

## The Auditory Processing Deficiencies in People Who Stutter: A Narrative Review

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### Review Article

#### Abstract

**Introduction:** Stuttering is a multifactorial disorder. So far, numerous findings have been reported regarding various deficits in auditory processing components in the people who stutter. Despite studies on correlation of auditory processing deficits and stuttering, this assumption has not been proven yet. The purpose of the present study was to investigate and collect the results of studies regarding the auditory processing deficits in the people who stutter.

**Materials and Methods:** This study was a narrative review to collect research on auditory processing deficits in people who stutter. ISI, PubMed, Scopus, Science Direct, and PsycINFO databases were searched to retrieve English articles that were published from 1995 to 2020. For studies conducted in Iran in Persian, SID and Magiran databases were searched. "Stuttering", "auditory feedback processing", "neurophysiology", and "brain maturity" were the keywords of interest.

**Results:** In the first stage, 211 articles were found. Finally, after reviewing the inclusion criteria, 86 articles in English and Persian were included. In addition to reviewing articles concerning the existence of auditory processing deficits, the present study emphasized that auditory processing problems in the people who stutter altered the assessment, diagnosis, and treatment approaches.

**Conclusion:** Although there is no evidence of anatomical abnormalities in the auditory system of people who stutter, numerous studies have reported unstable evidence of central impairments in their auditory processing. Neuroimaging and electrophysiological studies showed involvement of the central and peripheral areas of auditory processing.

**Keywords:** Auditory feedback; Auditory processing; Brain maturity; Neurophysiology; Stuttering

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#### Introduction

Stuttering is a disorder of speech fluency that is characterized by the sticking, repetition, and prolongation of sounds and syllables and has a developmental and acquired origin (1). Successful treatment of stuttering requires accurate knowledge of its nature; while the numerous findings on stuttering have caused disagreement in explaining its basic mechanism and the multiplicity of hypotheses and theories. Theories related to stuttering lie in a range of neurophysiological and brain developmental problems, genetic and psychological characteristics, lack of lateral hemisphere superiority, and abnormalities in the motor areas of speech and auditory processing (1-3). Despite the contradictions, the new findings, with the help of neuroimaging, suggest disturbances in the structure and function of

the brain, and therefore the possibility of neurological damage in stuttering is not far-fetched. In addition, several studies have reported the presence of mere auditory disorders and combined auditory-motor involvement (4-8). Impaired central auditory processing function is at least one of the causes of speech impairment (2). However, even with the use of brain imaging techniques and other electrophysiological tests, no definitive answer has been provided so far (3). Considering that auditory processing is one of the common indicators among most models and variables effective in stuttering, the present study aims to collect studies related to auditory processing in individuals with stuttering. Examining auditory processing in people with stuttering can provide a prelude to the initiation of neuro-auditory rehabilitation, which has received less

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attention in the treatment of these people.

### Materials and Methods

This study was a narrative review conducted to collect studies related to hearing-related defects in people with stuttering. For this purpose, online searches were performed in PubMed, Scopus, Information Sciences Institute (ISI), ScienceDirect, and PsychoINFO databases, and studies published in English from 1995 to 2020 were reviewed. To examine the articles published in Persian, a search was made in the Scientific Information Database (SID) and Magiran. The keywords used for the searches included “stuttering, auditory processing and feedback, neurophysiology, and brain maturation”. The selection of articles was such that two members of the research group, after reading the titles, first separated the related articles, which was repeated twice. In cases where there was disagreement between the two researchers, the article was reviewed by a third person. Articles that were not related to auditory processing in individuals with stuttering were excluded from the study. The two researchers then reviewed the abstracts, and if the abstracts were not sufficient to make a decision, the full text of the article was reviewed. Finally, 84 articles and 2 related books were reviewed. Articles on non-developmental stuttering and studies on non-auditory defects were removed.

### Results

#### Auditory system

Studies on the auditory system of people with stuttering included two main parts of the peripheral auditory system and central auditory system.

**Peripheral auditory system:** The auditory response of the brainstem is used to evaluate the function of the auditory pathway from the cochlear nucleus (CN) to the brainstem (5). The findings related to the difference in the auditory response of the brainstem were contradictory. According to the results of studies, even if there is a difference in the auditory response of the brainstem, its effect on the evaluation of the brain cortical components will be minimal (5-12).

