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Individual Variability of Broca's Area of the Brain in Women

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In this article, we studied individual features of the macroscopic structure of Broca's area of the brains in 9 women (18 hemispheres) aged from 20 to 30 years, without any mental or neurological disorders. By using MRI, the structures of the sulci and gyri of the pars triangularis and pars opercularis of Broca's area were studied: the anterior and ascending rami of the lateral sulcus, the radial, diagonal, precentral, inferior frontal, and lateral sulci. We also studied the relationship between the pars triangularis and pars opercularis as well as their relationships with neighboring cortical structures. We measured the volume of the pars triangularis and pars opercularis and the thickness of their cortex. Significant individual variability in the location and relationships between the anterior ramus of the lateral sulcus and the ascending ramus of the lateral sulcus, as well as structural features of the pars triangularis and pars opercularis of Broca's area were demonstrated.

Key Words: *brain; macroscopic structure; individual variability; women; Broca's area*

Analysis of individual human behavior is increasingly attracting the attention of scientists. The correlation between the shape and size of human skull and the individual characteristics of human behavior was widely discussed in the literature, but this theory was later proved to be erroneous [1]. The progress in science have made it possible to correlate certain features of human cognitive functions with the features of structural organization and functional characteristics of the brain. Brain visualization with MRI helps to determine the criteria for individual variability of the human brain and its individual structures [2] and to identify the relationship of individual features of its structure with behavior, thinking, and various disorders [3,4].

Morphological studies of the brain, especially associative cortical structures, made a great contribution to understanding of individual variability of human cognitive functions. Broca's area (BA) plays an important role in the formation of speech functions. It is responsible for speech skills, movements of the speech apparatus muscles, movements of lips, larynx, tongue, and pharynx. BA is involved in the implementation of the syntactic and semantic aspects of speech, memorizing grammar, control over the creation of speech programs, articulation, and intonation of speech.

Here we studied individual variability of BA structure in woman's brain.

MATERIALS AND METHODS

We studied the macroscopic structure of BA in the brains of 9 women (18 hemispheres) aged from 20 to 30 years without mental or neurological disorders. The study was approved at a meeting of the Ethics Committee of the Research Center of Neurology (Protocol No. 7-4/22, August 29, 2022).

The study was performed using an ultra-high-field magnetic resonance tomograph Siemens Magnetom Prisma in the T1 MP2RAGE mode in the sagittal plane (176 slices, slice thickness 1 mm; scanning parameters: TR=5000 msec, TE=2.74 msec, TI1=700 msec,

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TI2=2500 msec, flipangle 1=4°, flipangle 2=5°; matrix size 256 mm). Reconstruction of the brain surface was performed by processing the obtained MR images in the CAT12 toolbox, an extension to SPM, which is a statistical program for processing MRI data, using the Segment module in accordance with the standard procedure described in the CAT12 application manual. The volume of gray matter and the thickness of the pars triangularis and pars opercularis were measured using the CAT12 toolbox in the ROI Tools module using the neuromorphometrics and aparc_a2009s_thickness atlases. The coefficient of variability was calculated using Microsoft Excel 2007.

The reconstructed surfaces of the cerebral hemispheres made it possible to analyze the main sulci and gyri of BA such as the anterior and ascending rami of the lateral sulcus, the radial sulcus, the diagonal sulcus, the precentral sulcus, the inferior frontal and lateral sulci. The relationship of the pars triangularis and pars opercularis with each other and with neighboring cortical structures were studied.

RESULTS

We established the topographic features of the ascending ramus (*ramus ascendens*) and the anterior ramus (*ramus anterior*) of the lateral sulcus (*sulcus lateralis*) in the left and right hemispheres of the brain in women. The anterior ramus and the ascending ramus extend from the lateral sulcus in different ways: sometimes they have a common V-shaped trunk, in other cases they extend from a common location having a common Y-shaped trunk, or they can separate from the lateral sulcus at a certain distance [5]. The third variant is most typical in female brain. This type of sulcus localization occurred in 45% of cases (Fig. 1). The first and second variants of localization of the anterior ramus and the ascending ramus of the lateral sulcus, *i.e.* common branching from the lateral sulcus, were identified in 55% of cases.

