Review Article

Mechanisms of Listening Effort in Individuals with Hearing Loss

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ABSTRACT

Introduction: Listening effort refers to the cognitive resources required to understand speech, particularly in challenging environments. Individuals with hearing loss experience increased listening effort due to auditory deficits, affecting their communication and cognitive load. Understanding the mechanisms underlying listening efforts is essential for developing effective hearing interventions. This study aims to explore the mechanisms underlying listening efforts in individuals with hearing impairments.

Materials and Methods: A narrative review was conducted using specific keywords in Google Scholar (as a search engine) and the research databases Web of Science, Scopus and PubMed. Relevant articles were selected based on their alignment with the focus on the mechanisms of listening effort in individuals with hearing loss.

Results: Hearing loss triggers compensatory cognitive strategies, engaging the prefrontal regions and working memory to process degraded auditory signals. Neural adaptations, including cross-modal plasticity and reliance on top-down processing, further elevate mental workload. Degraded temporal processing and attentional demands in noisy environments exacerbate effort, often leading to fatigue.

Conclusion: Understanding these mechanisms informs interventions, such as adaptive hearing technologies, cognitive training to optimize resource allocation and personalized communication strategies. Integrating neurophysiological insights into clinical practice can reduce cognitive fatigue and enhance communication outcomes.

Keywords:

Listening effort; Hearing loss; Cognitive load; Mechanisms

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Introduction

Hearing and speech comprehension are crucial to human social life [1]. In clinical settings, speech audiometry is one of the main audiological tests typically measured by correctly calculating the proportion of identified keywords in quiet or noise to determine people's perceptual abilities in real life conditions [1, 2]. Listening effort is an aspect of speech understanding that has been under-evaluated. The framework for understanding effortful listening defines listening effort as the deliberate allocation of mental resources to overcome obstacles in goal pursuit when carrying out a (listening) task [3]. Although listening to speech is relatively effortless under ideal listening conditions, processing speech may become more effortful due to the degradation of the signal quality, use of the complex language structure, or the message with less familiar content [2, 4, 5]. Also, a complex interaction between factors, such as working memory, attention, motivation, and cognitive capacity, is related to the listening effort experience [3].

Hearing impairment is one of the most prevalent disabilities in the population and poses significant challenges in daily life, particularly in areas, such as speech recognition and communication [6]. Therefore, in this context, hearing-impaired individuals may experience effortful listening in their daily lives [2]. The internal representation of acoustic stimuli is often degraded in individuals with hearing impairments, leading to difficulty in processing sounds. The acoustic signal must be accurately decoded for effective speech recognition, which is particularly challenging for hearing-impaired individuals [7]. Furthermore, speech is frequently surrounded by background noise and other sounds in everyday situations, further complicating communication [8]. Research indicates that hearing-impaired individuals experience greater difficulties in speech perception under these conditions than individuals with normal hearing [9–11]. It is suggested that the effort to continuously process auditory input contributes to an increased cognitive load during listening [12]. Consequently, hearing-impaired individuals must exert additional effort to achieve successful speech perception [5, 7]. Decreased access to auditory information and the need for compensatory cognitive resources cause hearing-impaired patients to exert more listening effort [2]. Sensory degradation due to hearing loss increases the cognitive demands on the central auditory processing system, especially for speech comprehension. This compensatory effort engages various brain regions, suggesting the presence of underlying mechanisms that contribute to listening effort [3]. Hearing impairment can profoundly impact an individual's social interactions and quality of life, frequently resulting in withdrawal from leisure activities and social roles [13–15]. This could be partly explained by the greater effort required for successful listening [16].