**Central auditory system:** New findings with the help of brain imaging techniques indicated hyperactivity and inactivity of different areas of the brain during speech and also, defects in communication between brain areas responsible for speech production in people with stuttering (5, 6, 7 8-11), especially in the auditory, motor, and communication areas of these two areas (1,5,2,9). In other words, the brain activity pattern in the inferior

frontal gyrus (IFG), pre-motor cortex, auditory cortex, and decreased functional communication has been reported in these areas (8-11). The activity of the auditory cortex in neuroanatomical, neurophysiological, electrophysiological, and behavioral studies has been investigated as follows.

#### Neuroanatomical studies

Although neuroimaging studies have contributed to our understanding of the neurophysiological potential of stuttering and provided important results for researchers, our knowledge of the cause of stuttering is still limited.

**Volumetric magnetic resonance imaging (Volumetric MRI):** Based on the studies accomplished, the researchers concluded that there were abnormalities in the size of the planum temporale and gray areas related to speech and language (2,3). Planum temporale is the part of the Wernicke’s area that plays an important role in the processing of auditory information (3,5,9). Hearing impairment may be related to abnormal anatomy of the temporale auditory cortex; abnormal anatomy in the auditory areas, especially the planum temporale, has been observed in a group of subjects with stuttering (3). In adults with stuttering, the size of the planum temporale is abnormal (1). Further investigations suggested that in most people with stuttering, the planum temporale was larger in both hemispheres compared to that in the non-stutterers and was larger in the right hemisphere than in the left hemisphere (7). The abnormal anatomy of the planum temporale may be a risk factor for developmental stuttering in some children (5,6). In other words, an abnormal planum temporale is likely to alter speech auditory feedback, in which case treatment with delayed auditory feedback can be a compensatory process (6). MRI studies have indicated that the structures of the right hemisphere and the superior temporal gyrus (STG) in people with stuttering differ from those in healthy individuals (3,7).

**Morphology based on density of brain tissue in different volumetric units [Voxel Based Morphology (Voxel)]:** Given the studies, the volume of gray matter in the speech areas related to IFG, STG, and insula increases in adults with stuttering (3,5). The neuroanatomical differences observed in children with stuttering are unique compared to adults, and the gray matter is reduced in the inferior frontal lobe on both sides, the anterior insula on both sides, the middle temporal gyrus, and the right posterior STG (5,6). Findings of other studies showed that the growth of gray matter in the motor areas of speech in the cerebral cortex has an abnormal trend (6, 8-10).

Based on a study, white matter volume in the right STG, planum temporale, gyrus precentral, and IFG increased in stuttering adults, with no differences found in the gray matter (8). However, given the results of some other studies, it is said that the gray matter in IFG decreases bilaterally and the white matter decreases in the motor areas related to the face and larynx (5,8).

**Computed tomography scan (CT-Scan):** The results of studies revealed that there was abnormal asymmetry in the occipital lobe in adults with stuttering (3,7). Therefore, the affected areas in people with stuttering can be listed as follows:

1. **STG:** This gyrus includes frontal lobe, planum temporale, and supramarginal gyrus. The activity of this area decreases during speech in the areas of the primary auditory cortex bilaterally and in the posterior STG. While the Brodmann regions 22-41-42 are active during simple speech production, the posterior STG regions, including the planum temporale and supramarginal gyrus, are more active during speech perception and production. The severity of stuttering is related to the bilateral activity of the inferior temporal regions (2,9).
2. **IFG:** Bilateral increase in activity in this area during speech tasks has been reported in adults with stuttering (8-11).
3. **Supplementary motor area (SMA):** This area consists of the middle wall of the hemisphere and part of Brodmann area 6. The SMA activity increases during inactive listening to words (11).
4. **Insula:** is the largest structure in the Sylvian sulcus and consists of two anterior and posterior parts that differences in anatomy and function of this part has been observed in people with stuttering.
5. **White and gray matter:** Studies showed differences in the anatomy of white and gray matter (5, 6, 8,9). The decreased gray matter volume of an area of the cerebellum and medulla bilaterally is related to the neural mechanism of speech-controlling disorders and may be the main cause of stuttering. The increased gray matter volume in the temporal lobe, parietal lobe, and frontal lobe may be the result of long-term functional compensation for cerebellar and medullary dysfunction (6). An increase in the gray matter in left IFG, bilateral superior temporale, primary auditory cortex, inferior parietal lobule, IFG speech areas, and insula, and a decrease in gray matter in IFG, bilateral medial temporal regions, anterior insula (5,6), increase in white

