International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Auditory Figure Ground Disorder in Children

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Abstract

Listening in real life with noise competition is a great challenge for a considerable number of schoolchildren with auditory processing disorders. These children usually have difficulty in auditory figure ground (AFG) ability. Diagnosis and follow-up of those children is mainly conducted using psychophysical tests that may not be sufficient considering the possible learning effect of these tests or the testing difficulties at a young age. The target of auditory processing is to construct an image for the auditory signal in order for this to be used in auditory comprehension. In real life, these signals are challenged by another one or compromised by a particular situation that may then distort the resulting auditory image. This, in turn, may overload the capacity of the intrinsic redundancy of the auditory system and lead to confusion in auditory comprehension. One solution offered by the auditory system itself is to suppress undesired competitors, especially background noise, in order to make the signal more defined and clear. This ability is called auditory figure ground (AFG) Auditory Figure-Ground Disorder, a form of Auditory Processing Disorder, impairs a child's ability to focus on important sounds among background noise, affecting communication and learning. The disorder linked to dysfunctions in specific brain regions, affecting sound differentiation and prioritization. Recent studies emphasize role of neural and cognitive mechanisms, such as temporal coherence and attention, in managing auditory figure-ground processing. Continued research is essential to develop effective strategies that support social, academic, and cognitive development for affected children.

Keywords: auditory processing disorders, cochlear implant

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1. Introduction

Auditory Figure-Ground (AFG) disorder, a subtype of auditory processing disorder (APD), affects an individual's ability to separate relevant auditory information from background noise. This difficulty can lead to significant challenges in communication and learning, particularly in environments with considerable auditory distractions. The Bellis/Ferre model provides a comprehensive framework for profiling APD, identifying distinct neurophysiological regions of dysfunction in the brain and their implications for language and learning. This model categorizes APD into three primary profiles: Auditory Decoding Deficit, Prosodic Deficit, and Integration Deficit, each associated with dysfunctions in primary auditory cortex, non-primary auditory cortex, and corpus callosum, respectively. Additionally, model outlines two secondary profiles: Associative Deficit and Output Organization Deficit, which relate to dysfunctions in left associative cortex and temporal-frontal auditory associative areas [1].

1.1. Auditory Figure-Ground Processing

AFG processing is ability to focus on a target sound or speech signal in presence of background noise or competing sounds. This skill is crucial for effective communication in everyday life, as it allows individuals to separate desired speech signal from competing sounds. The refinement of neural pathways involved in AFG processing can minimize consumption of neural resources, leaving more available for other cognitive and linguistic processes [2]. AFG relies on basic auditory abilities and higher-level cognitive functions such as attention and memory, which are essential for filtering and prioritizing auditory information [3]. Ability to discern and focus on desired acoustic signals among competing noises is vital for communication, especially in environments with significant auditory distractions, like busy classrooms and crowded restaurants.

1.2. Challenges Faced by Children with AFG Disorders

Children with AFG disorders often exhibit difficulty understanding speech in noisy environments, frequent requests for repetition, and struggles with following verbal instructions, particularly in-group settings. These symptoms can mimic other conditions, such as ADHD or language disorders, making accurate diagnosis challenging. Additionally, children may face social difficulties due to misunderstandings and withdrawal from group activities, affecting their emotional and social development [4]. The increased cognitive load required for children with AFG disorders to process auditory information can lead to mental fatigue and decreased performance in other cognitive tasks [2]. Children with AFG disorders may struggle with sustained attention and may be more prone to distractibility in noisy environments [3]. Delays in language development can occur due to difficulties in processing and understanding speech in noise, which can impact vocabulary acquisition and language comprehension [1]. Social withdrawal or difficulty in peer interactions may arise from misunderstandings and the inability to follow group conversations, leading to isolation and reduced self-esteem [4]. Anxiety may develop in children with AFG disorders due to repeated communication failures and difficulties in noisy settings [5]. The inability to focus on teacher instructions and classroom discussions can lead to academic underachievement and require specialized educational support [6].

