# Auditory Functions in Professional Bus Drivers Exposed to Occupational Noise

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**Abstract**

**Introduction:** Occupational noise exposure can negatively affect hearing acuity and temporal processing, particularly in workers like bus drivers who are regularly exposed to high noise levels. Professional bus drivers, exposed to prolonged noise from engines and traffic, are particularly at risk for NIHL, but remain the least studied in India. This study aimed to assess the impact of prolonged noise exposure on hearing, temporal processing abilities, and speech identification among bus drivers, comparing them with a control group of non-noise-exposed office workers. **Methods:** Sixty-eight bus drivers and thirty office workers (control group) participated in this cross-sectional study. The participants in the experimental group had a mean age of 37.5 years (range = 29 years to 46 years) and the duration of service as drivers ranged from 1 to 9.8 years. Hearing acuity was assessed through pure tone audiometry, while temporal processing was evaluated with gap detection and amplitude modulation tasks. Speech identification was tested in 'quiet' and 'in noise' conditions. **Results:** Participants in the drivers' group had a mean pure tone average of 18.56 dB HL in the left ear and 19.04 dB HL in the right ear and the difference between the two groups was statistically significant. The mean gap detection threshold of participants in the drivers group (3.10 milliseconds) was significantly different from that of participants in the control group (2.44 milliseconds) as were the amplitude modulation detection thresholds especially for higher modulations at 128 Hz and 256 Hz. Speech identification scores for monosyllables in quiet were not significantly different between the two groups in contrast to speech identification in noise score (at 0 dB and -5dB SNR conditions). **Conclusions:** Prolonged noise exposure not only causes a decrease in hearing sensitivity but also impaires temporal processing abilities. Impaired temporal processing may have contributed to difficulties in speech identification, especially in noisy environments, highlighting the significant impact of noise on auditory function in occupational settings.

**Keywords:** Bus drivers, NIHL, Speech perception, Temporal processing, Gap detection, Amplitude modulation, Temporal processing.

## Introduction

Noise pollution is a significant environmental threat in both developed and developing countries and is a leading cause of hearing loss, particularly in adults [1]. Prolonged exposure to elevated noise levels is well-documented to result in noise-induced hearing loss (NIHL) [2]. Approximately 360 million people globally (roughly 5% of the world's population) suffer from disabling hearing loss, 328 million of whom are adults [1]. Among adults, 16% of disabling hearing loss is attributed to occupational noise exposure [3].

Traffic noise is a major contributor to environmental pollution worldwide, particularly in urban areas [4]. Public transport drivers, including bus drivers, are among the professional groups most vulnerable to NIHL, as they are routinely exposed to noise levels exceeding permissible limits in their workplaces [5]. Heavy motor vehicle drivers face a combined exposure to noise, vehicle vibrations, and additional wind noise, all of which contribute to the risk of hearing damage.

Noise exposure has also been associated with psychological conditions, including stress and depression [6]. Long-term exposure can cause various physiological and psychological disturbances, such as sleep disorders, fatigue, elevated heart rate, and increased blood pressure [7]. NIHL can further impact drivers' quality of life and professional performance [8].

Janghorbani et al. [9] reported a prevalence of bilateral NIHL in 18.1% of bus drivers exposed to noise. Additionally, the prevalence of NIHL increases with the duration of exposure. For instance, Majumder et al. [10] observed that 4.25% of drivers exposed to occupational noise for less than 10 years exhibited hearing loss, compared to 19.2% of those with more than 10 years of exposure.

Evidence suggests that individuals exposed to noise may develop impaired temporal processing and show reduced speech perception in noisy environments [11] even before pure-tone hearing loss becomes evident. However, contradictory studies suggest that noise-exposed individuals with clinically normal hearing may show no measurable deviations in temporal processing or speech perception in noise [12, 13]. Prendergast et al. [12] proposed that such deviations might only co-occur with audiometric sensitivity loss under extreme noise exposure. Identifying early signs of temporal processing deficits and speech perception difficulties could enable timely intervention, potentially preventing further noise-related damage.