matter volume in the left IFG and right superior temporal lobe, anterior middle frontal gyrus, right insula, left medial STG, decreased white matter in the arcuate fasciculus (AF) region, and left Rolandic operculum were identified in patients with stuttering (8).

**Functional imaging studies:** Studies on the continuous speech of people with stuttering showed differences in the level and extent of activity in the left and right hemispheres in the auditory and motor areas (10-12). The researchers concluded that the observed functional differences were related to stuttering and indicated that these areas function differently in individuals with stuttering (10,11), with some of the functional differences given in the following.

**Positron emission tomography (PET):** showed increased blood flow in the pre-motor areas, lower frontal cortex, right cerebellum, left somatosensory and left motor cortexes, right Rolandic, substantia nigra and posterior cingulate, less activity in the frontotemporal and left parietotemporal areas, and reduced sugar metabolism in Broca, Wernicke, Caudate, and prefrontal areas (12).

**Single Photon Emission Computed Tomography (SPECT):** showed a decrease in hemispheric superiority in areas related to onset of movement, motor control of speech, and language processing (13).

**Cerebral blood flow (CBF):** showed increased activity in the right Broca region relative to the left and the primary and secondary auditory cortexes of the right (13).

**Functional Magnetic Resonance Imaging (fMRI):** illustrated decreased activity of STG, left auditory cortex, left premotor areas, frontal and temporoparietal areas, temporal auditory communication areas, left sensorimotor areas, right frontal operculum, insula, and angular gyrus, and increased activity of the speech motor areas, right and left auditory regions, right STG, bilateral Heschl gyrus, right frontal and temporal motor regions, and cerebellar and Putamen regions (14).

#### **Electrophysiological studies**

In the electrophysiological studies, the electrical activity of the brain is amplified and recorded with the help of electrodes attached to the scalp (8). Electrophysiological research has shown that language perception is different in adults with stuttering (8,15-18). During speech production, neural activity decreases in the auditory cortex and neural activity increases in the motor area. Given the results of some studies, auditory activity in the STG of people with stuttering is bilateral instead of unilateral, while after treatment, the location and amount of

activity in the left hemisphere increases (8). The magnetoencephalography (MEG) findings confirmed the increased brain activity time and differences in the left and Broca auditory cortex, impaired neural communication between the left Broca sensory-motor cortex, and temporale in people with stuttering. Several studies have been performed using electroencephalography (EEG) to suggest differences in hemispheric superiority and brain function in subjects with stuttering (15-17). These studies indicated an increase in the activity of the right hemisphere of the brain (8) and supported the hypothesis of right hemisphere hyperactivity in stutterers (3-5), especially in the counterpart structures of the left hemisphere speech areas. Irregularities in activity between the two hemispheres in the auditory and motor areas and abnormal waves on the EEG in the parietal and occipital regions showed inactivity in the anterior insula (16).

**Behavioral studies:** The hearing process behavioral tests are also used to compare the performance of children with stuttering compared to normal children (18). Based on the results of previous studies, there is a possibility of subtle defects in the central auditory processing of children with stuttering.

**Hearing tests:** Many tests are used to assess the auditory system, but what has received much attention in research on people with stuttering is as follows.

