Cognition for Speech Understanding in New Hearing Aid Users

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ABSTRACT

Hearing loss is one of the most neglected and least considered health problems, even when there is a considerable proportion of people suffering from different extent of hearing loss. Hearing aids used around the world work by simply amplifying the detected sound waves including unwanted background noises, which makes it more difficult for users to extract and perceive important speech. It requires more attention and focus of the users to maintain a span of attention on the speech. Cognitive abilities of the users also play an important role in the maintenance of attention required for speech processing.

An inductive research method is used with a systematic review of literature resources in this study to explore the role of cognition in speech processing and the impacts of unfamiliar signal processing methods to improve hearing for hearing aid users. The search of articles is limited to the latest (within 10 years of publication) resources on Google Scholar and PubMed databases. A total of 10 articles were analysed using the thematic analysis process to present compelling evidence of arguments made in this research.

It was found that without the context of the spoken words, it is difficult for new hearing aid users to discernibly comprehend the speech themselves. Although the cognitive abilities of the users help in processing of the speech, unfamiliar environments pose a significant challenge for new hearing aid users.

Keywords: Speech recognition, hearing aid, speech processing, cognition

INTRODUCTION

Hearing aid is a small electronic device worn behind or in the ear, which improves the speech comprehension and hearing of people who have impaired auditory ability. The National Institute on Deafness and Other Communication Disorders (NIDCD) states that only about 20% (1 in 5) of the population use hearing aids (NIDCD, 2022). That means 80% (4 out of 5) of the population with damaged sensory cells in the inner ears are not using hearing aids, even though they would benefit from using one.

The primary function of a hearing aid is to magnify or amplify the surrounding sound vibrations for better comprehension of the sound. In a noiseless environment, the amplification process helps significantly in increasing the clarity of sound and benefits the comprehension of speech. However, it becomes more challenging for sound perceptions by the individual, when the hearing aid is used under a noisy environment. As stated by Souza et al. (2019), the variability of the individual characteristics such as working memory ability and hearing loss extend have significant impact on the cognitive ability of the individual to process unfamiliar signals. Hearing aids help in the processing of speech, and cognitive resources are better utilised for understanding of the auditory signals.

The primary aim of this thesis is to explore and identify the relationship between cognition and speech processing with the use of an unfamiliar signal processing method in established hearing aid users. In simpler terms, the thesis would examine different sources of information and studies in order to understand how the cognitive abilities of the individual helps in the speech processing methods and aid in the hearing while using the hearing aids.

BACKGROUND

Mechanism of Hearing aid

Hearing has a simple mechanism, in which sound waves travels from the outer ear to the eardrum, and convert sound waves into vibration by three tiny ear bones (malleus, incus and stapes). The motion of the stapes induces the vibration or movement of the fluid in cochlea. Such movements are detected by sensory cells of the organ of Corti, which send nerve impulse to the brain. The auditory center of the brain further identifies and interprets the received signal creating the sense of hearing. Chandrasekhar et al. (2019) opined that hearing loss can be due to problems in the transmission of sound to the middle or inner ear (conductive loss), as well as due to damage to the auditory nerve (sensory loss). Conductive hearing loss occurs when the conduction of sound through the external middle ear is hindered. Any damage to the cochlea only to the auditory cortex, which is included neural pathway for sound signals causes sensorineural hearing loss.

There are mainly two types of hearing devices. Bone conduction hearing devices help in hearing through the direct transfer of the vibrations to the cochlea bypassing the outer and middle ear, which impedes the sound conduction and improves hearing. Whereas the implantable middle ear hearing devices stimulate the ossicles, bypassing the external ear or auditory canal altogether. However, background noise is also being amplified with sound, which makes it difficult to differentiate noise from sound. Therefore, it becomes a challenge in speech understanding for hearing aid users.

