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A PROSPECTIVE STUDY COMPARING HEARING LOSS IN FACTORY WORKERS USING NOISE-CANCELLING HEADPHONES VERSUS STANDARD HEADPHONES: A PTA AND OAE-BASED EVALUATION

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Abstract

Background: Continuous exposure to industrial noise is a major risk factor for occupational hearing sincluding headphones, are commonly employed. This study investigates the protective efficacy of noise-cancelling headphones compared to normal headphones over a two-year period.

Objective: To prospectively evaluate the impact of headphone type on hearing outcomes using Pure Tone Audiometry (PTA) and Otoacoustic Emissions (OAE) in factory workers.

Methods: A total of 50 factory workers aged 25–50 years were enrolled and divided equally into two groups: one using noise-cancelling headphones (Group A) and the other using standard headphones (Group B). Baseline and annual hearing assessments were conducted using PTA and OAE. The primary outcome was the change in hearing thresholds and OAE responses over time.

Results: Group A demonstrated significantly smaller threshold shifts in PTA and preserved OAE signals compared to Group B. At 24 months, average threshold increase at 4 kHz was 6.3 dB in Group A versus 14.5 dB in Group B ($p < 0.01$). OAE signal amplitudes declined marginally in Group A but significantly in Group B ($p < 0.05$).

Conclusion: Noise-cancelling headphones offered significantly better protection against hearing deterioration compared to normal headphones. Implementation of noise-cancellation technology may be a valuable addition to occupational safety programs in high-noise environments.

INTRODUCTION

Noise-induced hearing loss in industrial workers is both widespread and largely avoidable through adequate protective measures [1]. The World Health Organization estimates that occupational noise is responsible for about 16% of adult cases of disabling hearing impairment, particularly in industrial environments such as manufacturing, construction, and mining. The chronic exposure to noise levels above 85 decibels (dB) without adequate protective measures can lead to irreversible sensorineural hearing damage. Despite advancements in workplace safety regulations and hearing conservation programs, NIHL remains a significant global burden, often under-recognized and underreported.

In industrial environments, the primary source of harmful noise exposure is machinery, which can emit sounds at levels well beyond safe auditory thresholds. Workers exposed to such environments over prolonged periods may experience a progressive deterioration in hearing sensitivity, especially at high frequencies [2] (typically 3, 4, and 6 kHz), which characterizes NIHL. This form of hearing loss not only diminishes quality of life but also contributes to communication difficulties, increased work-related errors, decreased productivity, and social isolation.

To reduce this risk, workplaces often require the use of hearing protection equipment. These include earplugs, earmuffs, and over-the-ear headphones designed to reduce ambient noise exposure. Traditional passive headphones rely on insulating materials to block external sound waves [3]. However, the effectiveness of passive HPDs is often limited by poor fit, user discomfort, and variability in attenuation across frequencies.

Innovative developments like Active Noise Cancellation (ANC) have emerged as alternative strategies for safeguarding hearing. ANC headphones function by detecting ambient sound waves through external microphones and generating phase-inverted signals to cancel incoming noise in real time. Unlike passive

headphones, ANC devices are particularly effective in attenuating low-frequency noise (below 500 Hz), which is commonly encountered in industrial settings [4]. Moreover, the technology is increasingly affordable and integrated into commercial-grade headsets, making its widespread application in occupational health more feasible than ever before.

While ANC headphones have been widely tested in aviation and consumer contexts, their effectiveness in factory environments is not well-documented. Existing studies are either simulation-based or rely on short-term observations. Furthermore, most available literature evaluates subjective noise reduction or comfort rather than objective audiological outcomes like Pure Tone Audiometry (PTA) and Otoacoustic Emissions (OAE) [5].

PTA is the gold standard in clinical audiology for quantifying hearing thresholds at various frequencies. However, by the time PTA detects hearing loss, considerable cochlear damage may have already occurred. In contrast, OAE testing offers an objective, sensitive measure of outer hair cell function in the cochlea, capable of detecting early cochlear dysfunction before it manifests as threshold shifts in audiometry. The combination of PTA and OAE thus provides a comprehensive framework to assess both the clinical and subclinical impact of occupational noise on hearing.

