Effects of Sensorineural Hearing Loss on Auditory Processing and Working Memory in Younger Adults

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

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June, 2026

Dedicated to – My Grandmother

CERTIFICATE

This is to certify that this dissertation entitled **"Effects of Sensorineural Hearing loss on Auditory processing and working memory in younger adults"**is a bona fide work submitted as part of the fulfilment of the degree of Master of Science (Audiology) of the student with Registration Number **P01II24S023001**. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Effects of Sensorineural Hearing Loss on Auditory processing and Working Memory in Younger Adults"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled "Effects of Sensorineural Hearing loss on Auditory processing and Working Memory in Younger Adults" is the result of my own study under the guidance of Dr. Prawin Kumar, Associate Professor of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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ABSTRACT

Sensorineural hearing loss (SNHL) is among the most prevalent sensory conditions globally, affecting millions of individuals across all age groups and carrying implications that extend well beyond the peripheral auditory system. While the audiological consequences of SNHL, including elevated pure-tone thresholds, reduced frequency resolution, and diminished speech intelligibility, are well characterised, the broader impact on central auditory processing and higher-order cognitive functions such as working memory remains an area of active investigation, particularly in younger adult populations.

The present study, therefore, aimed to investigate the auditory processing and working memory abilities in individuals with sensorineural hearing loss and compare them with those of individuals with normal hearing. A total of 40 (20 -Normal hearing, 20 -sensorineural hearing loss) Kannada-speaking younger (18-40 years old) adults were recruited in the study. Auditory processing was evaluated across three domains using the Gap Detection Threshold test (Temporal resolution), Pitch Pattern Sequence Test (Temporal ordering ability), Kannada version of the Speech Perception in Noise test (Monaural low-redundancy speech perception). Working memory was assessed using the Digit Forward Span (FSP) and Digit Backward Span (BSP) subtests, which measured phonological storage capacity and executive manipulation ability, respectively.

A Shapiro-Wilk test of normality confirmed that data across all measures were not normally distributed, and therefore non-parametric statistical procedures (Mann-Whitney U Test) were employed. With respect to auditory processing, the SNHL group demonstrated markedly elevated gap detection thresholds, poorer PPST scores, and lower (poorer) SPIN-K scores compared to the NH group. For the working memory, the digit forward span and backward span showed significantly reduced performance in the SNHL group relative to the *normal hearing group. The above finding suggest that executive manipulation of information in working memory was disproportionately affected relative to simple phonological storage. Within the SNHL group, Spearman correlation analysis revealed a consistent and selective pattern of associations. Both forward span and backward span were significantly and positively correlated with PPST scores, indicating that individuals with better temporal ordering ability within the SNHL group also demonstrated greater working memory capacity. Overall study showed reduced performance in auditory processing and working memory abilities among SNHL compared to normal hearing individuals as well as positive interaction between two measures in the clinical population.*

Keywords: *sensorineural hearing loss, auditory processing, working memory, gap detection threshold, pitch pattern sequence test, speech perception in noise, digit span, temporal processing, effortful listening, cognitive load*

CHAPTER 1
INTRODUCTION

The human ear acts as a sensory organ for the detection of auditory signals. It transmits acoustic energy from the outer ear (which consists of the pinna and ear canal) through the middle ear (consisting of the auditory ossicles) to the inner ear (cochlea, responsible for sound transduction). The cochlea converts this energy into neural signals and transmits them to the cochlear nerve, which finally reaches the auditory cortex via the brainstem (Rahman et al., 2020). Neurons along the central auditory pathway and brainstem maintain precise spike timing (Oertel, 1999), which is important for the detection of acoustic features that change in millisecond timescales.

According to the American Speech and Hearing Association (1996), auditory processing disorder (APD) is defined as a deficit in one or more of the following auditory processes: temporal processing, including temporal integration, temporal ordering, and temporal masking; auditory discrimination and auditory processing in adverse listening conditions; and binaural auditory processing, including sound localization and lateralization, and dichotic listening.

Sensorineural hearing loss (SNHL) produces significant changes in the human cortex and may permanently diminish auditory perceptual skills. Several investigators have argued that this long-term sensory deprivation may produce irreversible changes in the anatomical and functional integrity of the central auditory structures (Francis & Mani, 2000; Frisina, 2001). Damage may happen in terms of reduced hearing sensitivity, auditory processing, such as gap detection and speech discrimination (Snell & Frisina, 2000). Studies emphasized that these distortions disrupt frequency resolution, temporal fine structure, and binaural integration, making speech understanding difficult, particularly in noisy environments

(Moore,2021; Li, Guo, Yang, Feng, and Yin, 2017). Sensorineural hearing loss is often simplified as a loss of sensitivity to soft sounds. However, SNHL causes a cascade of physiological changes that degrade the quality of neural signals reaching the brain. Contemporary research emphasizes that damage to the hair cells or the auditory nerve does more than just attenuate the signal; it distorts the very "neural code" sent to the brain (Sousa et al., 2022).

Research in neurosciences has provided evidence that auditory deprivation induces plasticity changes in the auditory cortex, altering excitatory–inhibitory responses and neural coding efficiency (Kotak, Fujisawa, Lee, Karthikeyan, Aoki, and Sanes, 2005). It has been observed that in animal models, SNHL increases cortical excitability while reducing inhibitory responses, suggesting compensatory but maladaptive changes in auditory processing (Kotak et al., 2005). Human studies have similarly reported that individuals with SNHL exhibit poorer performance on auditory processing tasks such as speech-in-noise and dichotic listening, both of which are strongly associated with working memory and executive control (Pichora-Fuller et al., 2016; Chinnaraj et al., 2022).

Studies show that auditory deprivation during sensitive periods can impair language acquisition, memory encoding, and attention, with long-term effects on cortical function (Sharma et al., 2002). The type and severity of hearing loss may differentially impact cognition. SNHL introduces permanent cochlear distortions that degrade the frequency resolution, temporal fine structure, and binaural integration (Moore, 2021). John et al. (2012) demonstrated that both advancing age and SNHL independently reduce performance on the Gaps-in-Noise (GIN) test, with the poorest thresholds observed in older adults with SNHL. Similarly, Li et al. (2017) reported that individuals with high-frequency SNHL show a deficit in gap detection in the low-frequency region, indicating temporal deficits. A study done by de Andrade et al. (2023) reported that adults aged 16–59 years with SNHL performed significantly worse than normal-hearing peers on Pitch Pattern Sequencing (PPS) and Duration Pattern Sequencing (DPS) tasks, reflecting deficits in auditory pattern recognition and sequencing.

Several studies have shown that the problem worsens with ageing. With ageing, studies reported a decline in cognition along with hearing loss. In older adults, auditory processing deficits lead to poorer working memory, attention, and executive functioning (Wayne & Johnsrude, 2015). Chinnaraj and colleagues demonstrated that older adults aged 50–70 years with SNHL had significantly poorer auditory processing and working memory compared to typically developing individuals (Chinnaraj et al., 2022).

Need for the study

A review report from the Lancet Commission by Livingston et al. in 2020 shows that hearing loss not only affects sensory impairments but also creates a significant risk factor for cognitive decline (Livingston et al., 2020). Although Maggu & Sharma (2024) showed that in young adults (18–30 years), basic auditory processing measures (gap detection test, and temporal fine structure) were not strongly related to cognition, suggesting that compensatory mechanisms may operate at younger ages, Chinnaraj, Jain, Parameshwara, and Trinesh (2022) found that auditory processing skills such as speech-in-noise, dichotic listening, and gap detection were significantly poorer in older adults aged 50–70 years with SNHL, compared to both age-matched normal-hearing peers and young adults. These findings highlight that both ageing and sensorineural hearing loss contribute to degraded central auditory performance. A similar result was presented by Wayne and Johnsrude in 2015 concerning working memory and executive function.

Neurophysiological evidence shows that SNHL increases excitability and reduces inhibition in the auditory cortex of adolescent and young adult animal models (equivalent to human teens and early 20s), suggesting that cortical reorganization may place a greater load on cognitive resources during listening (Kotak et al., 2005).

Despite this evidence, adults aged between 18 and 40 years remain understudied. In this age range, communication demands are high. Detecting early signs of auditory–cognitive interaction in this population may therefore offer opportunities for timely intervention, reducing long-term cognitive risk. Moreover, by directly comparing normal hearing sensitivity and SNHL across younger adult and adult age groups, it is possible to distinguish, measure, and identify an age range where the auditory processing and auditory memory start declining the most markedly. Thus, there is a need to study auditory processing skills and cognition among adults with sensorineural hearing loss.

Aim of the study

The present study aims to investigate the auditory processing and working memory abilities in individuals with sensorineural hearing loss and compare them with those of individuals with normal hearing.