Epidemiology of Hearing loss

Hearing loss is a persistent problem that has been faced by many individuals around the globe. Unfortunately, this is regarded as fallible in most cases even without other serious complications. Nevertheless, the World Health Organization (WHO) estimated there are more than 2.5 billion people around the world that have some degree of hearing loss, among which more than 700 million people require some degree of hearing rehabilitation (WHO, 2022). It is also estimated that more than 1 billion young adults are at risk of avoidable hearing loss or permanent hearing loss, which is a significant concern (WHO, 2022).

While hearing aids work better in environments with ambient noises, the functional efficiency of hearing aids significantly decreases in noisy environments. According to Rönnberget et al. (2019), hearing aids typically amplify all the sound waves including background noises, which interferes with the speech processing and cognitive abilities for hearing. The inability to differentiate between noise and sound from hearing aids cause a critical impact in cognitive abilities and speech processing under challenging or noisy conditions for hearing aid users. While there are several methods and signal processing algorithms used in the hearing aids, the minimal strain of listening still exists, particularly in noisy environments.

There are various types of signal processing methods used to enhance the intelligibility of voice signals, including fast acting and slow acting. That is aimed at reducing noise development or augmentation of noisy environments. Rallapalli et al. (2020) discussed the use of noise reduction technologies to isolate the target speech from the background noises with an input separation algorithm.

In addition, working memory and cognition also help in speech processing. Heald & Nusbaum (2014) opined that speech processing is a method, in which the acoustic signals from the speech perceptions are transformed to represent different patterns, that help the user to determine the structure of the linguistics or the speech itself. It is propagated by the cognition and individual awareness abilities, which develops representations in the mind to adapt the knowledge of the culture and patterns. It also results in development of contextual information, which is beneficial for understanding of the meaning and information of the speech itself. The differentiating idea is in the isolation of speech from background noises that can be helped by the cognitive ability of the hearing aid users to perceive such differences and context of the speech.

Digital Signal Processing (DSP) helps in the modification of sounds that enter the ear and analyses it to help better speech recognition. It helps in the process of customization of the digital messages that are received by the hearing aids and amplifies specific sections such as speech without background noises. However, as stated by Roque et al. (2019), the cognitive abilities of the individuals using the hearing aids also has impacts on the speech processing due to different factors, such as working memory, inhibitory control and processing speed. These hearing aid users' characteristics of using the hearing aids cannot be simply quantified and requires further investigations for better understanding of the auditory signals.

The hearing aid users' engagement of the cognitive abilities can limit its use in other areas and have negative impacts on functional capabilities. Hence, there is a need for more cognitive resources for processing of speech, and hence improve understanding the context of spoken words. While hearing aids amplify sounds, an individual's cognition can be limited and may require constant processing of sound signals to understand concurrent active engagement with sound, especially in loud or noisy environments. The Ease of Language Understanding (ELU) model suggests that

the cognitive abilities of individuals are more actively engaged in circumstances when sound is fragmented or not audible clearly, which is because conscious memory engages to make sense of sounds (Kronenberger, 2019). In addition, contextual meaning, non-verbal cues and other factors that are associated with the speech processing also require constant attention. The hearing aids are unable to differentiate the spoken words from background noises, thus amplifying all input signals into the ear. Unfortunately, it is therefore responsible for creating confusion and challenges for hearing aid users to decode the speech, with the help of their cognitive abilities. As a result, the use of innovative, sophisticated mechanisms and algorithms are needed to mitigate such issues, which is because the environment of sound source cannot be predicted and modelled ideally. In such instances, the capabilities of hearing aids are very limited to the amplification of intelligible sounds for the users. Hence, speech processing is hinged on the ability of the hearing aid users' cognitive abilities, which requires excessive dependency on the working memory capabilities.

In addition, the standardised speech recognition tests are contingent on the use of repeated words for accuracy determination. However, the consideration of other factors, such as non-verbal cues, context or gestures cannot be perceived by hearing aids. This creates a gap in the speech processing of hearing aid users. And, in turn, it has a negative impact on the intelligibility of speech itself. As stated by Roque et al. (2019), the limitation to the working memories or cognition reduces the performance of speech processing or recognition, because the ability of the hearing aid users to fill in the gaps is significantly reduced. Additionally, the speed of processing information also has a direct negative effect on the speech processing for the individuals, which is determined by the cognition of hearing aid users. The users also face difficulty to simultaneously ignore the irrelevant sound stimulus present in the incoming sound signal, known as inhibitory control. This problem is also compounded by the use of hearing aids, as it amplifies all sound signals irrespective of its relevance to the listener. As a result, a relationship between cognition and speech processing is needed to establish hearing aid users' rehabilitation and development in the future.