Comparison of the length of the anterior ramus and the ascending ramus of the lateral sulcus of the female brain showed that the ascending ramus was longer in 33% of cases, the anterior ramus was longer in 39% of cases, and in 28% of cases, these rami had equal length.

The radial sulcus was revealed in the brains of all examined women; it extended from the inferior frontal sulcus (50% of cases) or was independent and had no connection with other sulci (50% of cases). In some cases, small additional sulci were found along with the radial sulcus.

The study of the precentral and lateral sulci of the female brain revealed their fusion in 50% of cases. In the other 50%, these sulci did not connect, which occurred due to merging of the orbital part of BA with the precentral area of the brain. In 89% of cases, the lower frontal sulcus connected with the precentral sulcus.

The diagonal sulcus is located in the pars opercularis dividing it into two parts. This sulcus was found in only 39% of cases.

We thoroughly studied the macroscopic structure of the pars opercularis and pars triangularis of BA in the female brain. Previously, we identified three types of structure of the sulci surrounding the pars opercularis and pars triangularis [5]. The closed type of structure is characterized by connection of very

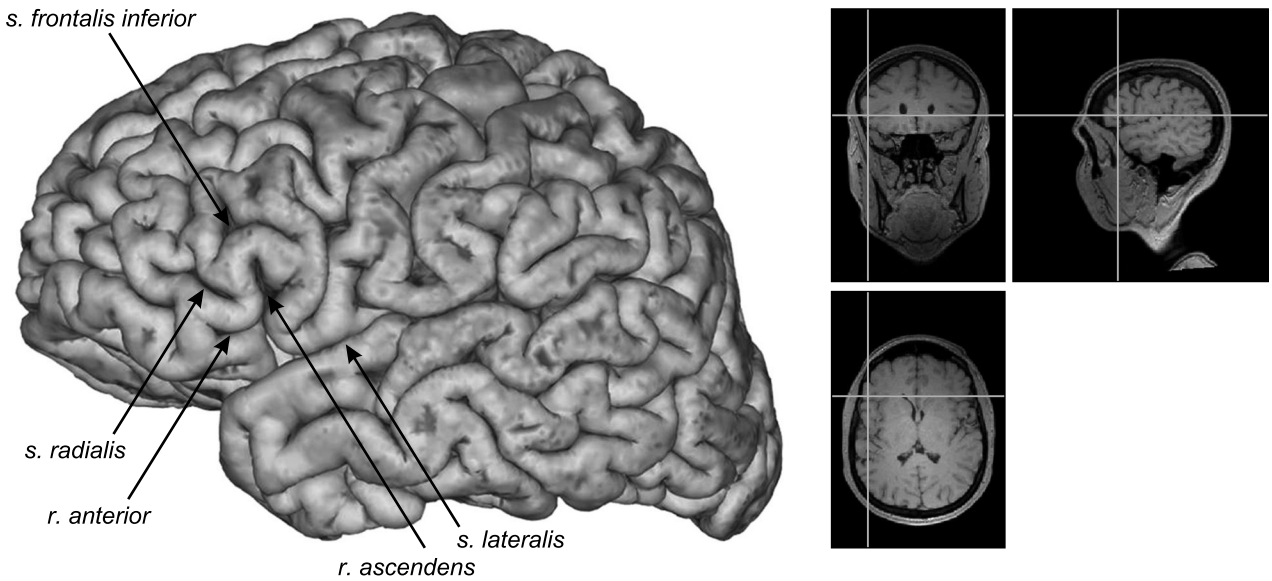

Fig. 1. Localization of the sulci in BA. Left hemisphere.

close location of the sulci with the formation of clear boundaries of the pars opercularis and pars triangularis of BA. In the second type of structure, the sulci are located at a certain distance from each other (discontinuous type). In the third type, the sulci are located at a great distance from each other (mixed type). In the discontinuous and mixed types, interstitial or limitrophic cortical areas connect the pars opercularis and pars triangularis of BA with neighboring cortical structures of the precentral gyrus, middle frontal gyrus, and orbital part of the inferior frontal gyrus.