1. **Auditory brainstem response (ABR):** The ABR results indicate the presence of auditory deficiencies in people with stuttering (6,7).
2. **Reaction time:** using the Pure Tone Audiometry (PTA), people with stuttering have lower accuracy and longer reaction time, and their responses are slower than those of the healthy individuals (19,20).
3. **Altered auditory feedback (AAF):** included altered auditory feedback, speech choral, unison, and masking (21). Since 1950, researchers have been using altered auditory feedback to reduce stuttering, and Goldiamond et al. first used it to reduce dysfluency in people with stuttering (22). It has since been found that people with stuttering are significantly affected by altered auditory feedback (21,22). Altered auditory feedback leads to the enhanced fluency in people with stuttering and decreased fluency in healthy ones (22). The important hypothesis is that changes in auditory signals change under auditory feedback and reduce auditory cognitive impairment in individuals with stuttering (21,22). The results of the volumetric

MRI studies showed that in two groups of people with stuttering with normal planum temporale and with abnormal planum temporale, the severity of stuttering was higher in individuals with abnormal planum temporale and the response of this group to auditory feedback was higher and this intervention increased the fluency of speech (21-26). The results of research show that during the use of Choral speech, the activity of the superior temporal gyrus increases in adults with stuttering (21). Moreover, as the results of the studies, before treatment with prolonged speech, right STG activity was increased in adults and after three weeks of treatment, a change in activity was observed towards left STG (21-25).

**Subcortical studies:** These studies showed defects in the basal ganglia, thalamus, and cerebellum of people with stuttering (22-27). These areas are involved in auditory processing due to their role in speech production (23,24).

**Basal ganglia and thalamus:** Basal ganglia are a group of subcortical structures that function as an integrated functional unit (23). These ganglia are located at the base of the anterior brain and have extensive connections to the cerebral cortex and thalamus (10,11). The basal ganglia are associated with various functions such as voluntary motor control, learning, eye movements, cognition, and emotion, and are composed of four motor, cognitive, limbic, and eye movements\ cycles (1,10). Stuttering can be the result of a disturbance in the cycle between the basal ganglia and the language motor areas of the cortex (24). The basal ganglia affect many speech characteristics due to their association with the cortex, especially the Broca area and the motor cortex of speech (21). Recently, brain imaging studies have reported different and abnormal functioning of the basal ganglia in people with stuttering (21-24). The basal ganglia include the caudate nucleus, the putamen, the internal and external globus pallidus, the subthalamic nucleus, and the substantia nigra (25). The nuclei of putamen, globus pallidus, and caudate nucleus show a different pattern of activity both in healthy and stuttering individuals and in resting, normal speech, and scheduled speech conditions (21). The signal change in these nuclei between the resting and normal speech conditions was not significant in people with stuttering (26), but in the case of scheduled speech (speech fluency enhancement), the activity of the nuclei was similar to those of the normal individuals (23).

The regression correlation analysis revealed that the change in the basal ganglia activity was inversely

related to the severity of stuttering in subjects (24-26). Hyperactivity was observed in putamen during speech and non-speech production (24,25). At the same time, on the basis of the findings obtained from PET, glucose metabolism was reduced in the left caudate nuclei and speech comprehension-expression areas (25).

**Cerebellum:** The cerebellum and its connections to the cortex are effective in stuttering (23-25). Speech production in adults with stuttering is associated with increased activity in the right hemisphere, including the frontal region and the left cerebellum (25). Additionally, the volume of gray matter decreases in the posterior part of the cerebellum and the cerebellar tonsil (23,25). Based on brain imaging studies, it has been observed that the cerebellum is very active in individuals with stuttering (22-25). Cerebellar hyperactivity has often been reported in people with stuttering (20,23,25-27), which has been interpreted as a mechanism for compensating for deficiencies in achieving skillful movements (25). In this regard, there is a hypothesis that in order to overcome the defect of the cortico-basal pathways, the cerebello-cortical pathway becomes doubly active (24,25).

### Discussion

Understanding the nature of stuttering has always been an interesting and complex subject. The present study was performed aiming to address the auditory processing deficiencies in individuals with stuttering. It seems that the differences between the two normal groups and people with stuttering indicate differences in their brain function and these differences are effective in the processing, control, guidance, and production of speech (28-31). Given the results of previous studies and investigations (8,27-32), there are differences in the pattern of brain waves in patients with stuttering and those without stuttering. In infancy, the activity of slow waves, such as the delta wave, is greater, which decreases with age and brain maturation, and is replaced by alpha waves (19,20,33). The results of the present study suggested an increase in the activity of waves in the right hemisphere and support for the hypothesis of right hemisphere hyperactivity in patients with stuttering (25-27). This may be related to the old Orton-Travis hypothesis that considered the lack or defect in the formation of lateral superiority as effective in causing and exacerbating stuttering (27). This hypothesis is one of the first important theories about the underlying neurological causes of stuttering (1,5,6). However, in most previous studies, differences in the

brain wave pattern of people with stuttering and others have been noted (15,16,19,25-27).

