech, increase with mastering of children's articulation skills. Those obtained results specify, that despite of a feasibility of ultrasonic indications used for want of exposition of vowels adult speech, for exposition some vowels - similar of sounds of children of the end of the first year of life indicative about shaping vowels of Russian, the babies sounds have not still all properties of vowels.

The next questions of this research were to determine adult's native speakers possibilities to attribute children sounds to Russian language phoneme. Sounds, typical for infants' age and conditions and sounds song like as phoneme and syllable structure for Russian language from audio records of 5 infants during the first year of life, were selected for tests. These tests were presented to different categories of people ($n=133$) and specialists ($n=4$). Our auditors were the mums having children in the age of three years and are higher, adult, with experience of care taken with children and without those. Specialists have professional experience of working with children's sounds more than 4 years. According to our data [8] about specific vocalization characteristics, which might reflect different function status of infants, we applied instrumental analysis of sounds taken into account infant condition. Significant differences between spectral characteristics of discomfort and delight infants' sounds were not revealed. Phonetic transcriptions with IPA indicated that in diversity of sounds presence, sounds of front and central line, lower and middle rising can be mainly revealed. The sounds of back line, lower and middle rising are absent in the vocalizations of 3 month-old. Significant distinction between frequencies of sound using of three months old infants in different emotional conditions was not revealed. The sounds of front line lower rising predominate in 6 months old infants' vocalizations when they are in discomfort conditions. The sounds of central line middle

and upper rising predominate in calm vocalizations. Joyful sounds are described as sounds of front line lower rising and central line central and upper rising. Calm children's vocalizations of the second half of their life are described as vowels of front line lower and middle rising, central line middle rising as vowels of back line middle rising. We revealed that sounds which children produce in joyful state are characterized as vowels of front line lower rising (10%) and middle line middle rising (84%). Sounds transcribed as [f] which are specific for Russian language are began to the end of first children life. IPA does not transcribe consonant-like sounds of the first half of children's first year. Bilabial plosive ([p], [b]), bilabial nasal ([m]), bilabial fricative ([β]), labiodentals approximant ([v]), plosive [t] and [d], lateral approximant [l], velar plosive [k], voiceless epiglottal fricative [ħ], epiglottal plosive [ʔ], dental/alveolar [pʰ], velar [kʰ] consonants could be revealed in vocalizations produced children during second half of the first year. But revealed consonant-likes sounds are not complete set of Russian consonants. Thus, the test was simplified model child vocal-speech development during the first year of life. Significant distinction between auditor groups with "experience" and "without experience" was not revealed by means of sounds' description. All auditors recognized easier simple vowel-like sounds in complex sounds' combinations. They revealed key- phonemes. Great mistake percentage was revealed when we described sounds of 6month old children. Different auditor groups revealed reliably (with probability more than 75%) the first half of children's first year sounds, similar to Russian adult vowel [a], [u], [o], [i]. In sound signals of children of the second half of children's first year were revealed vowels [a], [e], [u], [i]. The vowel [f] special for phonological system of Russian language was not revealed by Russian auditors (with probably more 75%). Sounds distinguished by Russian auditors closed mostly to symbols using for the transcription of corresponding Russian adult vowels. The meaning of the first and the second formants disposed on the areas of corresponding Russian adult vowels, when we use the two formant coordinate plot.

Figure 1. The first two formants of infant's vowels, referred by all auditors with more than 75 % by probability to the relevant categories of Russian vowels.



The lines indicated the phoneme boundaries between vowels [i], [e], [u], [o] è [a] in two first formants coordinate plot. F1 – frequency of first formant (Hz); F2 – frequency of second formant (Hz).

So, auditors chose that infant's sounds, which characteristics corresponded to sounds of adult speech. Specialists revealed reliably (with probability more than 75%) in children's

vocalizations vowel-like sounds, which were attributed to all categories of Russian adult vowels. Phonetic description of sounds revealed by specialists had great variety of used phonetic symbols. By instrumental analysis we could describe these sounds as with help the two formant plot, as by the set of above-mentioned characteristics. We can suggest, that when the auditors describe sounds, they carry out the process of comparing heard sound with some standard, which they have. Native speakers form this standard on the basis of a set of acoustic characteristics. When standard characteristics and characteristics of stimuli are coincidental they are attributed by auditors to corresponding category of acoustic standard. When these characteristics are not coincidental, auditors attribute them to the other category.

Present data show, that phonological development of Russian children during the first year of their life evaluate from abundant sound quality (3 month), described on the basis of the acoustic characteristic set to the beginnings of sounds (12 month) which are specific for phonetic system, contented all of vowels and described by acoustic characteristics of Russian adult speech.