Objective of the study

1. To assess the auditory processing abilities of individuals with sensorineural hearing loss and compare them with those of individuals with normal hearing.
2. To assess the working memory of individuals with sensorineural hearing loss and compare it with those of individuals with normal hearing.
3. To assess the relationship between auditory processing abilities and working memory in individuals with sensorineural hearing loss.

Hypotheses of the study

1. There is no difference between individuals with SNHL and normal hearing in auditory processing abilities.
2. There is no difference between individuals with SNHL and normal hearing in working memory.
3. There is no relationship between auditory processing abilities and working memory in individuals with SNHL.

CHAPTER 2

REVIEW OF LITERATURE

Auditory processing refers to the efficiency and effectiveness with which the central nervous system (CNS) uses auditory information. The auditory processing disorders are seen with and without other co-morbid conditions. Study by Maggu and Sharma (2024) reported that in young adults with normal hearing, basic auditory processing measures (gap detection, temporal fine structure) were not strongly related to cognition, suggesting that compensatory mechanisms may operate at younger ages. In another study by Chinnaraj and colleagues reported that auditory processing skills such as speech-in-noise, dichotic listening, and gap detection were significantly poorer in older adults with SNHL, compared to both age-matched normal-hearing peers and young adults (Chinnaraj et al., 2022). These findings highlight that both ageing and sensorineural hearing loss contribute to degraded central auditory performance. A similar result was presented by Wayne and Johnsrude (2015) concerning working memory and executive function.

2.1Auditory Processing and Age-Related Changes

2.1.1Temporal processing

A fundamental component of auditory processing is the brain's ability to handle the timing of acoustic signals. Precise neural timing in the brainstem is essential for encoding sound features (Oertel, 1999). Temporal processing involves the ability to detect rapid changes in sound over time, such as the short silences (gaps) between phonemes (Temporal Resolution), and the ability to recognize and sequence the duration or pitch of acoustic events (Temporal Patterning/Ordering), which is essential for perceiving the prosody and rhythm of speech.

The Gaps-In-Noise (GIN) test is the primary tool used to quantify temporal resolution. Strouse et al. (1998) compared 12 young adults (mean age 26.3 years, SD 3.6) and 12 elderly adults (mean age 71.1 years, SD 4.2), and all these participants had normal hearing thresholds (≤20 dB HL from 250–6000 Hz). The results indicated gap detection thresholds averaged about 3.5 ms (SD 0.8) in young listeners but were significantly higher in elderly listeners at 6.7 ms (SD 1.2), showing poorer monaural temporal resolution. In a similar line, Kumar and Sangamanatha studied four different psychophysical tasks in 176 participants aged 20–85 years. They divided those participants into six different age ranges to find out age-specific responses more precisely. The findings of the study showed gap detection thresholds increased from about 3 ms in young adults (20–30 years) to over 23 ms in those above 70 years, indicating that individuals in their 20s and 30s performed significantly better on all psychoacoustic measures compared to older groups. They also reported a systematic, age-related decline in temporal processing, which begins after the fourth decade of life (age 40) and accelerates rapidly after age 70 years.

Palmer and Musiek (2014) investigated gap detection thresholds in 11 younger adults (mean age 22 years) and 11 older adults (mean age 64.36 years) with normal hearing using both behavioural and electrophysiological measures (N1–P2 cortical responses), where behavioural gap detection thresholds and electrophysiological gap detection thresholds were highly similar across participants, with a mean difference of only 0.43 ms. The overall mean Behavioural GDT was 5.52 ms, while the mean electrophysiological GDT was 5.09 ms. Importantly, older adults consistently showed poorer temporal resolution. Their Behavioural GDTs and Electrophysiological GDTs were significantly longer than those of younger adults, with medium effect sizes (Cohen's d ≈ 0.5).

Buss et al. (2017)examined how gap detection (the ability to perceive brief silences in noise) develops in children (ages 5.2–15 years, n=40) compared to adults (n=10), focusing on stimulus frequency (500 vs. 5000 Hz) and ramp duration (4 vs. 40 ms) where children consistently showed higher thresholds than adults, but performance improved steadily with age. The results showed that at 5000 Hz, thresholds were about 1.6× lower than at 500 Hz across all ages, and with 4-ms ramps, thresholds were about 1.9× lower than with 40-ms ramps. Whereas adult thresholds averaged 4.6 ms (4-ms ramps) and 7.6 ms (40-ms ramps), while the youngest children (5–6 years) averaged 10.1 ms (4-ms ramps) and 17.5 ms (40-ms ramps).

Chinnaraj et al. (2022) studied 60 participants divided into three groups: 20 young adults with normal hearing (mean age 22.23 ± 2.86 years), 20 older adults with normal hearing (mean age 58.80 ± 6.16 years), and 20 older adults with mild to moderate sensorineural hearing loss (mean age 60.01 ± 6.01 years) to find out the effect of age and hearing loss on auditory processing. Each participant underwent a battery of tests, including speech perception in noise, dichotic consonant–vowel, gap detection threshold (GDT, measured in ms), duration pattern test, and working memory tasks. The results showed that the gap detection thresholds were lower (better) in young adults (mean 2.44 ms), higher (poorer) in older normal-hearing adults (6.33 ms), and poorest in older hearing-impaired adults (18.94 ms), indicating age and hearing loss-related decline in auditory temporal processing.

The Pitch Pattern Sequence Test (PPST) measures the temporal pattern/ordering ability, a task that requires efficient communication between the two cerebral hemispheres via the corpus callosum. Musiek and Chermak (2014) reported that younger populations consistently perform between 88% - 90% of scores in PPST in both ears.

Majak et al. (2015) recruited 76 Polish-speaking adults aged 18–54 years, all with normal hearing and no chronic illnesses. Participants in the study completed three tests i.e. the Duration Pattern Test, Frequency Pattern Test, and Gaps-in-Noise Test, administered monaurally after practice trials to ensure comprehension. The study found normative cut-off scores for DPT (≥55.3% correct) and FPT (≥56.7% correct), with GIN thresholds averaging around 6 ms. Results showed no significant effects of age, gender, or ear side. Strong correlations were observed between the left and right ear. However, studies by Sousa et al. (2022) in older adults reveal a significant drop, with mean scores often falling to 65% - 72%. This decline is attributed to age-related demyelination of white matter tracts in the corpus callosum.

2.1.2 Monaural Low-Redundancy Speech Perception test

Monaural Low-Redundancy Speech Perception involves the ability to recognize speech when the signal is degraded, such as when it is filtered or presented against a background noise. Normal processing uses the brain's internal "redundancy" to fill in missing acoustic cues. The hallmark of age-related auditory decline is the inability to understand speech in noise, which is quantified as SNR Loss.

Schoof et al. (2014) studied 19 younger adults (mean age 23.7 years, SD 2.9) and 19 older adults (mean age 64.1 years, SD 3.3), all with near-normal hearing (≤25 dB HL up to 4 kHz, and at 6 kHz in at least one ear). All the participants underwent a speech perception test in three masker conditions steady-state speech-shaped noise (SS), 10 Hz amplitude-modulated speech-shaped noise (AM), and two-talker babble. Result indicated that older adults had significantly higher SRTs only in the two-talker babble condition, with a mean of −0.3 dB compared to −1.6 dB for younger adults (difference 1.4 dB, $p = 0.008$, Cohen’s d = 0.9). In SS noise, SRTs were −3.8 dB for older and −3.7 dB for younger adults, and in AM noise −6.4 dB versus −6.7 dB, both non-significant.

Murphy et al. (2018) studied 77 adults aged 50–70 years, all native Brazilian Portuguese speakers, with either normal hearing or mild-to-moderate age-related hearing loss. In the Speech-in-Noise Test, participants were presented with sentences at 50 dB SL above their speech recognition threshold while competing background noise was introduced. The mean scores were 88.1% for the right ear and 91.7% for the left ear, showing relatively strong recognition but with noticeable variability across individuals. In another study by Vijayasarathy and Barman (2020) reported that the QuickSIN in young adults typically show an SNR loss of 0 to 2 dB. Whereas older adults with mild-to-moderate SNHL often exhibit an SNR Loss of 7 to 12 dB. This means that the speaker's voice must be significantly louder than the background noise to achieve 50% comprehension.