1.3. Etiology of AFG Disorders

The etiology of AFG disorders is multifaceted, involving genetic predispositions, neurological development, and environmental exposures. Neurological factors may include delays in brain maturation or structural anomalies in auditory pathways [1]. Environmental factors, such as exposure to persistent background noise or limited language interaction during critical developmental periods, can exacerbate these difficulties. Understanding these underlying causes is crucial for developing effective intervention strategies.

1.4. Mechanisms of Auditory Figure-Ground (AFG)

1.4.1. Grouping of Simultaneous Auditory Figure Components across the spectral array

Neurons within the auditory system encode various sound attributes such as pitch, timing, and intensity. This encoding is essential for the brain's ability to recognize and differentiate between distinct auditory stimuli. A significant challenge in auditory neuroscience involves understanding how the auditory system isolates a specific sound source from complex auditory environments common in everyday life. Historically, research primarily focused on the differentiation of "figure" and "ground" components based on frequency variations. This approach inspired by discoveries showing that auditory segregation correlates with the activation of neuronal populations within the primary auditory cortex, influenced by factors such as neuronal adaptation, forward masking, and frequency selectivity [7]. Recent studies have expanded this understanding by exploring the neural mechanisms underlying the grouping of simultaneous auditory figure components across the spectral array. Neurons in the auditory cortex can exhibit synchronized firing patterns when responding to coherent sound sources, suggesting a mechanism of neural coherence. This synchronization allows for the integration of auditory information across different frequency bands, enabling the perception of a unified auditory figure among a complex background [8]. Moreover, higher-order auditory processing regions provide additional computational resources for analyzing complex auditory scenes, enhancing the brain's capacity to distinguish figure from ground [9].

1.4.2. Grouping of Figure Components According to Temporal Coherence

In many scenarios, auditory input is derived from numerous, often-indeterminate sources. The auditory system's primary function is to dissect this complex auditory mixture to identify potential sound sources. Bregman (1990) described this process as auditory scene analysis (ASA), through which the auditory system organizes incoming acoustic information. This is crucial in dynamic environments where both the listener and the sources are in motion. Despite these complexities, individuals consistently and accurately deconstruct auditory scenes without confusion [10]. Recent advancements in understanding ASA have shed light on how the auditory system groups figure components according to temporal coherence. Temporal coherence refers to the synchronized timing of sound elements that belong to the same source, enabling the auditory system to bind these elements into a coherent perceptual whole. Studies have shown that neurons in the auditory cortex can track temporal coherence cues to segregate sound sources effectively [11].

1.4.3. Cortical and Subcortical Processing

Subcortical structures, particularly the inferior colliculus in the midbrain, are pivotal in the early stages of the auditory figure-ground process, facilitating the segregation and integration of sound elements. The medial geniculate body, a higher structure in the midbrain, plays a role in auditory figure-ground by estimating the timing of coherent components of the figure [7]. Subcortical structures, including the olivocochlear system and the medial geniculate body (MGB), modulate auditory inputs before they reach the cortex. The olivocochlear system, particularly the medial olivocochlear (MOC) neurons, sends efferent fibers to the outer hair cells in the cochlea, suppressing their activity in response to background noise through the release of acetylcholine (Ach). This suppression of inner hair cell (IHC) activity reduces the amplification of background noise, thereby enhancing the signal-to-noise ratio (SNR) of the auditory signal reaching the cortex [12].

The primary auditory cortex is responsible for the initial processing of auditory information, encoding basic sound features such as frequency, intensity, and duration. Neurons in this area respond to various frequencies, enabling the differentiation between sound sources based on spectral content. This frequency selectivity is essential for separating auditory figures from background noise [7]. Conversely, the auditory association cortex, also in the temporal lobe, integrates auditory information with other sensory inputs and higher-order cognitive functions. It significantly helps to group auditory features across time and frequency, facilitating the perception of continuous auditory objects. This region enhances the brain's ability to segregate figures from the ground, crucial for understanding speech in noisy environments and recognizing complex auditory scenes [8].