RATIONALE

The hearing aid users face difficulty in hearing due to which the hearing aids enhance all sound levels while some sounds are not beneficial for speech understanding. However, less concern has been paid to the differentiation of background noises, which is also amplified by the hearing aids. This causes difficulty in hearing of the actual words as well as making out the context or meaning of the spoken words or sentences themselves. While amplification is beneficial for hearing, it is much more important for intelligibility and contextual understanding of the spoken words as well as being able to differentiate the ambient noises from the words. It enhances the effectiveness of using cognition for greater speech comprehension by hearing aid users. It would practice to integrate algorithms and strategies that reduces noises and enhances the intelligibility of hearing.

OBJECTIVES

The primary purpose of hearing aids is to help enhance the level of stimulation of sound signals in speech comprehension. Yet, it requires a considerable level of cognitive abilities to better understand the context and meaning of the spoken words which is used in differentiating background noise from useful spoken words. The objectives of this thesis are as follows:

- To explore the role of cognition in speech processing for hearing aid users
- To understand the impacts of unfamiliar signal processing methods to improve hearing for hearing aid users

METHODS

Research Philosophy

Mason et al. (2022) stated that the research philosophy is the embodiment of the processing, in which the data about the research topic would be analysed, gathered and utilized. In this research, the interpretivism research philosophy was adopted in order to understand the relationship between cognition and speech processing.

Justification: The impact on speech processing is dependent upon hearing aid users' cognitive abilities and working memory capacities, which vary vastly between users. Emotional characteristics and individual capabilities determine the contextual understanding of a speech, as well as utilization of amplification of sounds that include background noises and cannot be filtered by hearing aids. Therefore, the relationship between cognition and speech processing using an unfamiliar signal processing method in established hearing aid users can only be investigated with the help of interpretivism research philosophy, in which the integration of human mind into the exploration and investigation is required to understand all possible consequences.

Research Approach

In this research, an inductive research approach was used as it explored in the formation of links between the speech processing and cognition for hearing aid users.

Justification: The basic tenets of the development of relationship between cognition and speech processing were to enable understanding of the mechanisms, which are involved in the hearing aid, and understand the problems faced by hearing aid users for speech processing. While the processing of the speech is made difficult due to the amplification of all noises, it can only be understood with individual cognitive abilities. On the other hand, the primary idea is to induct existing literature on the topic to form a relationship between them. Hence, the inductive research approach was used to form new themes and theories for the development of the relationship.

Research Design

A descriptive method of research design was adopted in this research to showcase the relationship between speech processing and the cognitive abilities of the hearing aid users, with the use of qualitative information that already existed in literature.

Justification: It is critical to understand the implications of such mechanisms and the role of cognitive abilities of the hearing aid users to develop a relationship between the two. The relationship of causality is subjective in nature and therefore the utilization of descriptive research design was the most appropriate research design.

Data Collection Methods

In this research, a qualitative data collection method was utilized to collect information from various secondary sources such as Google Scholar, PubMed and others.

Search Strategy

The search for the relevant article and sources of qualitative information was done through the search of keywords, such as speech recognition, hearing aid and speech processing. A total of 226,000 eligible article are identified, while duplicated, record exceed 10 years of publication and non-English records are removed with automatic tools. The remaining records (n = 301) are screened by reading the title, articles with irrelevant topic are excluded. Among the 89 articles with a relevant title only 58 are retrievable. Then the abstract of the remaining articles are studied thoroughly and 48 articles are further excluded. The remaining 10 articles are included in this study.

Inclusion Criteria

The inclusion criteria for the articles were to provide relevant information about the speech processing and cognition for established hearing aid users. The researcher also considered the peer review of authenticity in order to include articles that are published in English only.