Stenbäck et al. (2021) studied speech recognition using two materials: Hagerman sentences (low semantic context of 50 words) and Swedish HINT sentences (high semantic context), 250 everyday sentences presented at 70 dB SPL with adaptive noise levels. The study included 48 individuals with normal hearing divided into two groups: 24 younger adults with a mean age of 25.6 years (SD = 5.4) and 24 older adults with a mean age of 60.6 years (SD = 6.9). The findings of the study show Hagerman sentences at 50%-word recognition, mean SNRs ranged from −7.4 dB to −13.5 dB, while older adults required slightly higher SNRs (−6.6 dB to −11.7 dB). For HINT sentences at 50% whole sentence recognition, younger adults achieved −14.7 dB SNR, compared to −13.1 dB for older adults, indicating an age-related decline in low redundancy speech perception. Athreya et al. (2025) studied 17,414 ears from 9,042 patients aged 18–90 years, split into a hearing loss group (9,373 ears, mean HFPTA ≈ 27.7 dB HL) and a normal-hearing group (4,277 ears, mean HFPTA ≈ 6.2 dB HL), analysis shows QuickSIN was more sensitive: performance worsened by 0.12 dB SNR loss per dB HL of hearing loss and 0.05 dB per year of age. Women performed marginally better in noise (0.26 dB lower SNR loss). Whereas in the normal-hearing group, word recognition in quiet remained near the ceiling level but declined slightly with age (−0.02% per year).

2.2 Age-Related Changes in Auditory Working Memory

2.2.1 Working memory

Working memory (WM) is a "mental workspace" used to store and manipulate information. Auditory memory specifically refers to the retention of acoustic information. Both undergo significant structural and functional changes with advancing age. Although early models proposed a storage capacity of approximately 7 ± 2 items (Miller, 1956). Schoof et al. (2014) studied 19 younger adults (mean age 23.7 years, SD 2.9) and 19 older adults (mean age 64.1 years, SD 3.3), with normal hearing and compared their auditory processing abilities (speech in noise, speech in speech bubble) and working memory (reading span). In the reading span test, participants had to recall the final words of sentences while processing their meaning. The study shows younger adults achieve an average span of 32 items (SD ≈ 5), while older adults recalled only 24 items (SD ≈ 4), a significant difference ($p < 0.001$, Cohen's d = 1.5). This decline in capacity was strongly correlated with speech reception thresholds in steady-state and modulated noise, explaining about 32% of the variance ($R^2 = 0.32$).

Contemporary research by Brown (2016) examined working memory in 75 younger adult (mean age of 27.9 years) and 75 older adults (mean age of 73.6 years) and compared their performance using forward and backward recall. Study result suggests that performance is influenced by task complexity and cognitive load. However, in the Backward Digit Span, which requires executive manipulation, the average drops to 4.5–5.5 items, indicating that simple storage (Forward Span) is relatively resilient to ageing, whereas executive manipulation (Backward Span) shows a sharp decline. This indicates a reduction in the "computational power" of the ageing brain, even when short-term storage remains relatively preserved, older adults exhibit significantly poorer performance on tasks requiring manipulation and reordering of information.

Murphy et al. (2018) in working memory study was measured using the backward digit span test with 77 adults aged 50–70 years, with either normal hearing or mild-to-moderate age-related hearing loss found out the average span achieved was 3.8 digits with a standard deviation of 1.1, indicating modest capacity across the sample. Statistical analysis showed that working memory was significantly correlated with performance on the Frequency Pattern Test (r partial = 0.43, $p < 0.001$).

Levi and Heled (2024) found the backward manipulation stage shows more pronounced ageing effects, evidencing an overall modality-specific impact of aging on WM performance. The Listening Span Test measures the capacity to process sentences while remembering specific words. Research utilizing the Ease of Language Understanding (ELU) model shows that as hearing sensitivity decreases by every 10 dB, the cognitive effort required for listening increases, effectively reducing "Cognitive Spare Capacity" by approximately 15-20% (Pichora-Fuller et al., 2016). The FUEL framework describes how auditory processing deficits and memory decline interact. When the auditory signal is degraded (either by age-related cochlear damage or central processing delays), the brain must recruit additional cognitive resources from the prefrontal cortex to "repair" the signal (Pichora-Fuller et al., 2016; Peelle, 2018). Using dual-task paradigms (e.g., listening while performing a tactile task), researchers have found that older adults show a 30-40% greater performance drop on the secondary task compared to younger adults (Peelle, 2018).

Schoof & Rosen (2014) studied working memory ability and tests for temporal processing in 38 monolingual native English speakers divided into two groups: 19 younger adults (19–29 years, mean age 23.7, SD 2.9; 10 males) and 19 older adults (60–72 years, mean age 64.1, SD 3.3; 3 males) and found out older adults working memory averaged 24 words recalled while compared to 32 in younger ($p < 0.001$, d = 1.5), and processing speed averaged 34 substitutions vs. 39 ($p = 0.04$, d = 0.7). The study revealed that working memory ability declines as age increases.

2.3 Effect of SNHL on Auditory Processing

The loss of sensory input leads to structural and functional changes in the auditory nuclei. Specifically, SNHL has been shown to increase excitability in the auditory cortex, as the brain attempts to compensate for reduced input (Kotak et al., 2005). This is not a lack of audibility; it is a "processing loss" resulting from the combined failure of temporal, spectral, and binaural mechanisms (Ozmeral et al., 2016). SNHL disrupts the binaural cues of Interaural Time Differences (ITD) and Interaural Level Differences (ILD), degrading the ability to focus on one source while ignoring a competing source in the other ear. Behavioural studies using spatialized speech tests Fuglsang et al. (2020) show that SNHL listeners do not receive the "spatial release from masking" that NH listeners enjoy; they cannot effectively "tune out" background noise because the brain cannot spatially separate the noise from the target speaker. Sousa et al. (2022) found out in an integrative review that individuals with mild-to-moderate SNHL show significantly reduced performance on auditory processing tests. Even when sounds are amplified to a comfortable level, SNHL listeners often exhibit a "left-ear deficit" or a general inability to integrate competing messages, suggesting that peripheral damage triggers a breakdown in the efficiency of the corpus callosum and central pathways.

2.3.1 Effect of SNHL on temporal processing

Accurate auditory processing relies on precise timing in the brainstem (Oertel, 1999). Deafferentation due to SNHL alters the electrophysiology of the cochlear nucleus, leading to a loss of this temporal "sharpness" (Francis & Manis, 2000). Li et al. (2017) studied 65 participants grouped into three categories based on the cutoff frequency of their hearing loss (1,2 or 4 kHz) and compared their performance with 11 age-matched normal hearing controls. Further groups were subdivided into mild, moderate, and severe groups based on the degree of hearing loss. All the participants went through Gap detection in noise test using low pass filter white noise at 1,2, and 4 kHz with gap ranging from 20ms down to 1ms. The result showed that even people with high frequency SNHL revealed significantly higher gap detection threshold of more than 10 ms compared to the normal hearing group of 4ms.

Sousa et al. (2022) in an integrated review using 13 studies indicated that individuals with SNHL struggle to identify patterns of frequency or duration, which directly correlates with difficulty in perceiving the prosody and emotional nuances of speech. Behavioural studies also demonstrated significantly higher (poorer) gap detection thresholds (GDT) in SNHL compared to normal-hearing (NH) individuals. While an NH listener might detect a gap of 2-5 ms, a person with SNHL may require 10-15 ms. This deficit leads to "temporal smearing," where the boundaries between speech sounds become blurred, making it impossible for individuals to distinguish similar words in a fast-paced conversation.

Andrade et al. (2023) investigated how individuals with mild to moderate sensorineural hearing loss process temporal aspects of sound compared to those with normal hearing. Nineteen right-handed participants aged 16 to 59 years, all with post-lingually acquired bilateral symmetric sensorineural hearing loss, were tested using three behavioural auditory measures. More than half of the subjects demonstrated abnormal performance in temporal ordering tasks, indicating significant difficulty in recognizing sound patterns. In the RGDT, the mean threshold was 14.1 ms, slightly above the normal reference, with 63.2% of individuals performing within normal limits.

2.3.2. Effect of SNHL on frequency selectivity and discrimination

The ear separates a complex sound into its individual frequency components using frequency selectivity (or spectral resolution). In a healthy cochlea, the "active mechanism" of the outer hair cells provides sharp tuning. SNHL typically results in the spectral smearing and broadening of auditory filters requiring much larger frequency shifts to perceive a change in pitch (Ozmeral et al., 2016). This "spectral smearing" makes background noise particularly devastating. Andrade et al. (2023) studied nineteen right-handed participants aged 16 to 59 years, all with post-lingually acquired bilateral symmetric sensorineural hearing loss, finding reports that performance on the Frequency Pattern Test (FPT) was clearly below normal reference values in individuals with sensorineural hearing loss. On average, participants scored 66.3% correct, whereas the expected cut-off for normal performance is 76% or higher. More than half of the subjects showed abnormal results, meaning they struggled to correctly identify sequences of tones that varied in pitch.