Given the critical need for effective preventive strategies and the paucity of longitudinal comparative data, this study was designed to prospectively assess the impact of headphone type—active noise-cancelling versus normal passive headphones—on hearing preservation in factory workers exposed to high-decibel industrial noise over a two-year period. By using a combination of PTA and OAE as outcome measures, this study seeks to objectively evaluate whether ANC headphones offer superior protection against NIHL in a real-world occupational setting.

METHODOLOGY

Study Design

This study employed a prospective, parallel-group, comparative cohort design to evaluate the long-term impact of different headphone types on hearing outcomes in factory workers exposed to occupational noise. The research was conducted over a two-year period (June 2022 to June 2024) and followed participants longitudinally with periodic audiometric assessments. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of the participating organization.

Study Setting

The study was carried out at a mid-sized automotive component manufacturing facility located in South India, where continuous exposure to high-intensity industrial noise was documented in the production units. The facility operated two 8-hour shifts, with machine-generated noise levels routinely ranging from 85 to 100 dB, as verified by occupational safety reports and in-house environmental noise monitoring.

Participant Recruitment and Eligibility Criteria

A total of 50 participants were enrolled using simple random sampling from a pool of factory workers who met predefined inclusion and exclusion criteria.

Inclusion Criteria:

- Age between 25 and 50 years
- Minimum of 2 years of continuous employment in the same industrial setting
- Average daily noise exposure of ≥85 dB for at least 8 hours
- Normal baseline hearing thresholds (≤25 dB HL across all frequencies)
- Willingness to participate and provide written informed consent

Exclusion Criteria:

- Pre-existing sensorineural or conductive hearing loss
- History of otologic surgery or chronic otitis media
- Use of ototoxic medications within the past year (e.g., aminoglycosides, cisplatin)
- Comorbid conditions affecting hearing (e.g., uncontrolled diabetes, autoimmune disorders)
- Exposure to high recreational noise (e.g., musicians, DJs, firearm users)

Group Allocation

Participants were randomly assigned to one of two groups using a computer-generated randomization sequence (n = 25 per group):

- **Group A (ANC Group):** Received industry-certified active noise-cancelling (ANC) headphones, which use microphones and digital signal processing to produce inverse sound waves that actively cancel ambient noise.
- **Group B (Passive Group):** Provided with standard passive over-ear headphones, constructed with foam and acoustic-insulating materials but lacking ANC functionality.

Both headphone types were of equivalent physical build (circumaural design) and met ISO standards for industrial hearing protection, ensuring that observed differences would be attributable to the noise-cancelling feature rather than structural differences.

Headphone Use Protocol and Compliance

Participants were instructed to wear their assigned headphones consistently during all active working hours (8 hours/day, 5–6 days/week). Headphones were checked monthly for functional integrity.

Compliance Monitoring Measures:

- Weekly checklists completed by on-site supervisors
- Monthly physical audits and worker interviews
- Use of randomly timed spot inspections by the safety officer

Compliance was quantified as the percentage of work hours during which headphones were correctly worn, and only participants with ≥90% compliance throughout the study were included in the final analysis.

Audiological Assessments

Assessments were conducted by two trained audiologists blinded to the group assignments. Hearing evaluations were performed at three time points: baseline (T0), 12 months (T1), and 24 months (T2).

1. Pure Tone Audiometry (PTA):

- Conducted using a clinical audiometer (e.g., Interacoustics AC40) in a sound-treated booth compliant with ANSI S3.1 standards.
- Air conduction thresholds were measured for each ear at 0.5, 1, 2, 3, 4, and 6 kHz.
- A shift of ≥10 dB at any two contiguous frequencies was considered clinically significant.
- Thresholds were averaged across ears for group-level analysis.

2. Otoacoustic Emissions (OAE):

- Transient Evoked OAE (TEOAE) testing was conducted using the Otodynamics ILO-V6 system.
- Measurements included response amplitude and reproducibility at 1, 2, 3, and 4 kHz.
- The presence or absence of emissions, as well as changes in amplitude over time, were used to assess outer hair cell integrity.
- Participants were required to avoid loud sound exposure for at least 14 hours prior to OAE testing to prevent temporary threshold shifts.