1.4.4. Cognitive Role in Auditory Figure-Ground

Higher-level cognitive processes, known as top-down processing, influence AFG function. This includes factors such as attention, expectations, and memory processing, which guide the brain in organizing and interpreting auditory scenes. For example, in a classroom setting, the sudden sound of a car horn outside can disrupt focus on a teacher's voice [13]. Increased activity in cortical cognitive regions, such as the prefrontal area, compensates for sensory representation deficits in other cortical areas. This enhanced prefrontal activity, following attention, has supported by behavioral-neurophysiologic studies [14]. The prefrontal cortex (PFC) is involved in the top-down modulation of auditory processing, enhancing the salience of relevant sounds by focusing attention and filtering out irrelevant noise. The PFC directs cognitive resources toward important auditory figures while suppressing background noise, increasing the responsiveness of auditory neurons to relevant stimuli and improving the SNR [15]. The cognitive control of the auditory cortex is fundamental for enhancing the neural representation of important auditory figures while suppressing irrelevant sounds. When attention directed towards a particular sound, neurons in the auditory cortex increase their firing rates, enhancing the neural representation of that sound.

This enhancement facilitated by top-down modulation from higher cognitive areas, such as the PFC, which instructs the auditory cortex to prioritize certain auditory inputs. This process is critical for focusing on a specific speaker in a noisy environment [16]. Simultaneously, the auditory cortex can suppress responses to irrelevant noise via inhibitory interneurons, enhancing the contrast between the figure and the ground [17]. Neurons in the auditory cortex synchronize their firing patterns in response to coherent sound sources, facilitating the perception of a unified auditory figure among a complex scene [18]. A balance between bottom-up and top-down mechanisms of attention supports task efficiency while maintaining awareness of surrounding environments. Top-down attention operates through facilitator and inhibitory processes, while bottom-up attention captures attention involuntarily through unexpected stimuli [19]. Memory plays a crucial role in the cognitive processing of AFG segregation by enabling the auditory system to retain and utilize information from experiences to interpret current auditory scenes.

Working memory allows for the temporary storage and manipulation of auditory information, essential for maintaining the continuity of auditory perception. This capacity enables listeners to hold onto recently heard sounds and compare them to incoming events, facilitating the identification of auditory figures from the background. Long-term memory also contributes by providing a repository of learned sound patterns and contextual knowledge that the brain can draw upon to make sense of complex auditory environments [20]. Research has shown that memory-related neural circuits, including those in the prefrontal cortex and hippocampus, are actively involved in AFG segregation. These regions work with the auditory cortex to integrate past experiences with real-time processing, enhancing the brain's ability to predict and differentiate between figure and ground components. Memory processes also help establish auditory ``, mental representations of typical sound structures that guide perceptual organization and expectation [21].

1.5. Importance of AFG in Real-Life Situations

Efficient auditory figure-ground (AFG) skills are essential for understanding speech in noisy environments, such as classrooms, restaurants, or social gatherings. This ability is crucial for social interaction, professional communication, and academic success. AFG skills integrate with other auditory and cognitive abilities, such as sound localization and attention, enhancing listening comprehension and overall cognitive and linguistic achievement [1]. Furthermore, a well-functioning AFG skill consolidates with other abilities like sound localization and attention, contributing to better cognitive, linguistic, and academic outcomes [22].

2. Conclusions

Efficient auditory figure-ground processing is essential for understanding speech in noisy environments and is critical for social interaction, professional communication, and academic success. AFG skills integrate with other auditory and cognitive abilities, such as sound localization and attention, enhancing listening comprehension and overall cognitive and linguistic achievement. Developing interventions that target the mechanisms underlying auditory figure-ground disorder can improve outcomes for individuals affected by this condition, fostering better engagement and participation in various life settings. Continued research into the neural and cognitive aspects of AFG processing will inform the development of effective strategies to support individuals with auditory figure-ground disorder, ultimately enhancing their quality of life and communication abilities.

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