While evidence exists for noise-induced temporal and speech processing impairments in other professions - such as train drivers [11], aircrew pilots [14], industrial workers [15], and construction workers [16] - there is limited research specifically on bus drivers. Bus drivers, in particular, experience unique challenges from combined exposure to noise, vibration, and wind noise, which may exacerbate their risk of auditory complications.

The present study aims to investigate the relationship between pure-tone hearing sensitivity, speech identification, and temporal processing in a group of bus drivers exposed to occupational noise. Notably, a preliminary version of this study was presented as a poster at the "International Conference on Communication Disorders and Audiological Practices" held in Trivandrum, India, on September 16, 2022, where it received the Best Poster Award in Audiology.

## Methods

### Participants

The study involved sixty-eight bus drivers (front-engine) from the city of Kolar and its suburbs, aged 29 to 46 years (Group A). All participants had at least 1,000 hours of exposure to occupational noise and had been employed as bus drivers for a minimum of six months, as verified through official company records. The duration of noise exposure among these drivers ranged from six months to a maximum of nine years and eight months. A control group (Group B) consisting of 30 age-matched individuals, who were not exposed to occupational noise, also participated in the study. Participants in the control group were office personnel from the university where this study was conducted.

Inclusion criteria for both groups were the absence of a history of middle ear pathology, ototoxic drug use, diabetes mellitus, Bell's palsy, or traumatic ear injury. Individuals who regularly used personal music systems for more than one hour daily were excluded from the study. Additionally, all participants demonstrated normal tympanometry ('A' type tympanogram) and acoustic reflexes at normal sensation levels.

All participants were fully informed about the objectives of the study and provided written informed consent. The study was approved by the Institutional Ethics Committee of the university (SDUMC/KLR/IEC/219/2018-19).

### Instrumentation and Procedure

*Noise Levels*

The equivalent continuous sound level (Leq) and maximum noise level (Lmax) near the driver's seat in the buses were measured using the Android-based Decibel X app. Noise measurements were taken while the buses operated over a span of five days, during peak traffic hours (morning and evening) in Kolar. Measurements at the university campus - where the control group was recruited - were conducted on three separate days at different times, at multiple locations.

*Audiological Testing*

To assess ear health, participants underwent otoscopic examination to check for foreign bodies or earwax in the external auditory canal. The tympanic membrane was examined for the presence of the cone of light with an otoscope (Welch Allyn 22870). Middle ear status was evaluated using a calibrated immittance meter (Inventis Clarinet Plus). Participants underwent several behavioural tests: pure-tone audiometry, speech identification (both in quiet and noise), and temporal processing tests (including the amplitude modulation detection task and gap-in-noise test).

*Pure Tone Audiometry*

Air conduction testing (TDH-39 headphones encased in MX 41/AR ear cushions) and bone conduction testing (Radio ear B-71 bone vibrator) were carried out on all participants using a diagnostic audiometer (Grason Stadler Incorporation, Audiostar). Audiometric thresholds were measured for octave frequencies between 0.25 kHz and 8 kHz using the modified Hughson-Westlake method [17]. Testing was performed in a sound-treated room complying with ANSI S3.1 (1999) standards. The pure tone average (PTA) was computed as the average threshold at 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. Hearing loss was classified using Modified Goodman's Classification [18], which defines: Normal hearing - 0 to 15 dB HL; slight hearing loss: 16 to 25 dB HL; mild hearing loss: 26 to 40 dB HL, and so on.

*Speech Identification Scores (SIS)*

Speech identification was assessed using a recorded test [19], comprising 16 monosyllables (e.g., ba, cha, da) spoken by a female speaker. Participants identified and repeated these syllables in quiet conditions and under noise conditions (speech noise at 0 dB and -5 dB signal-to-noise ratios, processed using Matlab). The syllables were presented at 70-80 dB SPL through headphones (Sennheiser circum-aural HD 280 Pro). Responses were recorded for analysis.