2.3.3. Effect of SNHL on monaural low-redundancy speech perception

Test materials used in audiological research are generally categorised by their linguistic complexity, which dictates whether the listener relies on "bottom-up" (sensory) or "top-down" (cognitive/linguistic) processing. Sentences provide varying degrees of linguistic context. High-predictability (HP) sentences (e.g., "The farmer harvested his crop") allow listeners to use semantic "pointer words" to identify key targets (Wilson et al., 2012). Conversely, low-predictability (LP) sentences (e.g., "I want to know about the crop") provide minimal contextual cues, placing a higher demand on the sensory reception of the acoustic signal.

Monosyllabic Words common in tests like the Words-in-Noise (WIN), these allow for a pure assessment of auditory sensitivity in noise without the influence of sentence-level syntax or predictability (Wilson et al., 2012). SNHL severely disrupts the processing of temporal fine structure (TFS) and temporal envelopes, which are critical for localizing sound and understanding speech in noisy environments (Moore, 2021). A hallmark of SNHL is high individual variability in hearing loss characteristics. Even patients with identical pure-tone averages (PTA) can show vastly different SIN scores.

Billings et al. (2023) studied 10 younger normal-hearing adults (mean age 27.1 years, PTA ≈ 6.0 ± 4.4 dB HL), 10 older normal-hearing adults (mean age 67.2 years, PTA ≈ 7.9 ± 4.9 dB HL), and 10 older hearing-impaired adults (mean age 68.8 years, PTA ≈ 32.3 ± 7.7 dB HL) to find out outcome measures of different group upon different speech in noise test : QuickSIN, Words-in-Noise (WIN), Coordinate Response Measure (CRM), and Listening in Spatialized Noise–Sentences (LiSN-S). The finding of the study shows younger normal-hearing participants consistently had the lowest (best) SNR50s, followed by older normal-hearing, then older hearing-impaired. Similar study by Chinnaraj et al. (2022) found adults with normal hearing shows SPIN averaged 18.90 words compared to 11.52 in normal-hearing older adults and only 3.40 in hearing-impaired older adults, indicating a clear effect of hearing loss in case of low redundancy speech perception.

2.4. Effect of SNHL on Working Memory

Akeroyd (2008) summarized 20 published papers since 1989 and suggested that SNHL results in degraded auditory input, which increases cognitive load and places greater demands on working memory for successful speech perception. Several theories suggest that the link between SNHL and cognitive decline is causal. The "Information Degradation" hypothesis posits that the extra effort required to perceive sound exhausts the working memory capacity, which may eventually contribute to long-term cognitive decline (Wayne & Johnsrude, 2015). Behavioural "dual-task" paradigms—where a listener must understand speech while performing a secondary memory task—reveal that SNHL listeners perform significantly worse on the secondary task. This indicates that their "top-down" cognitive resources (attention and working memory) are entirely consumed by the effort of decoding the degraded auditory signal (Zhao et al., 2024;Fuglsang et al., 2020). Over time, this increased cognitive load is hypothesized to contribute to social isolation and potentially accelerate cognitive decline in older adults (Zhao et al., 2024).

Nishida et al. (2024) investigated the effect of background noise and memory load on listening effort in young adults with (mean age 24.1 ± 6.0 years) and without hearing loss (mean age 27.9 ± 4.9 years). The study employed a dual-task paradigm in which participants performed a speech-in-noise (multi-talker babble at signal-to-noise ratios of +5 dB and −5 dB) task concurrently with a memory task. Results indicated that background noise and higher memory load interacted to increase subjective and objective listening effort, implying that working-memory capacity moderates the cognitive impact of SNHL-related listening difficulty.

The Backward Digit Span task is significantly more demanding than the forward span because it requires both storage and active manipulation of the information. Studies have shown that individuals with hearing loss often exhibit reduced scores on backward span tasks compared to NH individuals, even when the digits are audible (Peelle, 2018); (Stenbäck et al., 2021). The necessity of "reversing" the sequence adds a layer of executive processing that is easily disrupted when the auditory signal is degraded. In another study by Chinnaraj and colleagues reported that digit forward span was 5.68 in young adults, 4.40 in older normal-hearing, and 4.15 in older hearing-impaired; whereas digit backward span dropped from 4.03 in young adults to 3.55 in older individuals with normal hearing and 3.00 in older individuals with hearing loss, which indicated the effect of age and hearing loss on the performance of working memory (Chinnaraj et al., 2022).

2.5 Correlation Between the Performance of Working memory and Auditory processing:

Murphy et al. (2018) studied 77 adults aged between 50–70 years to examined auditory processing through three tests: the speech-in-noise test (SNT), dichotic digit test (DDT), and frequency pattern test (FPT), alongside a working memory measure (backward digit span). The result of the study revealed that, in backward digit span, participants averaged 3.8 digits (SD 1.1) & working memory showed a significant correlation ($r = 0.43$, $p < 0.001$), explaining about 17% of the variance. This highlights that temporal sequencing tasks are strongly dependent on cognitive capacity.

Torrente et al. (2022) investigated 116 older adults aged 65 years and above with SNHL and who had never used hearing aids. All the participants went through auditory processing tasks (speech-in-noise, dichotic digits, staggered spondaic words, frequency pattern recognition, gap detection), and a battery of cognitive assessments (attention, memory, language, processing speed, executive function, visuospatial skills). The result of the study revealed average frequency pattern test was 66.3%, below the normal cut-off ≥76%. More than half of participants showed abnormal scores, indicating difficulty in sequencing tonal patterns and the backward digit span averaged 3.8 ± 1.1 digits, and regression analysis showed that working memory explained about 17% of the variance in FPT accuracy (r partial = 0.43, $p < 0.001$).

Overall, the review of literature showed the effect of age and hearing loss on different domains of auditory processing and working memory. The auditory processing abilities explored in the present study include speech in noise, gap detection test and pitch pattern sequence test. The relation of the auditory processing with the working memory showed mixed findings in term of with and without significant relationship between the two measures among adults with normal hearing as well as with hearing loss.

CHAPTER 3

METHOD

The study was aimed to investigate the auditory processing abilities and working memory in individuals with sensorineural hearing loss and compare this with normal hearing individuals. To assess auditory processing abilities such as temporal processing, temporal ordering and sequencing and auditory closure the following method were adopted.

Research Design

Between-group and within group comparison study.

Participants

The study included a minimum total number of 40 adults, out of which 20 adults with sensorineural hearing loss (Clinical group) and 20 adults with normal hearing (Control group) in the age range of 18 to 40 years. All the participants included in the study are the native speakers of Kannada.

Inclusion and Exclusion Criteria for both groups

Control group: Adults having pure tone thresholds within ≤ 25dB HL in both ears mean age of 23.75 years, has been considered as a control group in the study. Along with that, the speech recognition threshold correlating with pure tone thresholds has also been considered as an inclusion criterion for the study. Those individuals having any otological or neurological problems were excluded from the study.

Table 2.1: Demographic data for the control group (Individuals with normal hearing)

SL NO	AGE (Yrs)	PTA RE (dB)	PTA LE (dB)	SRT RE (dB)	SRT LE (dB)	TEST EAR
1	24	7.50	10.00	10	10	RE
2	24	10.00	10.00	15	15	LE
3	23	7.50	5.00	10	10	RE
4	21	7.50	7.50	10	10	LE
5	20	5.00	5.00	10	10	RE
6	22	5.50	5.00	10	10	LE
7	23	5.00	7.50	10	10	RE
8	25	5.00	5.00	10	10	RE
9	28	2.50	5.00	10	10	RE
10	22	2.50	5.00	10	10	RE
11	26	7.50	7.50	10	10	RE
12	25	3.75	5.00	10	10	RE
13	26	5.00	7.50	10	10	RE
14	23	5.00	5.00	10	10	RE
15	22	5.00	7.50	10	15	RE
16	23	7.50	7.50	10	10	LE
17	23	7.50	2.50	15	5	LE
18	25	5.00	5.00	10	10	RE
19	22	5.00	7.50	10	10	LE
20	28	7.50	10.00	10	15	LE

Note: RE: Right Ear; LE: Left Ear; PTA: Pure tone average; SRT: Speech Recognition Threshold

Clinical Group: Adults with sensorineural hearing loss either unilaterally or bilaterally, having pure tone thresholds within ≤ 50 dB HL has been considered as an experimental group for the study. Along with that the speech recognition threshold correlating with pure tone thresholds has also been considered as an inclusion criterion for the same group. Those individuals having any ear discharge, conductive hearing loss, or neurological problems has been excluded from the study.