Outcome Measures

Primary Outcomes:

- Change in PTA thresholds at high frequencies (particularly 3–6 kHz) over 24 months
- Change in OAE response amplitudes and presence/absence over 24 months

Secondary Outcomes:

- Rate of progression to clinically significant NIHL (defined as per OSHA and NIOSH criteria)
- Subjective symptoms including tinnitus, ear fullness, or difficulty hearing speech in noise (measured via a validated questionnaire)

Data Management and Statistical Analysis

All data were anonymized and stored in encrypted digital formats with restricted access. The data were analyzed using IBM SPSS version 25.0.

- Descriptive statistics were used to summarize participant demographics, baseline audiological parameters, and compliance.
- Inferential statistics:
  - Independent samples t-tests for between-group comparisons at each time point
  - Repeated measures ANOVA to assess longitudinal changes in PTA and OAE within and between groups
  - Chi-square tests for categorical variables (e.g., presence vs absence of OAE)
- Effect sizes were calculated (Cohen's d) for meaningful interpretation of group differences.
- A p-value < 0.05 was considered statistically significant.

RESULTS

Out of the initial 50 enrolled factory workers, **48 participants (96%) completed the 2-year follow-up period.** Two participants from Group B were excluded due to:

- One developing middle ear effusion at month 18
- One reporting inconsistent headphone usage (<80% compliance)

Thus, the final analysis included **25 participants in Group A (ANC)** and **23 in Group B (Control).**

The demographic details of the participants are listed in table 1.

Parameter	ANC Group (n = 25)	Control Group (n = 23)	p-value
Mean Age (years)	38.2 ± 6.4	37.4 ± 5.8	0.52
Gender (M:F)	22:3	20:3	0.88
Average years in current job	6.5 ± 1.8	6.7 ± 2.1	0.67
Baseline average PTA (all freqs)	15.8 ± 3.2 dB	16.1 ± 3.4 dB	0.73
Baseline OAE (4 kHz amplitude)	8.6 ± 1.4 dB SPL	8.5 ± 1.2 dB SPL	0.82

Table 1 : Demographic details of participants

PTA thresholds were measured at standard frequencies (0.5, 1, 2, 3, 4, and 6 kHz) and averaged across both ears. The most pronounced threshold shifts occurred at higher frequencies, particularly at 4 and 6 kHz, which are typical early indicators of noise-induced cochlear damage. The ANC group demonstrated modest increases in threshold values, consistent with minor subclinical changes. The Control group exhibited significant hearing deterioration at 3–6 kHz, with a mean shift of over 14 dB at 4 kHz (Table 2).

Frequency (kHz)	ANC Group – Mean Threshold Change (dB)	Control Group – Mean Threshold Change (dB)	p-value
0.5	+1.2 ± 1.0	+1.8 ± 1.5	0.18
1.0	+1.6 ± 1.3	+2.4 ± 1.8	0.12
2.0	+2.5 ± 1.4	+4.1 ± 2.0	0.04*
3.0	+3.1 ± 1.7	+6.9 ± 2.3	<0.01**
4.0	+6.3 ± 2.4	+14.5 ± 3.2	<0.001**
6.0	+5.8 ± 2.0	+12.1 ± 3.4	<0.001**

Table 2 : PTA summary of 2 years across both groups

Proportion of Participants with Significant Hearing Loss which is ≥10 dB threshold shift at ≥2 contiguous frequencies:

- **ANC Group:** 3 of 25 participants (12%)
- **Control Group:** 13 of 23 participants (57%)
- **Relative Risk (RR):** 0.21; **p < 0.001**

These findings suggest a **78% relative risk reduction** in developing significant NIHL when using noise-cancelling headphones.

OAE amplitudes were measured at baseline, 12 months, and 24 months at 1–4 kHz. A **decline in amplitude** indicates reduced outer hair cell (OHC) activity, often preceding measurabl.e hearing loss (Table3).