*Temporal Processing*

a) Gap-in-Noise Test

Temporal processing ability was assessed using a gap-in-noise test, where participants were instructed to detect a silent interval within a 750-ms Gaussian noise stimulus. The test followed the maximum likelihood procedure (MLP) on MATLAB, using a two-alternative forced-choice method to track an 80% correct response criterion. The standard stimulus is a 750 milliseconds noise with no gap while the variable stimulus will have an in-built gap of varying duration. Duration of the gap in the varying stimulus varied depending on the response of the participants on the mlp. In each trial, a standard stimulus (with no gap) and a variable stimulus (two bursts of noise separated by an interval) were presented. The task of the participants was to identify the sequence that had a gap. Three sequences of 30 stimuli each were presented. The MATLAB protocol provides for computing the average gap detection threshold in each sequence, and then across the three sequences. The final gap detection threshold was the average result across all 90 stimuli presentations. Participants were given 10 practice presentations before the commencement of the test to familiarize them on the test.

b) Amplitude Modulation Detection Task

This task tested participants' ability to detect amplitude modulation in Gaussian noise. The noise was amplitude-modulated at 64 Hz, 128 Hz, and 256 Hz. The task was carried out using a two-alternative forced-choice method, where participants indicated the block with modulated noise. The depth of modulation was adjusted to achieve an 80% correct response rate. The modulation detection thresholds were calculated using the formula:

Modulation detection thresholds in dB = $20 \log_{10} m$

where m = modulation detection threshold in percentage

**Statistical Analysis**

Data analysis was conducted using IBM SPSS Statistics 23. Since the Shapiro-Wilk test indicated non-normal data distributions ($p < 0.05$), non-parametric tests were used. The Mann-Whitney U test was employed to compare mean pure-tone thresholds, speech identification scores, gap detection thresholds, and modulation detection thresholds between the study group and control group.

## Results

### Noise Levels

The equivalent continuous sound level (Leq) measured inside the buses ranged from 84.7 to 89.9 dB during the morning recordings, and from 87.1 to 90.2 dB in the evening recordings. The maximum noise levels (Lmax) reached 102.1 dB in the morning and 100.2 dB in the evening. In contrast, the average noise level at the university campus was recorded at 62.3 dB (Leq), with a maximum level of 65.6 dB (Lmax).

## Pure Tone Audiometry

The mean 4-frequency pure tone average (PTA) for the drivers' group was 18.56 dB HL in the left ear and 19.04 dB HL in the right ear. The PTA was significantly different (p < 0.001) between the drivers' group and the control group, as shown in Table 1.

It was observed that 33 (49%) of the drivers exhibited a 4,000 Hz air-conduction bone-conduction (AC-BC) notch in the right ear, and 31 (46%) in the left ear. A 4,000 Hz notch was defined based on a threshold difference ≥10 dB between the 4,000 Hz threshold and both the 2,000 Hz and 8,000 Hz thresholds [20].

**Table 1: The results of the comparison of mean Pure tone avaerage between participants of the study and control groups.**

| | Control group (N = 30) | | Study group (N = 68) | | Mann-Whitney U test | |
|---|---|---|---|---|---|---|
| | Mean (dB HL) | SD | Mean (dB HL) | SD | Z | p |
| **Right PTA** | 13.04 | 2.80 | 19.04 | 5.03 | -5.951 | <0.001 |
| **Left PTA** | 12.95 | 2.62 | 18.56 | 5.27 | -1.002 | <0.001 |

PTA: Pure tone average; SD = Standard deviation

Of the 68 bus drivers, 17 (25%) had normal hearing sensitivity, 43 (63%) exhibited minimal hearing loss, and 8 (12%) had mild hearing loss in the right ear. The corresponding figures for the left ear were 22 (32%), 36 (53%), and 10 (15%) (as per the Modified Goodman's Classification), as illustrated in Figure 1.