Exclusion Criteria

If the source of the article or information being provided was not credible, it was excluded from the study.

Data Analysis Methods

For qualitative data, a thematic analysis was utilized for this research in order to find the most pertinent concurrent themes and trends within the information.

Justification: The speech processing and cognitive ability are elements that cannot be sufficiently described and explained using numerical methods. Due to the subjective nature of the research topic and the collection of qualitative data from secondary sources, the thematic analysis of the information was found to be the most appropriate, which enabled the researcher to formulate conclusions of their own. Hence, a thematic analysis method was used.

Ethical Considerations

The primary ethical consideration for the researcher on this study was the purported utilization of different sources to access published papers and articles. Ethical considerations are critical for dependability and credibility of the conclusions that have been drawn by the researcher based on the works of another (Arifin, 2018). Hence, the researcher has acknowledged all the sources of information that has been utilized for this study, and wherever possible gained permission from the authors and publishers in order to include them for the purpose of this study.

Another dimension of ethical consideration is the protection of data and information that has been collected, which the researcher has protected the collected information with a secured password. This limited accessibility by others. Besides, the researcher has made sure the articles and papers collected for the study were safely disposed to prevent any unauthorized and illegal utilization of the resources.

Limitations

The limited source of sources in the field of hearing aid makes this study restricted to having only a small sample size and possible narrow perspective towards the analysis. Also, hearing aid is a rapidly developing technology. The wireless microphone or accessory technologies of hearing aids is not yet considered in the papers in the study. Although some wireless technology of new hearing aids is

helpful to users, this paper chooses to focus on available resources to gain an understanding of long-established hearing aid technology.

RESULTS

After careful consideration and examination of the various sources of information that were available, ten most relevant papers were included in this study. The critical analysis of the secondary sources has been summarized in Annexe.

Dryden et al. (2017) opined that there is a significant impact of cognitive measures on speech processing of speech perceptions among hearing aid users. The confluence of various factors, such as attention, alerting, orienting and other, are responsible for taking up the engagement of individuals to filter out background noises and makes it difficult for hearing aid users to understand the targeted speech.

The role of inhibitory control is also essential in order to understand the interference from the background noise which requires continuous maintenance of focus on the desired target of speech by hearing aid users. Dryden et al. (2017) also stated that poor inhibitory control results in the increase of susceptibility to background noises and makes it difficult for hearing aid users to concentrate on speech. Kronenberger (2019), on the other hand, found that there is a correlation between speech and language skills from users with different levels of executive functioning skills. It is necessary to understand that improvements in executive functioning skills help in better development of speech processing capabilities. This allows hearing aid users to better utilize their cognitive resources for speech processing. It ultimately improves hearing while background noises are not inherently reduced, due to the listener's focus on speech itself.

It is also necessary to consider the effect of age and neural encoding, which helps to understand the cognitive abilities of hearing aid users in speech perception. Roque et al. (2019) stated that the ability of hearing aid users to differentiate between similar sounding words, such as WHEAT and WEED is significantly improved with the induction of temporal speech cues. The induction of temporal speech cues helps in understanding the context, while nonverbal cues are integrated for a better contextual understanding of the speech itself. This results in improved speech processing. The study also suggests that perceptual crossover point is at 50% when the linear regression showed a 20% to 80% increase in the identification of the word WHEAT in hearing aid users. The most rudimentary relationship that can be developed is due to the focus of targeting specific speech rather than background noises, hence the increase in perception and speech processing abilities.

Rönnberg et al. (2019) in the study found that the ease of language understanding is greatly influenced by the contextual meaning associated with spoken words. The inferential meaning of sentences and the cognitive ability of hearing aid users to perceive nonverbal cues have positive impacts on language processing. The positive relationship of utilizing working memory capacity (WMC) for focusing and contextual utilization improve the hearing experience. Thus, the use of cognition is critical for the contextualization of speech processing. The proper use of cognitive abilities further improves hearing aid users' speech processing. In addition, the study suggested that utilization of priming methodologies and making inference improved the Ease of Language Understanding (ELU) functions overall. It is necessary to understand the extent of cognitive abilities that must be utilized by hearing aid users to understand its relationship under variable conditions, which expressly imitates real scenarios.

