ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Development of Binaural Hearing in Children 4-11 Years Old.

Tatiana Victorovna Mayasova*, Anna Alekcandrovna Lekomtseva, Elena Gennadievna Gutsu, Nadezda Nikolaevna Demeneva, and Elena Victorovna Kochetova.

Nizhniy Novgorod State Pedagogical University (Minin University), Nizhny Novgorod, Russian Federation 603950, Russian Federation, Nizhny Novgorod, Uliyanova Street, 1.

ABSTRACT

Present study addresses the development of binaural hearing in ontogenesis. In children, during their development from 4 to 11 years of age, the accuracy of localization increases, which is caused by the establishment of inter-hemispheric connections of the cortex. Imperfection of the acoustic-localizing function in small children (4-6 years old) is explained by the fact that, in this age, sound localization is mainly conducted with binaural mono-hemispheric mechanism. Along the development of inter-hemispheric connections, cortical involvement in the sound localization processes significantly increases, and precise differentiation of the sensations, including acoustical-spatial sensations, becomes possible. And in the age of 10-11 years old, when the myelination of trans-callosal tracts is completed, sound locating mechanism gradually becomes binaural bi-hemispheric, as in adults.

Keywords: monitoring of child development, binaural hearing, monaural hearing, acoustic-locating function, interhemispheric interaction, acoustical-spatial sensations, mono-hemispheric and bi-hemispheric mechanisms.

Corresponding author

ISSN: 0975-8585

INTRODUCTION

One of the central trends in the current stage of education system is the focus on supporting and assisting the development of child's individuality, consideration of children's individual differences and creation of individual educational and developmental route. Because of this, organizing and conducting informative monitoring of a child's development during different ages gains special significance[12]. However, obtaining empirical data by using only psychological and pedagogic techniques often allows only stating a certain fact of child development. Deep psychophysiological bases of individual differences in higher cognitive functions (attention, perception, memory, thinking, etc.) might remain not complete clear, which, undoubtedly, creates difficulties in modelling a strategy of psychological-pedagogic support of child development. Because of this, in our opinion, one of the productive approaches to solving this problem might be complex studies, which combine psychological and psychophysiological assessments. One of such studies is the research of binaural hearing in children [1].

Exploring this question is significant for psychology and psychophysiology, which study the problem of transforming objective into subjective and physical into mental. Mechanisms of sound localization are naturally integrated in the mechanisms of the whole-brain activity, which allow it to adequately reflect temporal and spatial structure of the surrounding world. Understanding the characteristics of binaural hearing development allows a more thorough understanding the specifics of cognitive functions development on different stages of lifespan development [2].

Currently there is a growing amount of data, which shows that binaural hearing is not a function of predominantly one of the hemisphere, but rather is supported by the integral activity of both cerebral hemispheres. The problem of inter-hemispheric functional asymmetry and inter-hemispheric interaction is tightly linked not only to physiology and medicine but also to psychology and pedagogics because the nature of inter-hemispheric interactions, undoubtedly, reflects the process of integral brain activity establishment in the ontogenesis [3].

OBJECTIVE OF THE STUDY

Present work studies binaural hearing development in ontogenesis. Objective of the study is to trace the dynamics of binaural hearing establishment in children of different ages and provide a quantitative characteristic of acoustic-localizing skill in children of different age groups.

METHODS

In order to study binaural hearing we used a "laterometer". The device is a two-channel generator of paired rectangular electrical impulses, which were converted into clicks, delivered to both ears via headphones. Special control block allowed delivering acoustic clicks binaurally both simultaneously and with changing time delay (ΔT). This delay could have been changed in automatic mode with 1-10 microseconds (mcs) interval, increasing the interval from 0 to 1000 mcs and decreasing it from 1000 to 0 mcs.