Based on the research, increased activity in the right hemisphere of people with stuttering has been observed in counterpart structures of the speech areas in the left hemisphere (1,7,11). Among these areas was the right hemisphere frontal operculum, which is similar in location to the Broca's area in the left hemisphere and the right insula, and serves as the interface between the Broca's area and Wernicke's area (27). Researchers explain this hyperactivity using the compensation mechanism (27,28). In accordance with this mechanism, when a person suffers from dysfluency in speech, they use the structures and networks of the right hemisphere as compensation, and because these areas are not fully specialized in this field, dysfluency remains in the person's speech (11-13,25).

On the other hand, in recent years, due to the positive effect of altered auditory feedback (20-22) in the treatment of stuttering, researchers' attention has been drawn to the fact that auditory processing can play an important role in stuttering (1,7,19,24). Auditory processing refers to the ability to decode, understand, store, modify, and apply auditory information (21,22). A review of research indicates that despite the existing contradictions, there is no evidence of anatomical abnormalities in the hearing system of people with stuttering (8-10,24-27). The results of studies indicate the involvement of brain areas associated with the auditory and motor processing such as the planum temporale, insula, inferior frontal, and motor and pre-motor areas (3,8,10,11). Considering the research conducted in people with stuttering, the function of the auditory cortex differed from that of non-stutterers (5,2,9,11).

During processing of the auditory input, the auditory sensory gating is disturbed and error signals in the auditory cortex can lead to abnormal speech processing in subjects with stuttering (22). Thus, taking into account the findings of the present study and their comparison with of previous studies (19,21), significant differences are observed in the pattern of brain waves and, consequently, in the structure and function of the brain of stutterers and non-stutterers, as well as auditory impairment in these individuals, but accurate identification of the nature of these differences and their role in speech production and processing requires further investigation.

### Limitations

The present study was a narrative review and no qualitative evaluation was performed on the studies

reviewed. Besides, it was not possible to review the studies in non-Persian and non-English languages.

### Recommendations

What seems necessary at the moment is that more research should be conducted on the etiology of stuttering, especially auditory processing defects, with a more valid methodology, and further systematic and meta-analytical studies should be performed in this field given the importance of knowledge on the nature of stuttering in its treatment.

### Conclusion

Functional deficiencies in the auditory-temporal cortex lead to impaired transmission of auditory information to the frontal motor areas and disruption of the coordination of the integrated neural networks and the speech output dysfluency. In other words, the basis of stuttering is perceptual skills rather than productive skills. Auditory processing is an important issue that shows the close relationship between speech production and comprehension and the basis of human speech.

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### Authors' Contribution

Parisa Zare: study design and ideation, study financial, support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results,

specialized statistics services, manuscript preparation, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments; Fatemeh Jafarlou: data collection, specialized statistics services, manuscript preparation, final manuscript approval to be sent to the journal office; Fatemeh Fekar-Gharamaleki: study design and ideation, study financial, support, executive, and scientific services, providing study equipment and samples, data collection, analysis and interpretation of results, specialized statistics services, manuscript preparation, specialized evaluation of manuscript in terms of scientific concepts, responsibility for maintaining the integrity of the study process from the beginning to publication, and responding to the referees' comments.

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### Conflict of Interest

The authors had no conflict of interest. Fatemeh Fekar-Gharamaleki and Parisa Zare completed the basic studies related to the project. Parisa Zare is a graduate of Tabriz University of Medical Sciences with an MSc degree in medical physiology. Fatemeh Fekar-Gharamaleki has been a PhD student in speech therapy since 2016 and has been working as an instructor at Tabriz University of Medical Sciences. Fatemeh Jafarlou has been working as an assistant professor at Tabriz University of Medical Sciences since 2017.

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