Souza et al. (2019) in their study found that apart from the effect of age, hearing loss and working

memory capacity of hearing aid users, the modification of sound signals also has relationships with their speech processing abilities. It is noted that the different amounts of modification on sound signals vary similarly with the speech processing capabilities of hearing aid users. The study also suggested that working memory capacity is a significant determinant of the cognitive abilities of hearing aid users, and it is necessary to have it integrated within the process of understanding speech processing, because the variability of modified sound signals can be better interpreted with the help of increased working memory capacity. The notional utilization of different hearing aid fittings has positive impacts on the cognitive abilities of individuals to process speech. Noise reduction alleviated noise's detrimental effects on memory in hearing aid users with adequate working memory capacity. The noise reduction impact was most noticeable in the recent positions. It is suggested that the underlying mechanism may be connected to the facilitation of targeted word isolation from background noises when background noise is reduced. This can enable quicker and more accurate word recognition, as well as improved word encoding in working memory.

Nuesse et al. (2018) indicated that the cognitive abilities of individuals change with age. There is a positive relationship between the cognitive functioning and the brain volume with the degree of hearing loss. The study also suggests that speech recognition can be negatively affected, not only due to the peripheral auditory deficiencies but also due to the reduction of cognitive abilities which are associated with age. Even if the loss of hearing and cognitive decline is not accounted for in young adults, it is necessary to understand that the acclimatization of hearing aids have compensated for the hearing loss, the audiometric hearing loss is responsible for negative effects on the cognitive ability for speech recognition and processing. It is also necessary to understand that the pure-tone thresholds which are utilized for description of hearing loss, have different central processes of hearing involved. In this regard, Heald & Nusbaum (2014) opined that the plasticity in speech processing for the different models utilizes active cognitive processes for speech perception. The cognitive abilities of hearing aid users provide contextual understanding of repeated tasks and words, which are heard by the hearing aid users to perceive through the noticeable differences in the nonverbal cues and gestures that may be utilized by the speaker.

However, the difficulty is in the case of the unfamiliar signal processing method in which hearing aid users are unable to process speech in accordance with the speed of the speaker. Also, the interference caused by background noises and the users' lack of cognitive resources for focusing and attention, have all made it more challenging for hearing aid users. Habicht et al. (2018) stated that there are no noticeable differences in the elderly novice and experienced users of hearing aids at the beginning of using hearing aids, which is due to lack of auditory acclimatization. The sentence in noise processing times and the speech evoked potentials are lost as latency in the processing of speech is noticeable for first time users. Despite this, it must also be stated that no changes in the processing times for experienced users are exhibited even with the use of HA fittings. Though the novice elderly users have shown 30% improvement in auditory acclimatization and sentence noise processing times after 24 weeks. The primary noticeable difference is due to the cognitive ability of hearing aid users to process contextual information which requires considerable cognitive focus to be consumed. The novice hearing aid users found it difficult to retain longer periods of attention to individually focus on speech while disregarding the background noises.

The study conducted by Zhou et al. (2018) stated that hearing aid users with cochlear implants

showcase increasing cross modal activity or cognition. It means that the poor understanding of auditory speech of non-cochlear implant users is resulted by the increasing cross-modal activity. The intelligibility of speech processing which utilizes extensive cognitive functions and capabilities of the hearing aid users has a correlation with speech processing capabilities. This has also been corroborated by Kavalekalam et al. (2018), who discussed the use of Kalman filters in order to test the Short-Term Predictor (STPs) for binaural hearing aid users. There is a noticeable increase in speech intelligibility due to the utilization of the algorithm that significantly reduces the background noise by actively utilizing methodologies of reducing background noises. As a result, it increased the focus on speech itself. Consequently, it means a lesser number of cognitive functions are engaged through this process, hence the ability of hearing aid users to process speech becomes significantly better.