By decreasing ΔT from 700 mcs with advanced delivery of the sound to one ear, we created a sensation of sound movement from "lateralized" point to the central. And by increasing ΔT from 0 to 700 msc with advanced stimulation of the other ear, we created a sensation of movement and "lateralization" of the subjective acoustic image (SAI) on the other side. In the full cycle of time delay change from 700 to 0 mcs one side and from 0 to 700 msc on the other side a subject felt SAI movement in subjective acoustic field from one ear to the other through the center, i.e. on a 180 º curve. The speed of SAI movement was directly proportional to the frequency of paired impulses delivery to the different ears and to the size of the chosen interval [4].

The study was conducted first with the forward shift of the right click (SAI movement from right ear to the left) and was then repeated with the forward shift of the left (SAI movement from left ear to the right). Subject's goal was to press a button of a fixator at the moment when SAI is at the point of transverse with the sagittal plane of the head, i.e. in the center of subjective spatial field. Ideally, SAI should appear at the point of transverse with the sagittal plane when ΔT=0, which corresponds with the hundredth click of a block of trials

(normal range of deviation is ⍰3º, i.e. 23.3 mcs) [5]. In order to characterize acoustic-locating function we used the following mode of dichotic stimulation:

- Frequency of impulse pairs delivery (period) – 10 Hz (100 ms)
- Initial delay (ΔT) between clicks in a pair – 700 mcs
- Interval of initial delay change – 7 mcs
- Amplitude of impulses (power of clicks) – 4.6 V
- Number of impulses in a block – 200 clicks.

Sample of Subjects

For the study we selected 261 children, both male and female, from 4 to 11 years old; we excluded children with various pathologies and hearing impairment. Material of the study was grouped upon yearly intervals. For the comparison we registered the same characteristics in 38 adults 19-21 years old.

RESULTS

Results of the experiment showed that, according to the mean group characteristics, for the majority of 4-11 year-old children it is common to precede the "center" registration both for SAI movement from right to left and from left to right (table 1). The obtained results reflect the development of acoustic-localizing function in ontogenesis. As a criterion for evaluating the level of this function's development we used the mean scores of the group of adults, as the characteristics of its complete establishment.

According to the mean group characteristics, subjective center is always shifted to the side of the ear, from which the sound movement starts, both in 4-11 year-old children and in adults. For all period between 4 and 11 years old there is a common dynamics towards decreased dispersion of the center localization characteristics, both for SAI movement from right to left and from left to right. We revealed that acoustic-localizing function development in ontogenesis manifests in decreasing with age level of dispersion in the group characteristics of center registration in the subjective acoustic field.

Table 1. Mean characteristics of the subjective center in different ages

Age and number of subjects	SAC upon SAI movement	M⍰⍰	dispersion
4 years old (21 people)	right-left left-right	-13º⍰27º -17º⍰31º	709 981
5 years old (22 people)	right-left left-right.	-20º⍰21º -17º⍰21º	454 455
6 years old (37 people)	right-left left-right	-11º⍰19º -9º⍰17º	344 303
7 years old (37 people)	right-left left-right	-20º⍰13º -18º⍰18º	165 320
8 years old (36 people)	right-left left-right	-13º⍰13º -14º⍰11º	155 113
9 years old (38 people)	right-left left-right	-15º⍰10º -14º⍰16º	102 244
10 years old (35 people)	right-left left-right	-16º⍰12º -15º⍰12º	137 140
11years old (35 people)	right-left left-right	-12º⍰11º -17º⍰12º	126 143
Adults (38 people)	right-left left-right	-9º⍰8º -7º⍰7º	60 46

In the group of the youngest children (4-5 years old) sector of subjective center localization has a very wide range - (-45□)-(+45□). Upon aging, by 6 years of age, sector of subjective center localization narrows to (-45□)-(+10□). In the groups of older children (8-9 years old) sector of subjective center localization becomes even smaller - (-30□)-(+3□). In children 10-11 years old the characteristics of acoustic-localizing function - (-25□)-(+3□□□- approach the characteristics of adults. Correspondence of the subjective center with the real center (0□3□) was registered only in 23% of the adult subjects. In other cases the subjects registered the subjective center earlier – 53% of subjects in the sector from -3□ to -10□ and 23% of the subjects in the sector from -10□ до -20□. According to the results of our study, the majority of adult subjects (76%) subjectively localize the center of acoustic space with a forward shift, which lies in the range of 10□.