In the pars opercularis, the closed type of sulcus structure was rare (only 11% of cases), whereas the discontinuous type predominated (89% of cases). For the pars triangularis, the discontinuous type of sulcus structure was also the most common (89% of cases), whereas the closed type was revealed in only 11% of cases.

Comparative analysis of the structure of the pars triangularis and pars opercularis of BA of the female brain showed that in 55% of cases the pars triangularis was connected by limitrophic areas with the pars opercularis. Of great interest are various types of connection of the pars triangularis with other cortical structures: it was connected with the middle frontal gyrus in 28% of cases, with the orbital part of the inferior frontal gyrus in 83% of cases; in 17% of cases, the pars opercularis connects with the middle frontal gyrus.

Significant individual variability of BA was revealed when measuring the volume of gray matter in the pars triangularis and pars opercularis (Fig. 2). The coefficient of variation of gray matter volume in the pars opercularis was 7% in the left hemisphere, 11.9% in the right hemisphere, whereas in the pars triangularis – 11.4 and 10.7%, respectively. Individual variability in the width of the cortex of the pars triangularis and pars opercularis was less pronounced. The coefficient of variation in the width of the cortex of the pars triangularis was 3.7% in the left hemisphere, 7% in the right hemisphere; for the pars opercularis – 3 and 7.1%, respectively. Thus, the study of the structure of BA of the female brain demonstrated significant individual variability in the localization and relationships of the main sulci, as well as structural features of the pars opercularis and pars triangularis.

Individual differences in the structural organization of BA are associated with the characteristics of speech and higher cognitive processes. In some people, the speech is bright, emotional, embellished with comparative phrases, while in others, the speech is monotonous and monosyllabic [6]. The discontinuous and mixed types of structure of the pars triangularis and pars opercularis of BA in the female brain revealed by us indicate an increase in their limitrophic

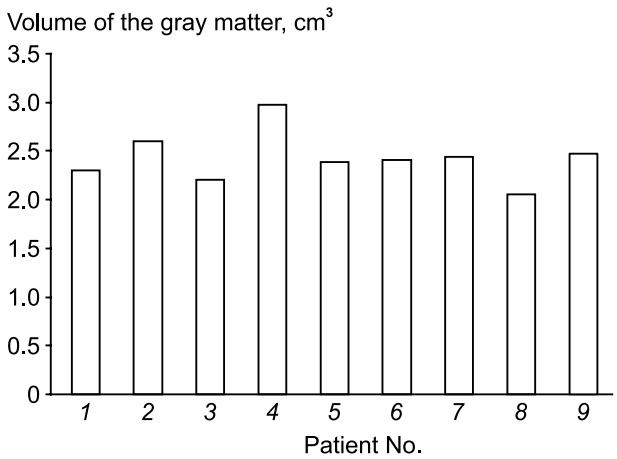

Fig. 2. Individual variability in the gray matter volume in the pars triangularis of BA in the left hemisphere of female brain.

areas, which can be activated during speech. As is commonly known, women are more fluent and use more words than men [7].

An important role in the individual variability of BA is played by the diagonal sulcus and the radial sulcus located in the pars orbitalis and pars triangularis. Due to these sulci, apparently, the area of the cortex of BA increases, which is a sign of individual variability of human cognitive functions.

It should be noted that the main sulci of the human brain begin to form and develop in prenatal ontogeny under the influence of genetic factors, determining to a greater extent the intensity and overall nature of individual variability of the macroscopic picture of human brain [8]. Considerable role is played by genetic factors underlying the formation of human intellectual activity [9,10]. Moreover, a person's environment, family, upbringing, and school play an important role in the formation of their individual activity, thinking, and behavior [11].