At the next part of this investigation were prepared new special test. This test contains vowels [a], [u], [o], [i], [e], which Russian native speakers determined as Russian phoneme categories (with probability more than 75%). Vowel [ɸ] were include in test with probability 65%. This test was presented to 15 auditors for non-Russian speakers auditors (Finns). The Finnish auditors determined only those sounds, which one were allophone of phonemes existing in their native language. They noted vowels duration, using the signs, relevant for phonologic system of the Finnish tongue. It testifies to influencing phonologic system of the native language of the auditors on the performances of their perception. Sound [ɸ], included in the test, the auditors in 34 % of cases featured as [i] or [e], and in 66 % a case did not description generally. Thus, the impossibility of exposition of a sound, which does not exist in phonologic system of the Finnish tongue, can testify (with allowance for above mentioned) to accessories of this sound to phonologic system of other tongue (in this case - Russian). Present data suggest that at the end of first year of babies' life the phonological system for Russian language are starts to forming.

The conducted examination has allowed raising the question about, how there is a mastering by the child of sounds specific to family tongue. Were development of a hypothesis of interaction, according to which assimilation by phonologic system of tongue is carried out for want of interaction of the babies with the mother. A type of interaction and the functions of a maternal voice vary with age of the child and depend on a psychophysiological state of the child and state of the mother. The "interaction" hypothesis is based on the supposition that infants gets knowledge of native language's sounds and then knowledge of general rules of language structure's forming through the interaction with his mother who possesses the information about linguistic space of the language. For the elaboration of this hypothesis vocal-speech interactions in 5 pairs "mother-infant" are studied during the first year of life. Firstly the analysis of maternal speech addressed to infants of 3, 6, 9 and 12 month of age (ID), and mothers' speech addressed to adults (AD) were conducted. The ID of the first half-year of life contained both calm and emotionally expressions (79±18 % to 3-month-olds and 92±7 % - to 6 month-olds). The "key" words were presenting in emotionally expressions of the mothers speech. The key words were detected as a word – question or word - exclamation. A key word evolved on the basis of listening as a most prosodic distinguished from adjacent words. The values of fundamental frequency (F0) of vowels from key words exceeded (on 60±12 Hz) average value F0 and duration (244±56 mc) from the vowels in maternal utterances. The differences in maternal speech addressed to children of the first and second half-year of life are detected. So, in maternal speech versed children of the second half-year of life the decrease of amount of key words (amount of key words in the maternal speech addressed to 9 month-olds is detected has compounded - 21±12 %; and 16±12 % - 12 - month –olds children's). The increased of information categories in ID of the second half-year of infants life were determined versus semantic-information categories in maternal speech address to first-half-year-olds. The instrumental analysis of characteristics of maternal voice has shown, that the duration of the expressions is individual quantity for each mum and makes a interval from hundreds mc about 2 minutes. The differences in duration and spectral characteristics of stress vowels from key words ID and AD are detected. The differences in duration relevant vocal are shown both for

speech of each mum, and for sampling. Significant differences are not revealed in duration relevant vowels ID for different types of interaction with mothers. The absence of significant differences in vowel duration of function words of maternal speech addressed to 9 and 12 month old infants and adults were revealed. The decreases of values of F0 stress vowels to 12- old -month were detected on the basis of instrumental analysis of frequency characteristics ID. Significant differences in the characteristics of AD (for different infants age) are not spotted. The obtained data allow suspecting, that the changes of the characteristics of a maternal voice with different infant age, are interlinked to his (its) learning function. The approach of a maternal voice to children's in the first half-year, can be basis for infant imitation of sounds from a maternal voice, augmentation of a sharpness of an articulation in the second half-year - to promote a transmission of information about phoneme categories of Russian.

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It has been shown that by the age of 12 months infant's vowel-like sounds can be defined in terms of Russian vowel categories both according to the spectral analysis and to their phonetic transcription by phonologists and the data of auditory listening by Russian native speakers.

Conclusions

This description of some phonetic and acoustic characteristics of vowel-like sounds and vowels shows, that phonological development of Russian children during the first year of their life evaluate from abundant sound quality (3 month), described on the basis of the acoustic characteristic set to the beginnings of sounds (12 month) which are specific for phonetic system, contented all of vowels and described by acoustic characteristics of Russian adult speech. Our research show that sounds, specific for native language, firstly appear during process, then infants imitate mother's voice. The importance of vocal-speech interaction for mastering of speech elements is discussed.

The research support by Russian Humanitarian Scientific Found (Project 01-06-00090a)

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