DISCUSSION

It is clearly understood that comprehending language information and recalling tasks are much more difficult when the backdrop contains background noises. The irrelevance of the speech information as well as the additional cognitive attention, which are required to be presented by the individuals utilizing hearing aids, causes segregation of the auditory stream with their cognitive intuitions. As stated by May et al. (2018), the engagement of cognitive functions significantly reduces the attention span. It is explained that the computational means and visual attention restricts the contextual understanding of the meaning of spoken words, hence minimal cognitive resources are available for recall tasks. As a result, the functioning of hearing aid users utilizing cognitive abilities to process speech becomes diminished. It becomes necessary for hearing aid users to utilize all their cognitive resources to understand and focus on the spoken words for better speech processing.

In addition, the intelligibility of sound is also negatively influenced by the presence of background noises. According to Gantz et al. (2018), background noise is making it difficult for hearing users, as they need to distinguish between the speech and noise coming with it. Unfortunately, hearing aids are responsible for amplification of all sounds, which poses a greater threat to hearing aid users for speech processing. The postulation of the auditory stream segregation is not possible. It is because the amplification of all input sound in its entirety is made by hearing aids, where all the disturbances and noises are enlarged for hearing aid users regardless. The analysis of these studies also indicated that the exploration of not only utilizing repeated words but unfamiliar signal processing methods should be established as part of recruitment requirements. According to Moore et al. (2018), it is the responsibility of the hearing aids to filter ambient noises from speech, since the predictability of the environment may consist of background noises. Once the hearing aid filters ambient noises from speech, it helps in the aggregation of noises and speech, hence focus of the attention by hearing aid users can be maintained. Utilization of algorithms that can differentiate between unfamiliar signals and speech, which may also be utilized in order to understand the implications of cognition and speech processing among hearing aid users.

Noise reduction will benefit hearing aid users in multiple areas: increasing the memory of speech and working memory capacity. Consequently, the allocation of cognitive functions for better speech is justified from ambient noise reduction. Due to the overextending engagement of cognition to filter out background noises and concurrently concentrate on speech, the focus and attention of hearing aid users are eventually strained. Even in familiar environments, the amplification of ambient noises is

responsible for reducing working memory capacity and contextual meaning of words, else the meaning of the sentences is lost to the listener, which further impedes speech processing abilities. In an unfamiliar environment, the stimulus overwhelmed the auditory nerves of hearing aid users, hence their cognition ability failed to effectively filter out any unnecessary sound. It is critically important to understand that the serial position curve has a substantial impact of reduced noise. The current findings do not imply that the reduction of background noise has an influence on a noise masker devoid of linguistic data.

On the other hand, background noise removal is most successful when ambient noise has a significant masking effect and segregation, or streaming is facilitated not just by auditory differences but also the existence of unwanted language information. Shehorn et al. (2018) stated that the active utilization of hearing resources does not conform with the representatives of everyday communication settings, which rarely has repetition of words or sentences multiple times for hearing aid users to become acclimatized. Therefore, the role of the cognitive abilities of individuals for speech processing becomes much more important in the unfamiliar signal processing situations. While the utilization of cognitive functions helps in speech recognition, it does relate to the speech processing capabilities of individuals utilizing cognitive functions. The ability of hearing aid users to utilize their cognition and identify contextual relevance of spoken words, in order to better understand the meaning and perform speech processing is inherent in nature. Hence, it is believed that there is a positive relationship between the cognition and speech processing using an unfamiliar signal processing method in established hearing aid users. This is because the interdependency between cognitive abilities to focus and attentively listen to speech, while filtering out background noises is a herculean task. The compounding effect of sound amplification makes the cognitive function much more challenging for hearing aid users, even in a familiar environment. The amplification process that are performed by hearing aids is certainly responsible for enhancing the amplitude of the input sound, rather than filtering background noises. It is necessary to understand that speech recognition and speech processing should focus on the analysis and active utilization of algorithms, which filters out background noises in order to free up cognitive resources, and therefore improves speech processing.