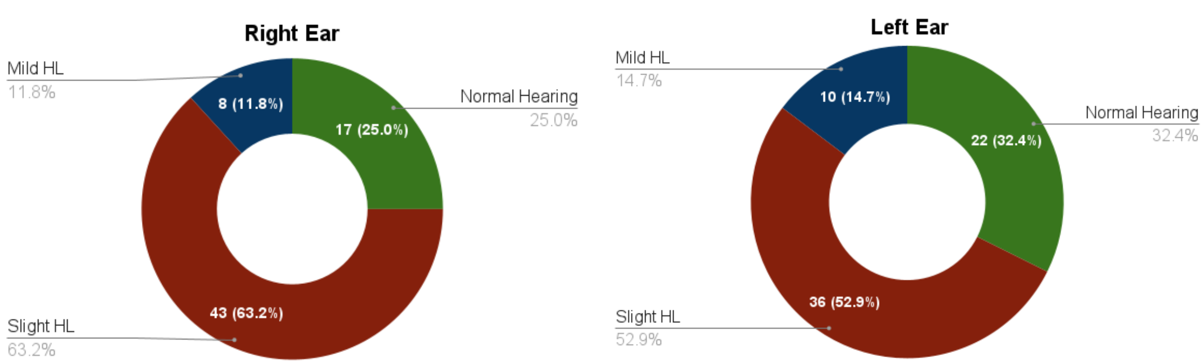


**Figure 1**: Hearing status of bus drivers in the right and left ear.
(HL: Hearing Loss)

## Temporal Resolution Abilities

### 1) Gap in Noise

Figure 2 shows that the gap detection threshold in the control group was significantly lower (indicating superior performance) than that of the drivers' group ($z = -3.681$, $p < 0.001$).

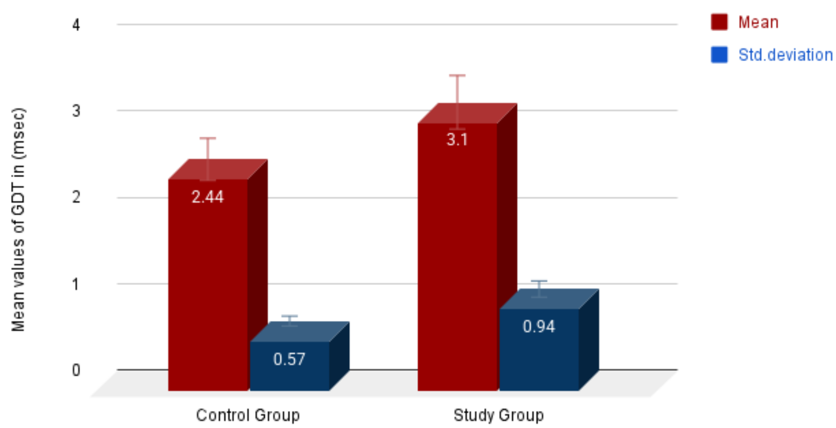


*Figure 2: Mean gap detection thresholds (GDT) of the participants of the two groups.*

### 2) Amplitude Modulation Detection

As illustrated in **Figure 3**, the modulation detection threshold was lower (indicating better performance) in the control group compared to the drivers. Although there was no significant difference in detecting the 64 Hz modulation frequency between the two groups, the detection threshold for higher modulation frequencies (128 Hz and 256 Hz) was significantly poorer for the drivers compared to the control group.