There are reports on neuroplasticity of the human brain and changes in the structure of the cerebral cortex during the development of various skills. An MRI study of the brains of London's taxi drivers revealed that drivers with a long record of service have a larger volume of the hippocampus involved in the formation of spatial memory (remembering city streets) [12]. Changes in the brain structure were also noted to occur during physical exercise, music lessons, and foreign language learning [13].

The main types of structure of the pars triangularis and pars opercularis of BA that we identified made it possible to put forward a hypothesis that these structural peculiarities of the sulci in BA determine individual speech abilities of a person. The interstitial or limitrophic structures located between the sulci can lead to structural and functional re-

structuring of the brain. Further study of the brain structure by using MRI is one of the priority areas of research in the field of morphology, physiology, and psychology for deeper insight and discovery of the basic laws of personalization of human behavior and thinking.

REFERENCES

1. Simpson D. Phrenology and the neurosciences: contributions of FJ. Gall and J.G. Spurzheim. ANZ J. Surg. 2005;75(6):475-482. doi: 10.1111/j.1445-2197.2005.03426.x
2. Lerch JP, van der Kouwe AJ, Raznahan A, Paus T, Johansen-Berg H, Miller KL, Smith SM, Fischl B, Sotiropoulos SN. Studying neuroanatomy using MRI. Nat. Neurosci. 2017;20(3):314-326. doi: 10.1038/nn.4501
3. Poldrack RA, Farah MJ. Progress and challenges in probing the human brain. Nature. 2015;526:371-379. doi: 10.1038/nature15692
4. Bryukhov VV, Krotenkova IA, Morozova SN, Krotenkova MV. A current view on the MRI diagnosis of multiple sclerosis: an update of 2016 revised MRI criteria. Zh. Nevrol. Psikhiatr. 2017;117(2-2):66-73. Russian. doi: 10.17116/jnevro20171172266-73
5. Bogolepova IN, Malofeeva LI. Brain of Men, Brain of Women. Moscow, 2014. Russian.
6. Somers DC, Michalka SW, Tobyne SM, Noyce AL. Individual subject approaches to mapping sensory-biased and multiple-demand regions in human frontal cortex. Curr. Opin. Behav. Sci. 2021;40:169-177. doi: 10.1016/j.cobeha.2021.05.002
7. Chekalina AA. Gender Psychology. Moscow, 2006. Russian.
8. Das S, Bal K, Bhattachrjee S. Morphological development of sulci in fetal brain: An anatomical study. Asian J. Med. Sci. 2022;13(4):45-50. doi: 10.3126/ajms.v13i4.41468
9. Nishikuni K, Ribas GC. Study of fetal and postnatal morphological development of the brain sulci. J. Neurosurg. Pediatr. 2013;11(1):1-11. doi: 10.3171/2012.9.PEDS12122
10. Lopez-Persem A, Verhagen L, Amiez C, Petrides M, Sallet J. The human ventromedial prefrontal cortex: sulcal morphology and its influence on functional organization. J. Neurosci. 2019;39(19):3627-3639. doi: 10.1523/JNEUROSCI.2060-18.2019
11. Luders E, Narr KL, Bilder RM, Szeszko PR, Gurbani MN, Hamilton L, Toga AW, Gaser C. Mapping the relationship between cortical convolution and intelligence: effects of gender. Cereb. Cortex. 2008;18(9):2019-2026. doi: 10.1093/cercor/bhm227
12. Maguire EA, Gadian DG, Johnsrude IS, Good CD, Ashburner J, Frackowiak RS, Frith CD. Navigation-related structural change in the hippocampi of taxi drivers. Proc. Natl Acad. Sci. USA. 2000;97(8):4398-4403. doi: 10.1073/pnas.070039597
13. Seung HS. Reading the book of memory: sparse sampling versus dense mapping of connectomes. Neuron. 2009;62(1):17-29. doi: 10.1016/j.neuron.2009.03.020