CONCLUSION

It is concluded from the above discussions that cognition ability presents a strong relationship with the attention and focus that are being offered by individuals utilizing or using hearing aids. Different environments and circumstances require constant acclimatization and coordinated functions of the individuals to be engaged, in order to better understand spoken words. It is the active responsibility of hearing aid users to filter out background noises, even when the input sound is significantly amplified by hearing aids, and the sole attention or focus of the individuals is on speech itself. However, speech processing utilizes the active cognitive capacity of individuals, such as utilization of context and nonverbal cues in order to understand the meaning of sentences. It becomes impossible or at least challenging for the established hearing aid users to continuously focus on speech without consideration of background noise, body language, attitudes, non-verbal cues and other factors. It is also responsible for a reduction in the contextual understanding of the meaning of sentences, which impairs speech processing abilities of the established hearing aid users in unfamiliar signal processing methods.

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postlingually deaf adult cochlear implant users, as revealed by functional near-infrared spectroscopy. Trends in hearing, 22, 2331216518786850. DOI: https://doi.org/10.1177/2331216518786850

ANNEXE. *Summary of the sources*

Sl. No.	Author	Title	Methods	Results
1.	Kronenberger (2019)	Executive Functioning and Language Development in Children with Cochlear Implants	N/A	It was found that the speech-language skills are interrelated with Executive Functioning (EF) skills, EF helps in better development of speech processing capabilities.
2.	Roque et al. (2019)	Effects of Age, Cognition, and Neural Encoding on the Perception of Temporal Speech Cues	YNH, 30 participants, ONH 30 participants, contrasting word pairs such as WHEAT and WEED	Perceptual crossover points of 50%, linear regression showed 20-80% identification of WHEAT
3.	Rönnberg, Holmer & Rudner (2019)	Cognitive Hearing Science and Ease of Language Understanding	Literature review was conducted	Contextual use and focus on WMC helps in hearing status, inference making and priming to improve ELU functions.
4.	Souza et al. (2019)	Understanding Variability in Individual Response to Hearing Aid Signal Processing in Wearable Hearing Aids	Older adults between 54-90 years, sensorineural hearing loss, two hearing aid fittings	Different amounts of modification of the signals are noted, effect of age, degree of hearing loss, working memory capacity is also noted.
5.	Nuesse et al. (2018)	Exploring the Link Between Cognitive Abilities and Speech Recognition in the Elderly Under Different Listening Conditions	46 elderly participants, German native language, visual acuity of 0.63,	Difference in SRTs, in dips the participants showed lower or better SRTs, no significant difference was noted in real conversation and speech like masker.

6.	Heald & Nusbaum (2014)	Speech Perception as an Active Cognitive Process	Literature review conducted	There is some degree of plasticity in speech processing in different models.
7.	Dryden et al. (2017)	The Association Between Cognitive Performance and Speech-in-Noise Perception for Adult Listeners: A Systematic Literature Review and Meta-Analysis	253 articles assessed for literature review, SiN measures, masker type	Results suggest that there is association between the cognition and speech perception through r≈.3,
8.	Habicht, Finke & Neher (2018)	Auditory Acclimatization to Bilateral Hearing Aids: Effects on Sentence-In-Noise Processing Times and Speech-Evoked Potentials	Elderly novice and experienced users, HA fittings for 24 weeks	No changes in the processing times for the experienced users, longer time taken by novice users initially, approximately 30% improvement in novice participants after 24 weeks.
9.	Zhou et al. (2018)	Cortical Speech Processing in Post-lingually Deaf Adult Cochlear Implant Users, As Revealed by Functional Near-Infrared Spectroscopy	2 deaf CI users and 19 NH listeners, native English speakers	Increase in cross-modal activity or cognition leads to poor understanding of auditory speech.
10.	Kavalekalam et al. (2018)	Model-Based Speech Enhancement for Intelligibility Improvement in Binaural Hearing Aids	Use of Kalman filter, short term predictor (STP) testing parameters	Proposed algorithm shows 15% improvement in intelligibility.