Table 2.2: Demographic data for the clinical group (Individuals with sensorineural hearing loss)

SL NO	AGE (Yrs)	PTA RE (dB)	PTA LE (dB)	SRT RE (dB)	SRT LE (dB)	TEST EAR
1	22	37.50	41.25	40	40	LE
2	39	50.00	53.75	45	35	LE
3	40	50.00	52.70	35	40	RE
4	29	37.50	55.00	40	70	RE
5	38	28.75	31.25	25	30	LE
6	38	28.75	31.25	25	30	RE
7	18	33.75	90.00	25	-	RE
8	26	10.00	46.00	15	45	LE
9	40	37.50	68.70	30	65	RE
10	24	23.75	50.00	25	45	LE
11	40	50.00	55.00	55	60	RE
12	31	48.75	13.75	50	20	RE

13	40	37.50	31.20	40	35	RE
14	40	37.50	31.20	40	35	LE
15	36	11.25	40.00	10	25	LE
16	36	15.00	47.50	20	45	LE
17	30	10.00	55.00	10	70	LE
18	19	42.50	47.50	45	50	RE
19	19	42.50	47.50	45	50	LE
20	38	12.50	46.25	15	45	LE

Note: RE: Right Ear; LE: Left Ear; PTA: Pure tone average; SRT: Speech Recognition Threshold

Ethical clearance

Ethical approval for bio-behavioural research is given by AIISH institute Review Board (IRB) with Reference number SH/IRB/M.4/AUD.16/2025-26. Before the involvement of participants in both clinical and control groups in the study, a written consent was obtained from each participant. The procedure and purpose of the study were thoroughly explained to them in detail before their participation. Participants had the freedom to withdraw from the study at any moment if they were not willing to be part of the study. Further, guidelines of the ethical committee recommendation as per Venkatesan & Basavraj (2009) were followed.

Instrumentation

For Pure tone audiometry, a calibrated Inventis piano audiometer and TDH-39 headphones, and a B-71 bone vibrator were used to establish air-conduction and bone conduction thresholds. Calibrated GSI-Tympstar (Version 2.0) middle ear analyser was used for tympanometry and acoustic reflexes. An Otodynamics DP ILO-V6 Echoport (version 6.0) was used to measure transient evoked otoacoustic emissions (TEOAEs). A calibrated personal computer installed with necessary optimization and Smriti Shravan software (Kumar & Sandeep, 2013) was used for auditory processing tests and working memory tests.

Test environment

The audiological testing was carried out in a sound-treated audiology setup, compliant with ANSI S3.1 (2013) standards. The audiological assessment was performed in a distraction-free environment for both the groups (Control and clinical group).

Test Procedure:

All the participants went through the following audiological test procedures to confirm the eligibility criteria before the experimental test procedure.

Preliminary evaluations

1. *Structured Case History:* A comprehensive and structured case history interview was conducted to gather detailed information on the participant's ear and hearing status, along with any relevant clinical signs and symptoms. The case history includes the onset of hearing loss, presence of ear pain, discharge ear, or presence of previous ear infection. Additionally, the participant's medical records, including any confirmed diagnoses of neurological disorders, was noted down.

2. *Otoscopic Examination:* All participants underwent an otoscopic examination to assess the condition of the ear canal and tympanic membrane. This examination was done to specifically check for any abnormalities, such as cerumen or isolated dry perforations, ear discharge, or foreign bodies within the ear canal.

3. *Pure tone and speech audiometry:* All the participants underwent pure-tone audiometry and speech audiometry. A modified version of the Hughson and Westlake approach (Carhart &

Jerger, 1959) was used to estimate the air conduction (0.25, 0.5, 1, 2, 4, and 8 kHz) and bone conduction (0.25, 0.5, 1,2, and 4 kHz) thresholds.

4. *Immittance Audiometry:* To assess each participant's middle ear status, a tympanogram at 226 Hz probe-tone and acoustic reflex thresholds (0.5, 1, 2, and 4 kHz) were measured. Participants were asked to be seated comfortably and instructed to remain still and quiet during the testing. Measurements of ear canal volume, static admittance, and tympanometry peak pressure were recorded for all participants.

Experimental test and procedures:

1. *Gap detection tests (GDT):* The GDT test developed by Shivaprakash (2003) was used as it provides a clinically feasible method of assessing temporal resolution. GDT was administered for both groups by seating the participants comfortably in a sound treated room. The test was carried out at an intensity level of 20 dBSL (ref: PTA) targeting the most comfortable level (MCL) of the participants. The test consisted of 3 trial items and 54 test items. Each item consisted of 3 noise bursts of 300 msec in duration and separated by a silence of 750 msec. Out of the 3 noise bursts, 2 were continuous, and 1 was discontinuous, i. e., had a gap. The gap was introduced at the centre (50% of total burst duration of each noise burst). The duration of gap within this noise burst was varied from 20 to 1 msec. The duration of the gap was reduced in 2 msec steps from 20 msec to 11 msec and in 1 msec steps from 11 msec to 1 msec. Three presentations were made at each gap duration. Six catch trials were included to reduce false positive responses. The participant had to respond in a three-alternate forced-choice paradigm, i. e., had to indicate which noise burst out of the three noises was discontinuous. The smallest gap that the subject could detect at least 2 out of 3 times, was considered as the "GDT threshold." for the participants.

2. Pitch pattern sequence test (PPST): The temporal ordering and sequencing were assessed using the PPST test developed by Shivani (2003). The PPST consisted of 30 test items and 21 practice items (consisting of two-tone patterns and 5 three-tone patterns). Each test item had the pattern of 3 tone bursts of 500 msec duration each, separated by 300 msec intervals between tones. The tone frequencies were 880Hz (Low) and 1430 Hz (High). The tones are in 6 different combinations (HLH, LHL, HHL, LLH, HLL and LHH). The subjects were made to sit comfortably in the sound-treated room with headphones placed on their ears. Subjects were trained to discriminate between high and low tones with practice trials by demonstrating the verbal and humming tasks. The test items were presented through the audiometer using external input from a laptop with a patch cord connected to the audiometer. A score of '1 ' was given for the correctly identified orders and sequence and '0' for incorrect responses. The presentation level for the PPST was at 20 dBSL (ref PTA).

3. Speech Perception in Noise Test: Speech perception in noise test in Kannada (SPIN K) developed by Vaidyanath and Yathiraj (2012) was used to assess auditory closure ability. The SPIN-K was assessed at 0 dB SNR. The participants were instructed to repeat the words at a presentation level of MCL. A score of '1'was given for the correctly repeated words and '0' for incorrect responses.

4. Working memory test: The digit Forward and digit backward span tasks were used for assessing working memory. Both the tests were performed using Smriti Shravan software, where the stimulus was presented for 3000 milliseconds with an inter-stimulus interval time of 1000 milliseconds and 5000 milliseconds were allotted for response time.

Statistical Analysis

Based on collected data, a normality test was performed using IBM SPSS (Version 26). Further, all the statistical tests were run using the same software. Test for normality revealed that the data collected for assessing auditory processing abilities and working memory are not normally distributed ($p < 0.05$) and hence a non-parametric test was done. Descriptive statistics were done to obtain the mean, median and standard deviation (SD) for each group. To compare auditory processing ability & working memory between typically developing individuals and SNHL group, an Independent-Samples Mann-Whitney U Test was performed. To find out the correlation between auditory processing and working memory in the SNHL population, Spearman's correlation analysis was done across test scores.

CHAPTER 4

RESULTS

The present study aims to investigate the presence of auditory processing and working memory abilities in individuals with sensorineural hearing loss and compare them with those of normal hearing individuals. Auditory processing ability was measured using gap detection threshold (in milliseconds), pitch pattern sequencing test score & speech in noise test scores. Working memory abilities were measured using the digit forward and digit backward span scores. All the test results were subjected to descriptive statistics (Table 1)

Table 4.1. *Mean, median and standard deviation of test scores for auditory processing and working memory.*

Test	**Group**	**Population (N)**	**Mean**	**Median**	**SD**	**Minimum Score**	**Maximum score**
GDT (ms)	**NH**	20	2.70	3.00	0.657	1	4
	SNHL	20	5.15	5.00	1.226	3	8
PPST	**NH**	20	28.40	28.50	.940	27	30
	SNHL	20	20.55	21.00	4.045	14	30
SPIN	**NH**	20	14.95	15.00	1.395	12	17
	SNHL	20	7.65	8.00	2.323	2	12
Forward span	**NH**	20	5.70	5.50	0.923	4	7
	SNHL	20	4.725	5.00	0.734	4	6

Backward span	**NH**	20	4.275	4.00	.752	3	5.5
	SNHL	20	3.17	3.00	.591	2	4

NH: Individuals with normal hearing (Typically developing individuals); SNHL: Sensorineural hearing loss; GDT: Gap Detection Threshold; PPST: Pitch Pattern Sequence Test; SD: Standard Deviation

1. **Comparison of Auditory Processing abilities between control and clinical group**