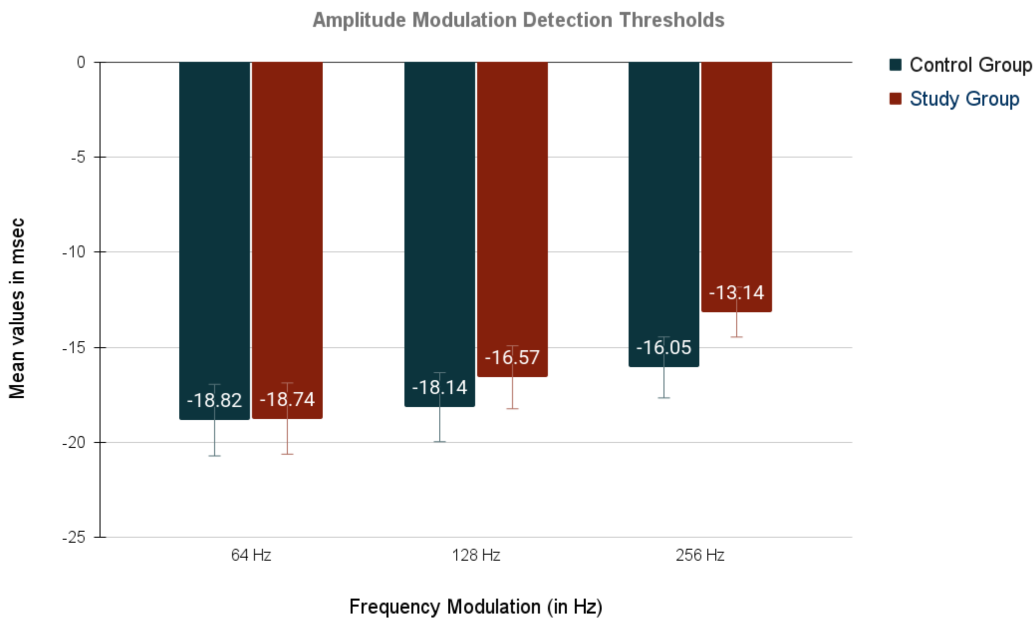


*Figure 3:* Mean amplitude modulation detection thresholds (dB) of the two groups at different modulation frequencies

**Speech Identification Scores (SIS)**

The SIS for monosyllables in quiet did not differ significantly between the two groups (z = -1.002, p > 0.05), as shown in Table 2. However, speech identification scores at 0 dB SNR were significantly better (higher) in the control group (z = -3.342, p < 0.001), as were the scores for the -5 dB SNR) condition (z = -4.600, p < 0.001).

**Table 2: Speech Identification Scores for mono-syllables between control & Study group**

| Condition | **Control group (N = 30)** | | **Study group (N = 68)** | | **Mann-Whitney U test** | |
|---|---|---|---|---|---|---|
| | Mean (%) | SD | Mean (%) | SD | Z | p |
| **Quiet** | 99.17 | 2.16 | 98.62 | 2.61 | -1.002 | 0.316 |
| **0 dB** | 84.16 | 9.53 | 76.07 | 11.53 | -3.342 | 0.001 |
| **- 5 dB** | 67.29 | 9.09 | 56.76 | 9.55 | - 4.600 | 0.000 |

## Discussion

The noise levels measured in this study provide insight into the degree of exposure the bus drivers may have experienced during their work. However, it is uncertain whether the noise levels observed here accurately reflect their exposure throughout their entire tenure, given that advancements in technology have improved working conditions over time.

The criteria used for participant selection in this study ensure that the only distinction between the study group (drivers) and the control group was their exposure to noise. Consequently, the observed reduction in hearing sensitivity in the drivers' group can likely be attributed to this noise exposure. However, it is important to note that the decrease in hearing sensitivity was only 'slight' (16–25 dB) or 'mild' (26–40 dB) according to Clark's [18] classification. There is ample evidence in the literature that prolonged exposure to high noise levels can damage hair cells and/or lead to the degeneration of sensory neurons [2]. The outer hair cells, in particular, are the most vulnerable to noise-induced damage [21], and prolonged exposure can cause widespread disruptions in the entire organ of Corti [22].