A narrative review of the existing evidence is essential to deepen our understanding of the current knowledge regarding the mechanisms underlying listening effort following hearing loss. To date, researchers have explored various aspects of listening effort in numerous studies, including analyzing its mechanisms [3, 5, 17], to provide a scientific basis for optimal management in the rehabilitation process of individuals with hearing loss [3, 18]. However, based on the existing literature, the neural and cognitive mechanisms underlying this increased effort remain under investigation. Understanding these mechanisms is important because it can help improve auditory rehabilitation strategies. This research can improve clinical interventions by studying how the brain processes sound and the effort involved, ultimately helping individuals with hearing loss communicate more easily and reducing mental fatigue [3]. Therefore, the present study aims to review the current literature on the mechanisms of listening effort in individuals with hearing loss.

Materials and Methods

Study design

This narrative review aims to explore the mechanisms of listening effort in individuals with hearing loss by reviewing and analyzing relevant studies.

Eligibility criteria

This narrative review included only English-language studies with available full texts that assessed the mechanisms of listening effort in hearing-impaired individuals. The inclusion criteria were relevant articles that examined the mechanisms underlying listening effort in individuals with hearing loss. No systematic inclusion or exclusion criteria were applied, allowing for a broad field exploration.

Sources of research

In this narrative review, studies published from 1980 to 2025 were searched for in different databases, such as Google Scholar, Web of Science, Scopus and PubMed.

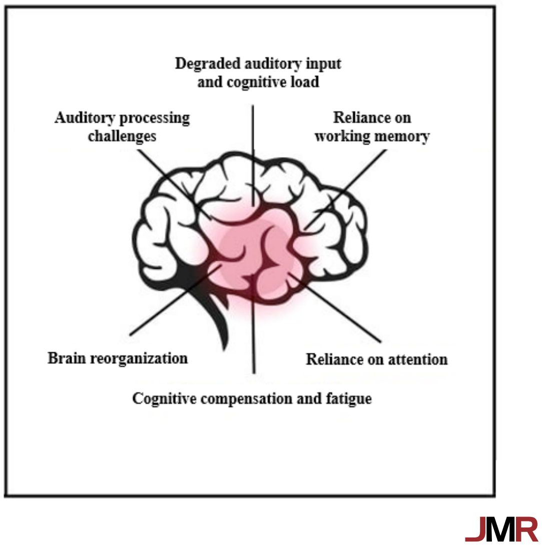

Figure 1. The mechanisms of listening effort in individuals with hearing loss

Search strategy

In this review study, the search was carried out in January 2025 using the medical subject headings (MeSH) terms: "Listening effort," "hearing loss," "cognitive load," and "mechanisms". Boolean operators (AND, OR) were used to combine these terms to ensure a broad but relevant search. A total of 876 articles were initially reviewed, and 45 articles were selected for final analysis and inclusion in the review.

Results

The findings of this study are shown in the graphical abstract (Figure 1). The underlying mechanisms are classified into six categories:

Mechanisms and important factors

Hearing loss often leads to increased "listening effort," in which individuals expend more cognitive resources to understand speech and sounds [19]. This increase in effort has been a focal point of auditory research because it affects the cognitive load, fatigue, and overall communication efficiency of individuals with hearing impairment [19, 20]. Herein, we provide a comprehensive overview of the mechanisms underlying the increased listening effort in hearing loss, referencing key studies.

Auditory processing challenges and listening efforts

Central auditory processing disorder is typically characterized by a distinct impairment in the processing and interpreting of auditory signals within the central auditory nervous system, encompassing both bottom-up and top-down neural connectivity [21]. According to the bottom-up theory, hearing loss reduces auditory input fidelity, requiring the brain to compensate for missing information [22], thereby increasing the cognitive load [3].

Pichora-Fuller et al. explored how listening effort increases cognitive demands. This compensatory effort often involves regions outside primary auditory processing areas, such as working memory and attention [3].