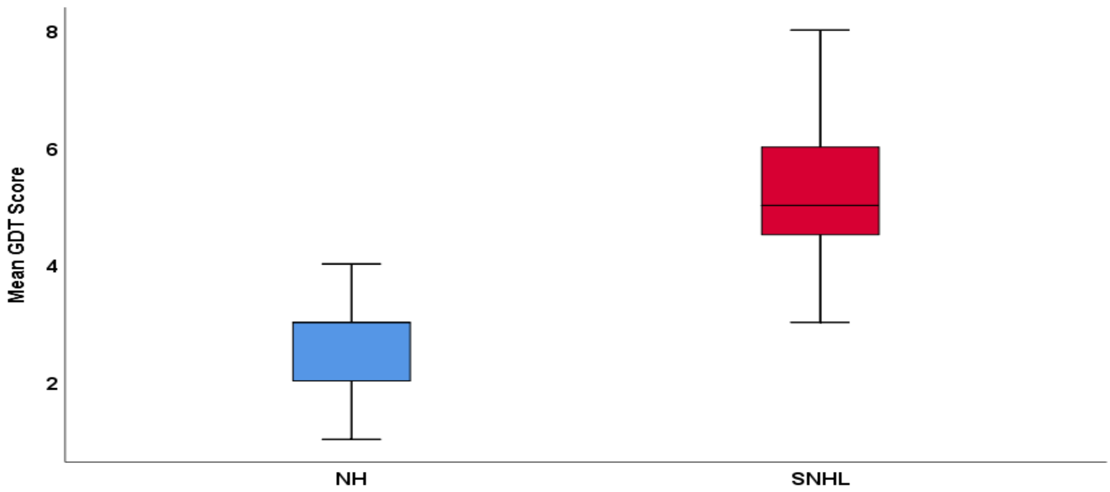
Independent-Samples Mann-Whitney U Test score (Table 4.2) shows the distribution of GDT ($Z = -5.134$, $p=0.001$) with large effect $r=0.81$, PPST($Z = -4.930$, $p= 0.001$) with large effect (r=0.78) and SPIN ($Z = -5.441$, $p=0.001$) with large effect (r=0.86) between NH and SNHL revealing significance difference between two groups (SNHL & NH). Figure 4.1 shows the box plots (median, Interquartile range, minimum and maximum values) of the GDT, PPST and SPIN between two groups (SNHL & NH).

Table 4.2. Statistical distribution of scores for the test of auditory processing and working memory ability

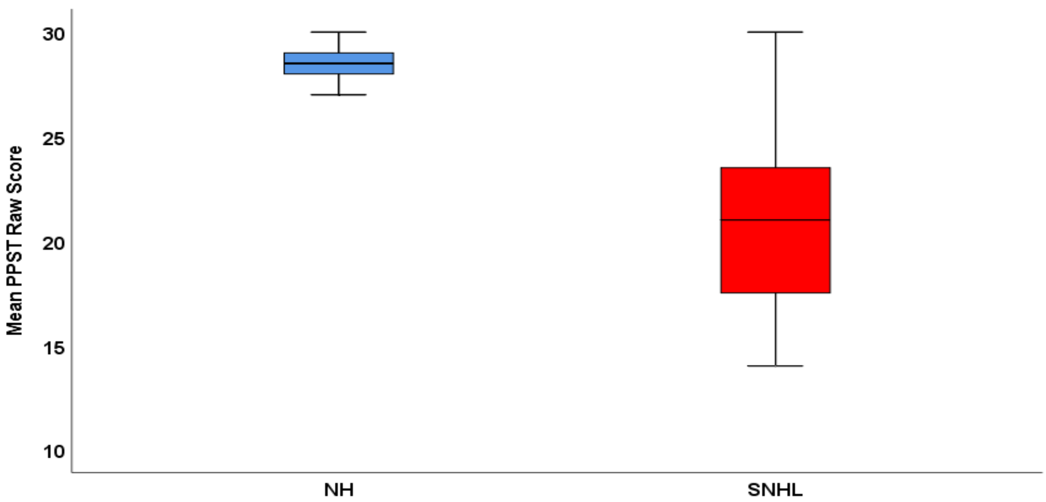
Test	**Mann-Whitney U test Rank**	**Z-score**	***p* value**
GDT	16.50	-5.134	0.001*
PPST	19.00	-4.930	0.001*
SPIN	0.50	-5.441	0.001*
Digit forward span	89.00	-3.082	0.002*
Digit backward span	54.50	-4.007	0.001*

GDT: Gap Detection Test; PPST: Pitch Pattern Sequence Test; SPIN: Speech in Noise Test;

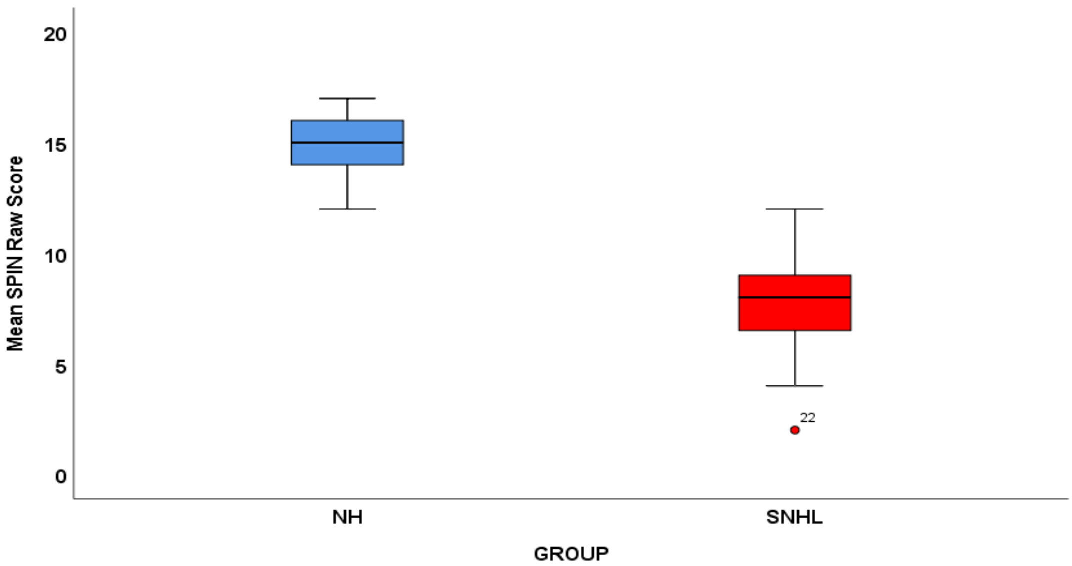
**Level of significance*



4.1.a



4.1b.



4.1c.

Fig 4.1: Box plot showed the median, Interquartile range (IQR), minimum and maximum values of the auditory processing tests between the control (NH) and clinical (SNHL) groups which includes 4.1(a) Gap detection threshold, (b) Pitch pattern sequencing test scores, (c) Speech in noise test scores.

Comparison of Working Memory abilities between control and clinical group

Based on the non-normality of data, non-parametric tests were done to compare performance across test groups. Mann-Whitney U test revealed a statistical significant difference between individual with normal hearing and sensorineural hearing loss for digit forward span ($Z = -3.082, p=0.002$) with medium to large effect size ($r = 0.49$) and digit backward span ($Z = -4.007$, $p = 0.001$) with large effect size ($r = 0.63$) as mentioned in the Table 4.2, Figure 4.2 shows the box plot (median, Interquartile range, minimum and maximum values) of the digit forward span and digit backward span between two groups.