In early or moderately advanced NIHL, pure-tone audiometry often reveals a characteristic 'boilermaker's notch' at 4 kHz, with an extension to neighbouring frequencies such as 3 kHz and 6 kHz [23], and some recovery observed at 8 kHz [24]. This typical notch at 4 kHz was also observed in this study in over 40% of participants (though not explicitly presented here), further corroborating the early signs of noise exposure affecting hearing sensitivity. These findings align with previous studies by Bhumika et al. [25] and Bright et al. [26], confirming the early onset of NIHL.

The study also found that the bus drivers performed worse on temporal processing tasks. Specifically, both gap detection and amplitude modulation detection thresholds were poorer among drivers compared to the control group. Previous research has attributed elevated gap detection thresholds to impaired attention control mechanisms in individuals with past noise exposure [27]. Drivers in this study showed poorer ability to detect amplitude modulations, particularly at higher frequencies (128 Hz and 256 Hz), when compared to the control group. These modulations correspond to phase-locked neural discharges of auditory nerve fibers [11] (Kumar et al., 2012). Noise exposure has been known to damage these afferent nerve terminals, which can result in disrupted phase-locking and synchronization in auditory nerve fibers, ultimately impairing the ability to detect modulations [11]. Poor modulation detection for higher modulation rates indicates that noise-exposed individuals struggle to perceive rapid fluctuations in sound stimuli.

It is crucial to note that individuals with cochlear hearing loss also demonstrate poorer performance on tasks like gap detection and amplitude modulation detection [28]. This is due to reduced audibility of high-frequency signals in hearing-impaired listeners [28]. Consequently, the poorer gap and modulation detection thresholds found in the drivers could be partially attributed to hearing loss, particularly in the high-frequency range. Therefore, attributing these deficits solely to the impact of noise exposure may not be entirely accurate. A comparison of noise-exposed drivers with normal hearing to the control group would have been a more effective method to isolate the effects of hearing loss on temporal processing. This gap could be addressed in future studies.

Gap detection and modulation detection are critical for speech perception [29]. When noise is added to speech stimuli, it further disrupts the temporal envelope of the auditory signal [30]. Therefore, it is logical to deduce that the poor gap and modulation detection abilities observed in drivers would negatively affect their ability to identify speech, particularly in noisy environments. Similar results have been reported among train drivers [11] and construction workers [16].

The analysis of the effect of noise exposure over different durations would have provided a deeper understanding of the relationship between noise exposure and hearing loss in the drivers. As the participants in this study were exposed to noise for periods ranging from 6 months to 9.8 years, the results may not be wholly representative due to this variability. A more detailed examination of the effects of duration of exposure on speech identification and temporal processing would be valuable in future studies. A longitudinal design, as opposed to a cross-sectional one, would also yield more reliable insights. Since the pre-exposure hearing status of the bus drivers was not available, attributing the observed hearing loss solely to noise exposure may be problematic.

## Conclusions

This study reinforces the growing body of evidence that prolonged occupational noise exposure has detrimental effects on both peripheral and central auditory processing. The presence of early-stage noise-induced hearing loss (NIHL), marked by mild reductions in hearing sensitivity and the characteristic 4 kHz audiometric notch, suggests that professional bus drivers are at considerable risk. Beyond pure-tone hearing deficits, impairments in temporal processing evidenced by poorer gap detection and amplitude modulation detection thresholds further highlight the impact of noise exposure on auditory function. These deficits may contribute to difficulties in speech perception, particularly in noisy environments, which can have significant implications for workplace communication and overall safety.

Given these findings, early detection and intervention strategies are critical in mitigating the long-term effects of occupational noise exposure among bus drivers. Routine audiometric screenings, especially at high frequencies, can help identify early auditory deviations before they progress to more severe impairments. Additionally, implementing noise control measures, such as enhanced cabin insulation and the use of personal protective equipment, could significantly reduce noise exposure levels. Raising awareness about hearing conservation and enforcing regulatory guidelines for occupational noise exposure are essential steps in safeguarding auditory health. Future research should focus on longitudinal studies to track the progression of hearing loss over time and assess the efficacy of preventive measures in this occupational group.

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