Degraded auditory input and cognitive load

Hearing loss degrades the quality of auditory signals, often distorting speech sounds or making certain frequencies less audible. This degraded input means that the auditory cortex receives incomplete information that the brain must process and interpret. Each step of this process increases cognitive load, especially when listening in noisy environments [5, 12]. For example, studies reported that hearing loss distorts the auditory signal by selectively reducing audibility across certain frequencies, often leading to a loss of high-frequency sounds critical for speech understanding [23, 24]. This selective degradation following hearing loss creates incomplete auditory input, making speech recognition difficult in real-world listening environments [3]. This degraded input quality poses additional difficulties in recognizing speech sounds in noisy environments, as the brain cannot rely solely on the auditory signal to differentiate speech from background sounds. Individuals with hearing loss experience reduced speech recognition ability in noise because the degraded signal limits their ability to access essential acoustic cues [5, 12]. Hearing loss exacerbates the challenge of separating speech from background noise, leading to greater listening effort [12]. Also, some studies have shown that temporal cues in speech are vital for comprehension, and hearing loss significantly impairs the processing of these cues. This disruption hinders the brain's ability to follow rapid temporal changes, crucial for understanding complex or fast-paced speech [17, 25]. Studies have highlighted that when these temporal cues are compromised, the brain must expend additional resources to fill in the gaps or predict missing information, contributing to increased listening effort [25].

Increased reliance on working memory

Working memory is integral for holding and manipulating information in real-time tasks, such as speech comprehension, which becomes especially crucial when auditory input is unclear [26]. This increased reliance on cognitive resources has been corroborated by research showing a link between degraded hearing and reduced cognitive performance as the brain reallocates resources from other functions [27]. For individuals with hearing loss, working memory compensates by engaging in several demanding processes:

Listeners with hearing impairment must rely heavily on their working memory to hold fragmented or distorted auditory input and retain incomplete speech signals long enough to fill in gaps [5]. This process requires maintaining partial information in memory while using context, language knowledge, and prior experience to reconstruct the intended message. Studies have shown that this cognitive compensation is essential but demanding, as it draws significantly on limited working memory resources, especially in dynamic listening environments [27, 28].

Furthermore, when clear auditory cues are absent, listeners with hearing loss often reconstruct meaning by piecing together words from context, memory, and prior knowledge. This process places an additional load on working memory, as it requires holding on to incomplete speech fragments, mentally replaying portions, and integrating audible segments with contextual cues to approximate the intended meaning [3]. This complex reconstructive process is mentally taxing, increasing cognitive load and leading to heightened listening effort and fatigue during conversation [25]. Rönnberg et al. proposed the ease of language understanding model, which suggests that when auditory input deviates from expectations, individuals with hearing loss exert additional cognitive effort to reconstruct the message. This reconstruction process strains working memory, especially in dynamic or noisy environments, where speech signals are more difficult to process accurately [5].

Increased reliance on attention

Attention is crucial for directing cognitive resources toward understanding speech, particularly under challenging listening conditions [3]. Individuals with hearing loss increasingly rely on attentional mechanisms to compensate for degraded auditory input. For example, the ability to filter out background noise and focus on the speaker's voice is compromised following hearing loss. This makes it difficult to isolate relevant speech from other sounds, such as overlapping conversations or ambient noise, increasing the need for selective attention [12]. Selective attention, the cognitive process of focusing on the desired aspect of a stimulus while suppressing irrelevant aspects, becomes more demanding as it compensates for diminished auditory clarity. This need for heightened selective attention increases the cognitive load, leading to greater listening effort [3].

Neural and cognitive compensation in hearing loss

When hearing loss occurs, the brain undergoes neural reorganization to compensate for reduced auditory input. This plasticity may involve auditory temporal region recruitment for executive functions, particularly during switching tasks, indicating that the absence of auditory inputs allows these areas to take on cognitive roles, reflecting neural reorganization and plasticity [29]. In hearing loss, cross-modal plasticity occurs, where areas of the brain that no longer receive sufficient auditory input are recruited to process other types of information. The brain shifts processing away from auditory regions and engages other modalities, which can increase the cognitive load [30].