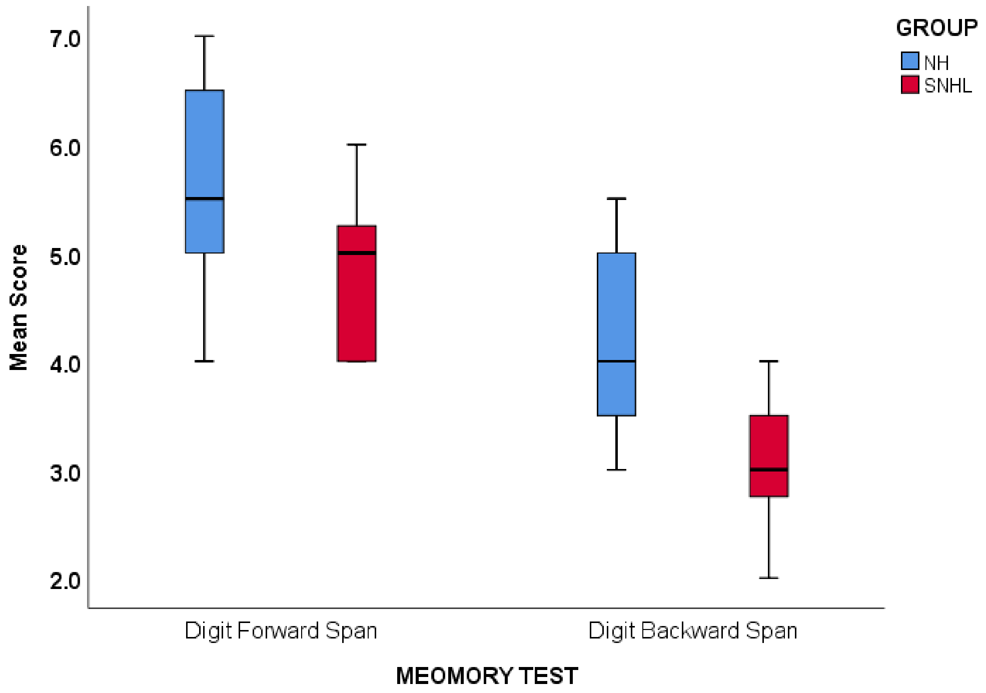


Fig 4.2: Box plot showed the median, Interquartile range (IQR), minimum and maximum values of the digit forward span test and digit backward span test between the control (NH) and clinical group (SNHL)

Correlation between the performance of auditory processing ability and working memory performance in SNHL group.

To establish correlation between the performance of auditory processing ability and working memory ability, Spearman's correlation analysis was done across test scores (Table 4.3). Result of the Spearman correlation analysis revealed strong positive correlation between digit forward span with pitch pattern sequence test scores (r_s (18) =0.554, p=0.011) as well as between digit backward span and pitch pattern sequence test scores (r_s (18) = 0.574, p=0.008). Figure 4.3 shows the heat map with a strong correlation between digit forward span (FSP) and PPST & a very strong correlation between digit backward span (BSP) and PPST score. The remaining auditory processing tests (GDT and SPIN) did not show any correlation with digit forward and backward span test scores (Table 4.3 & Figure 4.3).

Table 4.3: Spearman correlation analysis output between auditory processing tests and working memory test scores in SNHL.

Working memory tests	**Correlation coefficient**	**GDT**	**PPST**	**SPIN**
Digit forward span	**r-Value**	0.022	0.554*	-0.085
	p-Value	0.927	**0.011**	0.721
	N	20	20	20
Digit backward span	**r-Value**	-0.151	0.574**	0.048
	p-Value	0.524	**0.008**	0.842
	N	20	20	20

Note: r-value- Correlation coefficient value; p-value: Level of significance; N: Number of participants; GDT: Gap detection threshold; PPST: Pitch pattern sequence test; SPIN: Speech in Noise test

Fig 4.3: Correlation between auditory processing and working memory abilities.

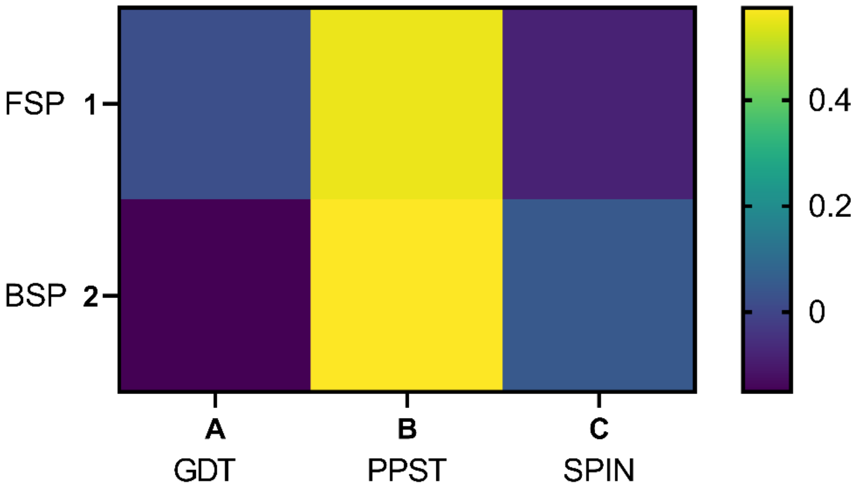


Fig 4.3: Visualizes the correlation among different test scores of auditory processing and working memory abilities through heat map.

CHAPTER 5

DISCUSSION

The present study investigated auditory processing abilities and working memory in adults with sensorineural hearing loss and compared them with those of adults with normal hearing. Auditory processing ability was evaluated using the Gap Detection Threshold (GDT), Pitch Pattern Sequence Test (PPST), and Speech Perception in Noise (SPIN-K) tests; working memory was evaluated using the Digit Forward Span (FSP) and Digit Backward Span (BSP) tasks. All the test results demonstrated statistically significant differences between SNHL and NH groups. In addition, within the SNHL group, significant positive correlations were found between working memory span (FSP and BSP) scores and PPST performance, while no such relationship was observed between both working memory scores with GDT as well as for SPIN scores. Based on the findings of the study, all three null hypotheses were therefore rejected. The following sections interpret each finding in relation to the existing literature.

5.1 Temporal Resolution performance using Gap Detection Threshold in both groups

The present study found that individuals with SNHL demonstrated statistically significant poorer GDT scores compared to the normal hearing group with a large effect size. This finding is consistent with the literature on temporal processing deficits in SNHL. Study done by Strouse et al. (1998) reported gap detection thresholds of approximately 3.5 ms in young normal-hearing adults, while Kumar and Sangamanatha (2011) found thresholds ranging from 2 to 4 ms in normal-hearing adults aged 20–30 years. Whereas the SNHL group showed a mean of 5.15 ms, which is slightly lower (better) compared to other studies (Sousa et al., 2022; Li et al., 2017). This relatively modest elevation in gap detection thresholds compared with Chinnaraj et al.'s (2022) finding of 18.94 ms in hearing-impaired older adults may be due to the younger age range of the present sample (18–40 years) and the mild-to-moderate degree of hearing loss. Importantly, Li et al. (2017) demonstrated that even high-frequency SNHL produces significantly elevated GDTs of more than 10 ms, arguing that peripheral cochlear distortion disrupts the temporal sharpness of neural coding that depends on the precision of brainstem spike timing (Oertel, 1999; Francis & Manis, 2000). The loss of outer hair cell function in SNHL is known to degrade the fine temporal resolution required to detect brief inter-stimulus gaps, leading to the 'temporal smearing' phenomenon described by Sousa et al. (2022). Since the first null hypothesis posited no difference in auditory processing between SNHL and NH groups, this hypothesis is hereby rejected for the GDT measure.

5.2 Temporal Ordering and Sequencing using Pitch Pattern Sequence Test in both groups

The SNHL group performed significantly lower (poorer) on the PPST compared to the NH group which was statistically significant between groups. The NH group performed 94.67%, which falls within the normative range of 88–90% reported by Musiek and Chermak (2014) and indeed slightly above this range, consistent with the younger age of the control group. Whereas the SNHL group's mean of approximately 68.5% is substantially below this normative ceiling and aligns with the performance decline reported by Sousa et al. (2022) in individuals with SNHL, who found mean PPST scores falling to 65–72% in affected populations.

The PPST is particularly sensitive to deficits in interhemispheric transfer via the corpus callosum and to degraded spectral and temporal pattern processing (Musiek & Chermak, 2014). Sousa et al. (2022) attributed the decline in PPST performance in SNHL to both peripheral spectral distortion and secondary changes in central auditory pathway efficiency. Andrade et al. (2023) similarly found that more than half of individuals with mild-to-moderate SNHL showed abnormal performance on temporal ordering tasks, with mean RGDT thresholds above normative limits. The results of the present study support these findings to a younger adult population with SNHL. The finding also corroborates with Chinnaraj et al. (2022) study, who reported a clear decline in duration pattern recognition with increasing hearing loss severity.

5.3 Auditory closure abilities using Speech Perception in Noise test in both groups

The SNHL group demonstrated very poor performance on the SPIN-K test compared to the NH group, yielding the largest effect size of any measure in the present study ($Z = -5.441$, $p = 0.001$; $r = 0.86$). This finding is consistent with the well-documented finding of other studies (Vijayasarathy & Barman, 2020; Moore, 2021).

The NH group mean SPIN scores is comparable to normative SPIN performance in young adults. Whereas the SNHL group poorer mean SPIN scores reflect a severe degradation in the ability to exploit linguistic redundancy and bottom-up acoustic cues simultaneously. Chinnaraj et al. (2022) reported SPIN scores consistent with the milder degree of loss and younger age range of the clinical sample in this study. Billings et al. (2023) similarly confirmed that individuals with SNHL consistently require higher signal-to-noise ratios for equivalent speech intelligibility. In a similar line, Vijayasarathy and Barman (2020) quantified an SNR loss of 7–12 dB in mild-to-moderate SNHL compared to 0–2 dB in NH young adults.