Therefore, the process of acoustic-localizing function development in ontogenesis is characterized by a more accurate localization of the perceived center in the subjective acoustic field.

DISCUSSION

It is known that each brain hemisphere independently is able to project an acoustic image only to the contralateral spatial field and only to the relative continuation of interaural line. Mechanism of integral sound perception is related to the initial “splitting” of the SAI into two opposites in right and left hemispheres, which consequently, as a result of interhemispheric interactions, integrate in a single neurophysiological equivalent of an acoustic image. Cooperative activity of the hemispheres during the perception of lateralized sound is similar to the mechanism, which occurs during monaural stimulation, when there is a maximal predominance of one of the hemispheres [6].

Perception of the SAI in the center of subjective spatial field is related to the integration of neurophysiological equivalents in the auditory cortical areas in both hemispheres with their equal activity. Intra-hemispheric binaural interaction is a necessary, but intermediate, stage, which provides the intensity of activation in this hemisphere but not the spatial localization of a signal yet – for that there should be interhemispheric integration. Finding the SAI in the sagittal plane is possible only with equal contribution of each hemisphere. Intermediate position of the SAI is a consequence of non-equal contribution of each hemisphere in the organization of acoustic sensation [7].

Spatial acoustic perception and the SAI production are based on binaural and bi-hemispheric mechanisms, which provide reflexive sound reflection by both sub-systems. The discovered fact that the accuracy of localization increases in children during their development from 4 to 11 years of age can be explained by the development of interhemispheric cortical connections. Imperfection of acoustic-localizing system in young children (4-6 years old), which was confirmed by a larger dispersion of the characteristics in this group, is explained by the fact that sound localization in these ages is mainly conducted by binaural mono-hemispheric mechanism. Binaural mono-hemispheric mechanism of acoustic perception is “just one of the mechanisms, which participate in acoustic localization”, and moreover, this participation is significant only when it is impossible to involve binaural bi-hemispheric mechanism [8, 9].

Upon further development of interhemispheric cortical connections, precise differentiation of the sensations, including acoustical-spatial ones, becomes possible in the processes of sound localization. Because of this, at the age of 10-11 years old, when myelination of trans-callosal tracts is completed, acoustic localizing mechanism becomes binaural bi-hemispheric, as in adults [10].

A significant role in binaural hearing and, particularly, acoustic-localizing function development belongs to the level of ipsilateral connections development, which, in turn, defines the power of ipsilateral stimulation of the hearing center (by the spatial summation of excitation). Acoustic-localizing function development begins from localizing the sounds, which are close to the interaural line (“lateralized”), and gradually the discreteness of subjective and objective spaces decreases, which was confirmed in our work.

Another point that drew our attention was the decrease of acoustic-localizing function in 7 year-old children. The level of the forward shift in these children is even larger than in 6 year-old children. This is probably related to that fact that in this age a child goes through the second critical period in the higher nervous activity development. Inhibitory processes during this period are insufficient for limiting the level of cortical activation related to the adaptation to school schedule [11]. Developing bi-hemispheric mechanisms

of acoustic perception are still very vulnerable and, therefore, phylogenetically older subcortical mechanisms of interhemispheric interaction take the leading role.

In our work we attempted to obtain the data about gender differences in acoustic-localizing function development. Analysis of the obtained results did not reveal gender differences in acoustic-localizing function development in 4 to 11 years-old children.

CONCLUSION

Therefore, the process of acoustic-localizing function development in ontogenesis is related to the development of intra- and interhemispheric integrational processes. Because of this, the characteristics of this function, obtained by the laterometric method, can reflect the maturity level of sensory functions of the cerebral cortex.

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