Lomber et al. demonstrated that parts of the auditory cortex begin processing visual and somatosensory information in individuals with profound hearing loss. While this allows the brain to adapt to sensory deprivation, it also means that these regions are no longer available for auditory processing [31]. Alongside structural changes in the brain, individuals with hearing loss develop cognitive compensation strategies to maintain speech comprehension. Top-down processing is essential in situations with degraded or unclear auditory input. Listeners rely more heavily on stored knowledge and contextual clues to "fill in" missing auditory details, especially in noisy or complex environments with limited acoustic cues [3, 5]. This increases cognitive load as it requires greater memory use and attentional resources. This added effort can lead to listening fatigue and impair performance in other cognitive tasks.

Pichora-Fuller and Singh further developed the understanding of cognitive compensation in hearing loss, explaining that individuals with hearing impairment rely heavily on working memory and attentional resources to interpret degraded inputs. Their study showed that degraded auditory signals force listeners to retain fragments of speech in their working memory while attempting to fill in gaps, which leads to increased listening effort. This study emphasizes how hearing loss reallocates cognitive resources to manage incomplete auditory information, especially in complex listening environments [33].

Discussion

This study reviewed mechanisms of listening effort in individuals with hearing loss. Listening effort refers to the cognitive and perceptual resources required to understand speech, particularly in difficult listening environments, such as background noise or degraded acoustics, especially after hearing loss [34]. To better manage and provide effective counseling to individuals with hearing loss who exert significant effort to listen, clinicians and researchers must be aware of the mechanisms of listening effort associated with hearing loss. Different studies have suggested several mechanisms.

Degraded speech makes understanding harder and impairs memory retention, especially for distorted words and sentences. This effect is more pronounced in older adults and those with hearing loss [35]. Hearing-impaired listeners struggle more with recalling complex stimuli, such as short stories. However, self-paced listening can help them perform better, indicating a higher cognitive load and greater cognitive challenges [36]. In conclusion, auditory and cognitive resources are involved in processing degraded speech, with hearing impairment increasing cognitive demands [35]. Researchers have examined areas with increased activity for degraded but intelligible speech to identify the neural signatures of listening effort. Studies have shown increased activation in the left lateral temporal cortex, inferior frontal cortex, and premotor cortex for degraded speech, suggesting an effort-related response [37, 38]. Increased activity for degraded speech is also observed in the cingulo-opercular network [39–42], which is linked to error monitoring and attention [35]. Effort-related increases in brain activity are observed in both auditory/language and executive systems, especially within the multiple-demand system, which supports speech understanding [43, 44]. Therefore, listening efforts following degraded speech often require listeners to rely more heavily on other areas of the brain, including different types of cognitive resources [35]. Various factors, including cognitive aspects, play a crucial role in the successful adoption and satisfaction with hearing aids [45].

Conclusion

Listening effort in individuals with hearing loss involves complex interactions between auditory and cognitive processes. Understanding these mechanisms is essential for designing targeted interventions, such as individualized auditory and cognitive training programs, that aim to improve speech perception and reduce cognitive fatigue. These insights also support the development of enhanced rehabilitation strategies that combine hearing amplification, cognitive support and real-life communication training. Furthermore, optimizing assistive listening devices, particularly auditory tools, such as hearing aids and cochlear implants, through improved signal processing and user-specific configurations can help reduce listening effort. Overall, a multidimensional approach informed by behavioral and neurophysiological evidence can support individuals with hearing impairment more effectively.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Research Ethics Committee of Tehran University of Medical Sciences, Tehran, Iran (Code: IR.TUMS.FNM.REC.1402.134).

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Authors' contributions

Writing the original draft: Zahra Iran Pour Mobarakeh; Review and editing: All authors; Supervision: Vida Rahimi.

Conflict of interest

The authors declared no conflict of interest.

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