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ScienceDirect

Procedia Computer Science 190 (2021) 487–491

Procedia Computer Science

www.elsevier.com/locate/procedia

2020 Annual International Conference on Brain-Inspired Cognitive Architectures for Artificial Intelligence: Eleventh Annual Meeting of the BICA Society

Review of fMRI methods in developmental stuttering and it's treatment

Anastasia Korosteleva[a], Irina Malanchuk[a], Liliya Arutyunyan[b], Migran Arutyunyan[b]

[a]*NRC "Kurchatov Institute", Moscow, Russia*
[b]*Speech Center "Arlilia", Moscow, Russia*

Abstract

The article gives a summary overview of the most important studies of stuttering by using functional magnetic resonance imaging (fMRI) in the last 20 years. This review also highlights problems in the literature in terms of methodology and research areas. It presented an integrated approach and technique fMRI studies aimed at both the primary diagnosis of stuttering and stammering on the dynamics of the mechanisms in the treatment process.

Keywords: stuttering; treatment; review fMRI

1. Introduction

Stuttering is a wide variety of symptoms, including spasmodic delays, impaired tempo and rhythm of speech, logophobia, obsessive thoughts, adaptive tricks, etc. This disorder affects millions of people around the world [1].

Over the past two decades, interest in neurophysiological studies of nervous system disorders has continued to increase. Given known limitations, fMRI is one of the leading methods for mapping of functional areas and brain neural networks due to its non-invasiveness and good spatial resolution.

In this paper, we focus on fMRI studies in the field of stuttering in two directions: the development of stuttering and the treatment of stuttering. A literature search was conducted in the Web of Science database for the keywords: "stuttering" OR "stammering" AND either "fMRI", "functional MRI", "treatment", published in 2000–2020. The search resulted in 62 articles on the topic of stuttering and just 10 articles that examined the treatment of stuttering. Such a small number of articles related to the treatment of stuttering is due, as we believe, to a high level of uncertainty

E-mail address: nnkorosteleva@gmail.com

10.1016/j.procs.2021.06.057

about the possibilities and results of treatment, and a small number of potentially "working" methods. Most studies of stuttering have been conducted in adults who stutter (AWS). In spite of the great significance of the AWS results and obvious difficulties in conducting research with children who stutter (CWS), it is certainly necessary to study them. This is due to the fact that the CWS brain was less likely to stutter, is more plastic, and therefore more likely to reflect the causal mechanisms of the disorder.

The general task of our work is to analyze the existing methods of fMRI studies of stuttering and to describe the author's comprehensive technique using fMRI.

2. FMRI methods in developmental stuttering

The fMRI was first used to study stuttering in 2003 [2]. Most early fMRI studies have studied local activation, while later studies have focused on functional connectivity between brain regions of interest. In addition, most studies focused on tasks related to speech production, and a very small number of studies focused on the state of rest and speech perception. This can be explained by the fact that stuttering was considered for a long time only from the side of speech production impairment, not paying attention to motor-behavioral reactions and the nature of the course of thought processes [3]. In this section, we consider in more detail 3 main types of tasks in studies of stuttering processes.

2.1. Speech Production Tasks

The first fMRI study with AWS was published in 2003 [2]. This study used speech conditions (loud versus silent reading) and language contrasts (reading of semantically meaningful text versus nonsense words). As a result, the control group (adults who do not stutter (AWDS)) showed the dominance of the left hemisphere in the Wernike's area and middle temporal gyrus, while in AWS the structures of the right and left hemispheres were equally activated. Thus, the authors concluded that stuttering occurred due to the abnormal activation of the cerebral hemispheres.

It has been suggested that the basis for differences in the brain activity may be motor behavior during stuttering [4]. The authors of the article examined the neural correlators of passive listening, the pronunciation of familiar speech and the pronunciation of two speech patterns (simulated stuttering and lingering speech) in AWS and AWDS. Researchers found less activation of left superior temporal gyrus in AWS during normal speech and increased activation of right inferior frontal gyrus during simulated stuttering compared to AWDS. It was also found that the AWS have an increased activation in the left middle and superior temporal gyri and right insula, primary motor cortex and supplementary motor cortex during passive listening compared to AWDS. The results indicate the presence of functional deficiencies in auditory processing, motor planning and performance in AWS, and these differences depend on these forms of speech behavior.

Multiple variations in brain activity in AWS during stuttering were the subject of interest for Wymbs et al., who noted that there was an inconsistency between AWS in excessive or insufficient brain activation during stuttering [5]. This inconsistency in brain activation may be due to the fact that not a single study divided AWS into groups according to the severity of stuttering.

In addition, different models of brain activation are associated with the planning and execution of speech [6]. Therefore, it is possible that stuttering may be the result of failure both at the planning stage and in the pronunciation process. This study indicates the need to consider a wider range of variables in order to understand some conflicting results in different studies.

2.2. Resting state tasks

Many researchers have suggested that differences in brain activity between AWS and AWDS may be present both during speech production and in the absence of a task when a person is at resting state.

Lu et al. [7] found that in several regions of the brain associated with speech: left superior and middle temporal gyri and the triangular portion of left inferior frontal gyrus in AWS had higher amplitudes of low-frequency oscillations (a measure of brain activity at resting state) than in AWDS. Moreover, in AWS, the relationship between right supplementary motor cortex and basal ganglia and between bilateral superior temporal gyrus and basal ganglia is reduced

[8]. These changes are likely to affect sensorimotor integration during speech. In addition, an increase in the connectivity between cerebellum and right inferior frontal gyrus was found, which positively correlated with the severity of stuttering. The authors of the article suggested that the increasing in the connectivity of these areas indicates a compensation mechanism.