The SNHL-related impairment in speech-in-noise is explained by the loss of temporal fine structure (TFS) processing and disrupted frequency selectivity, both of which limit the ability to segregate a target speech signal from a competing noise masker (Moore, 2021). Furthermore, degraded binaural cues resulting from disrupted Interaural Time Differences (ITD) and Interaural Level Differences (ILD) further reduce the spatial release from masking compared to the NH individuals (Fuglsang et al., 2020). The 0 dB SNR condition administered in the present study placed maximum demand on bottom-up sensory processing, making this measure particularly sensitive to cochlear-level distortions. The near-zero Mann-Whitney U statistic (U = 0.50) for this test reflects near-complete separation between the two groups which indicated a finding that reinforces the clinical severity of SNHL-related SPIN deficits even in a relatively young adult population.

5.4 Working Memory tests using Digit Forward and Backward Span in both groups

The SNHL group performed significantly poorer in both digit forward span (FSP) and digit backward span (BSP) compared to the NH group. The digit forward span showed a difference represented a medium-to-large effect, while the digit backward span showed a difference represented as a large effect. The NH group's performance in the digit forward span of 5.70 falls within the well-established normative range of approximately 5–7 items in younger adults (Miller, 1956; Brown, 2016). Whereas the SNHL group's FSP of 4.725 is meaningfully reduced, indicating that even simple phonological storage is compromised when listening with degraded peripheral input. Chinnaraj et al. (2022) reported a forward span of 5.68 digits in young NH adults, 4.40 in older NH adults, and 4.15 in older SNHL adults, placing the present SNHL group's performance (4.725) above the older SNHL reference but below the young NH reference — again consistent with the younger age range and milder hearing loss of the present clinical group.

The larger effect size for BSP (r = 0.63) relative to FSP (r = 0.49) supports the theoretical distinction proposed by Brown (2016), who found that whereas simple storage (forward span) is relatively preserved in conditions of auditory degradation, the executive manipulation required for backward span, which recruits prefrontal resources for reordering and inhibition is disproportionately affected. The FUEL framework (Pichora-Fuller et al., 2016) provides a mechanistic account: when the auditory signal is degraded by peripheral SNHL, additional cognitive resources must be recruited from prefrontal executive networks to 'repair' the auditory signal. This increased cognitive burden reduces the spare capacity available for the manipulation stage of working memory, in turn producing the larger backward span deficit.

5.5 Correlation between Auditory Processing and Working Memory in the SNHL Group

Spearman correlation analysis within the SNHL group revealed a consistent and selective pattern: both digit forward span and digit backward span showed significant positive correlations with PPST scores. No significant correlations were found between either working memory measure and GDT or SPIN. The selective correlation with PPST, but not GDT or SPIN, is a theoretically meaningful finding. PPST performance requires a listener to hold three tonal elements in working memory, mentally label them as high or low, and then report their sequence verbally — a task with an inherent working memory demand that GDT and SPIN do not share to the same degree. The GDT reflects a relatively automatic, pre-attentive temporal resolution mechanism, whereas the PPST requires active phonological loop and executive engagement (Musiek & Chermak, 2014). The SPIN-K, while cognitively demanding, appears to tap a different facet of auditory processing — bottom-up lexical access and closure — that does not load equally on digit span resources. Murphy et al. (2018) and Torrente et al. (2022) reported a partial correlation between working memory and Frequency Pattern Test scores in a similar SNHL population, a finding closely paralleling the PPST-WM correlation observed in the present study.

The absence of a significant GDT–WM correlation is consistent with study reported by Maggu and Sharma (2024), who found that basic auditory processing measures, including gap detection, were not strongly related to cognition in young adults, potentially reflecting relatively preserved compensatory mechanisms at this younger age range. Similarly, the lack of SPIN–WM correlation may reflect that at 0 dB SNR, the SPIN task was simply too degraded for many SNHL participants, producing floor-level performance driven primarily by peripheral signal quality rather than cognitive modulation. This interpretation is supported by the observation that the SNHL group's SPIN scores showed the greatest range (2–12 words), suggesting that at this extreme SNR, performance was near floor for the most affected individuals.

CHAPTER 6

SUMMARY AND CONCLUSION

The present study investigated auditory processing abilities and working memory in younger adults with sensorineural hearing loss (SNHL) and normal hearing (NH). Specifically, the study aimed to: (i) assess and compare auditory processing abilities (temporal resolution, temporal ordering, and auditory closure) between SNHL and NH groups; (ii) assess and compare working memory (digit forward and backward span) between the two groups; and (iii) examine the relationship between auditory processing and working memory within the SNHL group. A total of 40 Kannada-speaking adults, 20 in NH & 20 in SNHL group in the age range of 18–40 years were investigated in the study. Auditory processing ability was measured using the Gap Detection Threshold (GDT) test, Pitch Pattern Sequence Test (PPST), and the Kannada Speech Perception in Noise (SPIN-K) test, while working memory was assessed using digit forward span (FSP) and digit backward span (BSP) tasks. Non-parametric statistical analyses (Mann-Whitney U test and Spearman's correlation) were employed given the non-normal distribution of scores.

The results of the study yielded three principal sets of findings, corresponding to the three objectives outlined above.

1. Significant group differences were found on all three auditory processing measures. The SNHL group showed higher (poorer) Gap Detection Thresholds ($M = 5.15$ ms vs 2.70 ms; $p < .001$), lower Pitch Pattern Sequence Test scores ($M = 20.55$ vs 28.40; $p < .001$), and substantially poorer Speech-in-Noise performance ($M = 7.65$ vs 14.95; $p < .001$).

2. Digit forward span (M = 4.73 vs 5.70; $p = .002$) and Digit backward span (M = 3.17 vs 4.28; $p < .001$) were significantly reduced in the SNHL population compared to NH. The backward span showed a proportionally larger deficit than the forward span.
3. Significant positive correlations were found between PPST and both forward span (rs = .554, $p = .011$) and backward span (rs = .574, $p = .008$). No significant correlations were found between GDT and either span measure, nor between SPIN and either span measure. This selective correlation indicated that temporal pattern processing ability shares cognitive resources with working memory. At the same time, basic gap detection and speech-in-noise perception operate more independently of working memory capacity.

6.1 Status of Hypotheses

There were three null hypotheses assumed in the study. All the hypotheses were rejected based on the results.

Hypothesis	**RESULT**	**outcome**
$H_0 1$: No difference between SNHL and NH in auditory processing abilities.	GDT, PPST, SPIN — all $p < .001$	**Rejected**

H_o2: No difference between SNHL and NH in working memory.	FSP p = .002; BSP p < .001	**Rejected**
H_o3: No relationship between auditory processing and working memory in SNHL.	PPST–FSP rs = .554; PPST–BSP rs = .574	**Rejected**

6.2 Clinical Implications

The findings of this study reveal the need of significant implications for audiological practice, particularly in the assessment and rehabilitation of adults with SNHL.

Need for a comprehensive assessment battery: The significant deficits documented across all five measures — none of which are captured by standard pure-tone audiometry — underscore the necessity of including central auditory processing and cognitive assessments as part of the routine audiological evaluation of adults with SNHL

Implications for rehabilitation planning: The significant PPST–working memory correlation suggests that temporal pattern processing and working memory co-decline in SNHL. Audiological rehabilitation programmes should therefore move beyond hearing aid fitting alone to incorporate auditory training targeting temporal ordering and cognitive-communicative strategies.

6.3 Limitation of the study

There were few limitations observed in the study such as:

Heterogeneity of the SNHL group: The clinical group was heterogeneous in terms of the degree, configuration, and laterality of hearing loss (ranging from unilateral to bilateral, mild to moderate-severe). These variations were not controlled, which may have influenced the finding.

Cross-sectional design: The study compared groups at a single time point and cannot establish the temporal sequence of auditory processing and working memory decline in SNHL overtime. Longitudinal studies are required to determine causality and progression.

6.4 Future Research

The present findings of the study suggest several directions for future investigation:

Longitudinal studies tracking the same individuals with SNHL over several years would help clarify whether auditory processing deficits precede, accompany, or accelerate working memory decline, and whether early audiological intervention attenuates cognitive deterioration.

Studies controlling for the degree of hearing loss (mild, moderate, severe) and age of onset (congenital, prelingual, postlingual) would allow a more precise mapping of the effect of hearing loss in working memory.

Randomised controlled trials of combined auditory training and cognitive rehabilitation in working-age adults with SNHL are needed to determine whether the PPST–working memory relationship identified here can be manipulated therapeutically.

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