Cerebral Organization of Verbal Action in Stutterers

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Abstract—A comprehensive interdisciplinary study of the cerebral mechanisms of readiness for speech was performed based on a complete neuropsychological examination according to A.R. Luria with qualification and quantification of the detected symptoms and electrophysiological data by an original method of recording and localization of the potentials synchronized with the preparation for speaking. The data on stutterers were compared with those on normal subjects and showed that stuttering is not an isolated (purely peripheral) speech disorder but is a component of a syndrome consisting of specific mnestic, neurodynamic, and motor defects that reflect dysfunction of postfrontal and median structures of the brain (functional blocks I and III according to Luria). Differences between normal and stuttering subjects in the potential related to readiness for speech were associated with the activity of deep median structures (the pons and brainstem), right subcortical nuclei, the right frontal cortex, and the left mediotemporal cortex.

The theory of systemic dynamic localization of mental functions developed by A.R. Luria [1] analyzes all factors of the speech functional system in detail with the exception of readiness for speech, mentioned without considering its localization [2]. Disruption of this factor, involved in the centrally controlled tuning of the peripheral speech apparatus for a verbal act, is considered in defectology as the main mechanism of stuttering [3]. In addition, intra- and interhemispheric interactions during the verbal activity of stutterers are poorly known, although many authors have mentioned that disintegration of these interactions during psychic activity may be one of the mechanisms of stuttering [4–11]. When stuttering begins in early childhood, the formation of hemispheric specialization in performing both sensory (of all modalities) and verbal functions is interrupted [12].

Some authors hold that stuttering is only a motor problem; some others believe that it is caused by disruption of the higher level of organization of cognitive and motor processes. In our view, a combination of neuropsychological and psychophysiological methods may clarify the localization of the mechanism of readiness for speech and its connection with neuropsychological patterns of cognitive disorders in stutterers.

Our purpose was to study the cerebral mechanisms of stuttering with a comprehensive set of neuropsychological and psychophysiological methods. First of all, we were interested to learn how the statement preparation mechanism functions and how it is affected in stuttering.

METHODS

The following methods were applied in the study: (1) comprehensive neuropsychological examination according to Luria [13] with qualitative and quantitative evaluation of the data [14], (2) study of the lateral organization of sensory and motor functions (dichotic listening [15] and a modified version of the questionnaire and tests related to the lateralization of mental functions [16]), (3) recording of potentials related to the moment of pronunciation of sounds of Russian speech, and (4) dipole localization of the sources of the electrical activity of the brain [17] and special methods of preliminary processing of the EEG [18].

We examined ten stutterers and seven normal subjects aged 15–25 years, right-handers with a secondary or incomplete higher education.

Four sounds of Russian speech ([a], [o], [r], and [l]) were reproduced by a computer from prerecorded sound files through a speaker. The duration of each presentation was 150 ms.

We will consider the procedure of psychophysiological examination (methods (3) and (4)) in detail. Verbal stimuli were presented with a tape recorder to a subject, who sat in a chair at rest. The subject was instructed to reproduce each stimulus 1–2 s after the presentation. The moment when the sound was pronounced was recorded with a microphone with a special amplifier, and then the signal of exceeding a preset threshold was fixed as a label in the EEG record. The next stimulus was presented 3 s after the subject pronounced the sound. Each of the four sounds was presented 100 times (in total, 400 stimuli were presented and 400 labels appeared in the EEG). The test consisted of one series 40–45 min long.
The EEG was recorded monopolarly from 16 leads according to the international 10–20 system with a Nihon Kohden electroencephalograph and fed to a computer. The EEG and event-related potentials (ERPs) were processed and analyzed using the Brain-Sys program system.

EEG records were purified of artifacts caused by electrical interferences, subjects’ involuntary movements, and sharp eye movements (blinks). Then, an averaged potential was plotted for each subject for the sound initiation–related period between 1000 ms before the label (i.e., the moment of pronouncing a sound) and 600 ms after vocalization. In addition, to carry out generalized analysis, the potentials were averaged for the test and reference groups; we also evaluated the differential potential obtained by subtracting the potentials for both groups.

To improve the effectiveness of the dipole model, the ERPs were first divided into “cortical” and “deep” components on the basis of the MUFASEL algorithm [18]. Then, using the BrainLoc program, we calculated the coordinates of the motile equivalent electric dipole in a two-dipole model for the deep component of the ERPs in the “best model” regime: for each moment of time, the parameters of the dipole model with a higher dipole coefficient (DC) were found provided that this value was equal to or exceeded the threshold, which was 0.97 or more in our study.

This scheme of evaluating electrical activity offers some advantages over other methods. Averaging ERPs, we concentrate on the EEG signal related to (synchronized with) the event of interest and suppress noise, i.e., the EEG processes that are unrelated to (not synchronized with) this event and are casual relative to the task. The potential obtained by summation has a better signal-to-noise ratio but differs from all individual potentials; i.e., it is a mathematical abstraction in a sense. Nonetheless, this procedure is extremely useful and effective in psychophysiological and medical studies. Calculation of averaged ERPs for a group of subjects is the next step of analysis, which further improves the signal-to-noise ratio by leaving aside the subjects’ individual features. With regard for the tasks of this study, interindividual differences were considered as noise masking cerebral processes common to all subjects. The resulting potential is even more abstract mathematically, but the comparison of average group ERPs found in different samples (different nosological groups) has for decades demonstrated its practical and theoretical effectiveness in detecting objective features of the cerebral processes in question. In addition, this approach included calculation of the potential difference between the group ERPs in order to localize sources of electrical activity. The use of this value in a model with only a few equivalent dipoles (because of a limited number of channels in the initial record) makes it possible to improve the reliability of localization and to detect processes that differentiate the groups and are less manifest than the common processes. For instance, if each ERP has more than two dipoles, the most distinct sources are noticed first because of the low resolution of the two-dipole localization model. When the differential potential is localized, these less manifest processes can be detected by this model because common processes are “factored out” owing to subtraction. The sign of the resulting difference does not affect the result of localization. Thus, although the differential ERP is also a mathematical abstraction, its use in our study is justified methodologically.

The neuropsychological examination procedure followed Luria's scheme [13].

RESULTS AND DISCUSSION

Neuropsychological examination included diagnosis, qualification, quantification, and localization of numerous neuropsychological symptoms of disorders in praxis, speech, memory, intellect, and neurodynamics of mental activity (Fig. 1). The most common symptoms were memory disorders; the frequencies of motor and neurodynamic symptoms were almost equal. Other disorders were found in only a few stutterers. Speech symptoms were limited to speech fluency disorders.

All stutterers demonstrated enhanced trace inhibition, usually combined with a weakened and insufficiently selective capacity to memorize information. Notably, all memory disorders were not limited to a specific modality. The most characteristic motor disorders were difficulties in mastering a motor program in dynamic praxis and impulsiveness. One-third of the stutterers also tended to be exhausted by the graphic test for dynamic praxis and demonstrated mild kinesic disorders. Neurodynamic disorders were found in 90% of stutterers; however, they usually (with the exception of one subject) involved only one psychic sphere, manifesting themselves in a deterioration in general working capacity, bradykinesia, or bradynhea-

Fig. 1. Intensity of disorders in various psychic spheres in stutterers. Ordinate: average number of signs diagnosed for each sphere in neuropsychological tests.