2.3. Speech perception tasks

Several studies have focused on differences in brain activity during speech perception as a complement to the study of activations in speech production.

It is described in the works that during active listening (listening, after which speech is produced, is active), AWS had reduced activity in the supplementary motor cortex, insula and angular gyrus, but the opposite happened during speech production [9]. This is consistent with the findings of DeNil et al. [4] that stuttering is a violation of speech production, in which production places higher demands on brain areas compared to perception in AWS. On the other hand, during passive listening (after listening there is no task for producing speech), the activity in the bilateral auditory regions and the right frontal regions of AWS increases compared to AWDS. These differences in the neural mechanisms of speech perception and production in both AWDS and AWS are quite predictable, but still require in-depth study on ordered complexes of speech and language tasks.

3. FMRI methods in the observation of stuttering treatment

Studies [10], [11], [12], [13] showed that with the help of speech therapy it is possible to change the functional disturbances observed during speech and non-speech tasks in AWS. Most studies is focused on changes caused by conventional and external stimulation therapy. Few studies are aimed at studying non-invasive brain stimulation - transcranial direct current stimulation (tDCS) to enhance the effect of rehabilitation. This section will focus on 3 main areas.

3.1. Traditional approaches to stuttering therapy

Traditional speech therapy is aimed at changing breathing and controlling speech - this can be achieved by both speech and non-speech exercises. For example, one of the speech therapies, whose program consists of 3-week inpatient therapy and maintenance therapy for 1-2 years, reduces the excessive activity in the right inferior frontal gyrus [10].

Another study [11] claims that therapy aims to shift excessive activity in the left hemisphere. Furthermore, the treatment reduces the attempts of compensation by the right hemisphere and largely normalizes function of the regions involved in the union and auditory feedback motility. The only region showing an inverse correlation with the severity of stuttering before and after therapy is right Brodmann Area 47/12, what confirms its compensatory function. Perhaps the activating of Brodmann Area 47/12 separates the abnormal activity of Broca's area from the rest of speech production system, which allows it to restore normal function and provides long-term recovery. Researchers emphasize the need to consider not only brain activation levels, but also the degree of connectivity between its various regions.

3.2. Speech therapy with external stimulation

Therapy with external stimulation includes delayed and frequency-shifted auditory feedback, metronome stimulation of speech, choral speech, and so on. Some of these methods cause similar effects in the activation of brain regions compared to traditional therapy, increasing the activity of bilateral superior temporal cortex [12]. Under these conditions, AWS still exhibits excessive activity in the bilateral insula, cerebellum and midbrain, as well as insufficient activity in the bilateral ventral premotor and sensorimotor cortex relative to AWDS. However, metronome stimulation (AWS speaks with the metronome) increases activity in the basal ganglia AWS to a level comparable to that observed in AWDS. Thus, the external control of the tempo-rhythmic organization of speech, as new studies show, is an effective means of organizing a new type of neuronal activity in the treatment of stuttering.

3.3. Speech therapy with tDCS

The non-invasive neuromodulation method tDCS has shown a promising result in increasing the effect of therapy and an increase in neuroplasticity in AWS with severe stuttering [13]. During stimulation with high-resolution electrodes, subjects read aloud with a metronome. Brain activity was measured before and after tDCS stimulation. In case of severe stuttering, activity decreased from excessive to moderate in the areas of right postcentral gyrus and right thalamus. These 2 areas are part of the basal ganglia thalamocortical network, which supports the speech. The basal ganglia thalamocortical network is thought to play an important role in the interaction between cerebellum and cortical motor areas.

4. An integrated approach to the study of AWS using fMRI

The main disadvantage of the considered works lies in the fact that most studies focused on a narrow range of tasks associated with the production of speech, as a rule, at the stage of the pronunciation. We are dealing with a number of development factors and dynamics of stuttering treatment - psychological, socio-psychological, neurological. This allows us to understand the general mechanisms of stuttering in certain groups of subjects, and to implement an individual approach in the process of treatment and diagnosis of neuronal changes that correlate with the effectiveness of treatment for stuttering and psychological support of the patient. We support the need for an integrated approach to the study of stuttering [14]. We have developed a comprehensive methodology that includes, in addition to fMRI studies of neuronal processes of speech perception and production, methodological tools for identifying psychological factors and aspects of stuttering, as well as studying physiological parameters of respiration and larynx functioning.

The main task is to study changes in neuronal activity in AWS before treatment and at different stages of the therapy, up to a stable normalization of speech. The study of neural network mechanisms in AWS occurs when performing speech, multimodal tasks and resting state in the dynamics of stuttering treatment. Speech tasks include: producing arbitrary and prepared speech aloud and to oneself; visual perception of the text, interpretation of information, semantic organization of oral speech. Multimodal tasks include visual perception of images with speech situations and study of the state of rest. In addition to the study of functional systems, an analysis of the larynx and diaphragm using MRI is performed. Thus, in the proposed approach, changes in functional systems and physiological parameters are systematically studied.

5. Conclusions

Stuttering is a speech disorder that should be studied in a wider context of data. Most studies ignore the state of processes of attention, perception, memory, plasticity of thinking, individual mental and personality characteristics of people with stuttering. In modern studies, very little attention is paid to the treatment of stuttering, specifically the study of the dynamics of functional connections in the brain under the influence of therapy. This aspect of research is emphasized in this paper. Our comprehensive approach will allow us to assess the dynamics of the contribution of various types of factors in the process of stuttering therapy.

Acknowledgements

The work presented above is an initiative internal research work carried out by the Research Center ”Kurchatov Institute” (order No. 1059 of July 02, 2020).

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