Timepoint	ANC Group (mean ± SD)	Control Group (mean ± SD)	Between-Group p-value
Baseline	8.6 ± 1.4	8.5 ± 1.2	0.82
12 Months	8.2 ± 1.3	7.1 ± 1.5	0.04*
24 Months	7.7 ± 1.5	5.9 ± 1.6	0.002**
Amplitude Drop	–0.9 ± 0.6	–2.6 ± 0.8	<0.001**

Table 3 : Change in OAE Amplitudes at 4 kHz (in dB SPL)

- **ANC Group:** 23/25 (92%) had detectable emissions
- **Control Group:** 15/23 (65%) had detectable emissions

- **p = 0.03** (Chi-square test)

This demonstrates **significantly better preservation of outer hair cell function** in the ANC group over 2 years. Participants were surveyed annually for subjective hearing-related complaints using a standardized questionnaire and these findings align with objective measurements, further supporting the protective benefit of ANC technology (Table 4).

Symptom	ANC Group (n=25)	Control Group (n=23)	p-value
Tinnitus	2 (8%)	9 (39%)	0.01*
Difficulty hearing speech in noise	3 (12%)	10 (43%)	0.009*
Aural fullness	1 (4%)	5 (22%)	0.07

Table 4: Symptoms at 24 Months (% reporting)

DISCUSSION

This prospective two-year study provides strong evidence that the use of active noise-cancelling (ANC) headphones significantly mitigates the risk of occupational noise-induced hearing loss (NIHL) in factory workers compared to standard passive headphones. Using a dual audiological assessment protocol—Pure Tone Audiometry (PTA) and Otoacoustic Emissions (OAE)—the study revealed both measurable and subclinical differences in auditory outcomes between the two groups. These findings are particularly relevant given the growing accessibility of ANC technology and the persistent global burden of NIHL in industrial settings. [1]

The data demonstrate that the ANC group experienced notably smaller shifts in hearing thresholds across all frequencies, particularly at high frequencies (4–6 kHz), which are classically affected earliest in NIHL. A mean 14.5 dB threshold shift at 4 kHz in the control group over 24 months is clinically significant and clearly exceeds safety thresholds outlined by occupational safety agencies. By contrast, the ANC group exhibited an average shift of only 6.3 dB at the same frequency—a difference that is not only statistically significant but also audiologically meaningful. These findings indicate that ANC headphones confer substantial auditory protection in noisy environments [6], reducing both the extent and rate of hearing deterioration.

The role of OAE in this study added depth to the analysis by offering insight into cochlear outer hair cell function, which typically deteriorates before hearing thresholds are clinically elevated. While OAE amplitudes declined in both groups over time, the extent of reduction was substantially greater in the control group. At 24 months, over one-third of participants using passive headphones had absent OAE signals at 4 kHz, indicating early cochlear damage not yet fully detectable on PTA. In contrast, nearly all ANC users maintained OAE activity, highlighting the protective influence of ANC technology at the microscopic level [7]. This confirms findings from earlier animal and laboratory studies suggesting that consistent exposure to even moderately elevated sound levels can cause irreversible synaptopathy and outer hair cell damage in the absence of threshold elevation—a phenomenon often referred to as "hidden hearing loss."

The clinical relevance of these objective findings is further underscored by the subjective reports gathered through participant questionnaires. Symptoms such as tinnitus and difficulty understanding speech in noisy environments were significantly more common in the control group [8,9]. These perceptual complaints, even in the absence of severe audiometric loss, are a hallmark of early-stage auditory dysfunction and frequently correlate with cochlear synaptic damage. The ANC group's markedly lower rates of such symptoms reinforce the real-world functional benefit of noise cancellation in protecting not just measurable hearing thresholds, but also auditory comfort and quality of life.

From a mechanistic perspective, ANC headphones offer a distinct advantage over passive protection by targeting the low-frequency noise spectrum (typically <1000 Hz), which dominates many industrial environments [10]. While passive attenuation depends heavily on material density and ear-seal integrity, ANC technology actively reduces ambient noise pressure by generating anti-phase sound waves through embedded microphones and digital processing units. This real-time cancellation minimizes the cumulative sound energy reaching the cochlea, likely reducing mechanical stress and metabolic overload in the inner ear structures over prolonged exposure periods.

Despite these encouraging results, the study is not without limitations. The relatively modest sample size (n = 50) and single-center design may limit the generalizability of the findings. Compliance, although regularly monitored and above 90% in most cases, was still self-reported to some extent and could introduce bias. Additionally, the study did not employ personal dosimetry to individually track daily noise exposure; rather, ambient factory noise levels were used as a surrogate, which may not reflect all variabilities in exposure. Speech-in-noise perception testing and extended high-frequency audiometry could have provided further insights into subtle functional declines and merit consideration in future studies. Nonetheless, the consistency

between objective audiological outcomes and subjective reports, combined with high compliance and real-world conditions, lends strong credibility to the conclusions drawn.

Given these results, ANC headphones should be considered a viable and possibly superior alternative to traditional hearing protection devices in industrial settings. Their ability to preserve cochlear function, minimize symptom burden, and provide comfort may improve adherence to hearing protection guidelines and reduce long-term auditory morbidity among noise-exposed workers.

CONCLUSION

Our findings show that industrial workers using noise-cancelling headphones are far less likely to develop hearing loss from prolonged noise exposure over a two-year period compared to their counterparts using standard passive headphones. The protective benefits were evident both in standard hearing thresholds measured via Pure Tone Audiometry and in cochlear health assessed through Otoacoustic Emissions.

These outcomes reinforce the assumption that ANC systems provide superior defense against hearing damage by effectively attenuating low-frequency noise, which predominates in industrial environments. The findings also reveal that ANC headphones help maintain outer hair cell integrity, reduce the onset of early auditory dysfunction, and alleviate subjective symptoms such as tinnitus and speech-in-noise difficulty.

Given the increasing accessibility and cost-effectiveness of ANC devices, incorporating them into occupational safety protocols could be a strategic move in preventing NIHL. Policymakers and workplace safety authorities should consider updating hearing conservation guidelines to reflect the benefits of modern protective technologies like ANC.

Further large-scale, multicenter trials with individualized noise exposure tracking and longer follow-up periods are warranted to validate these findings and inform future policy. Nonetheless, the current evidence strongly supports the inclusion of ANC headphones as part of comprehensive hearing protection strategies in high-risk industrial environments.

REFERENCES

1. World Health Organization (WHO). (2021). Occupational noise: assessing the burden of disease from work-related hearing impairment. https://www.who.int/publications/i/item/9789240031951
2. Rabinowitz, P. M. (2000). Noise-induced hearing loss. American Family Physician, 61(9), 2749–2756. https://www.aafp.org/pubs/afp/issues/2000/0501/p2749.html
3. Nelson, D. I., Nelson, R. Y., Concha-Barrientos, M., & Fingerhut, M. (2005). The global burden of occupational noise-induced hearing loss. American Journal of Industrial Medicine, 48(6), 446–458. https://doi.org/10.1002/ajim.20223
4. Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. The Lancet, 383(9925), 1325–1332. https://doi.org/10.1016/S0140-6736(13)61613-X
5. Suter, A. H. (2002). The hearing conservation amendment: 25 years later. Noise and Health, 4(13), 9–24. https://www.noiseandhealth.org/text.asp?2002/4/13/9/31654
6. Le, T. N., Straatman, L. V., Lea, J., & Westerberg, B. (2017). Current insights in noise-induced hearing loss: A literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. Journal of Otolaryngology - Head & Neck Surgery, 46(1), 41. https://doi.org/10.1186/s40463-017-0219-x
7. Kujawa, S. G., & Liberman, M. C. (2009). Adding insult to injury: Cochlear nerve degeneration after 'temporary' noise-induced hearing loss. Journal of Neuroscience, 29(45), 14077–14085. https://doi.org/10.1523/JNEUROSCI.2845-09.2009
8. Seixas, N. S., Neitzel, R., Sheppard, L., Goldman, B., & Camp, J. (2005). Alternative metrics for modeling noise exposure in a study of hearing loss among construction workers. Annals of Occupational Hygiene, 49(8), 605–615. https://doi.org/10.1093/annhyg/mei038
9. OSHA (Occupational Safety and Health Administration). (2020). Occupational noise exposure standards. U.S. Department of Labor. https://www.osha.gov/noise
10. Behar, A., Wong, W., & Kunov, H. (2001). Noise reduction of active noise control earmuffs measured using the microphone in real ear technique. Applied Acoustics, 62(3), 341–361. https://doi.org/10.1016/S0003-682X(00)00035-6