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THE IMPACT OF OCCUPATIONAL NOISE EXPOSURE ON AUDITORY FUNCTION AND POSTURAL STABILITY: A CROSS-SECTIONAL STUDY IN AN INDUSTRIAL FACILITY IN SUMATERA

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ABSTRAK

Paparan bising industri kronis merupakan risiko kesehatan kerja yang dapat berdampak pada sistem pendengaran dan keseimbangan. Penelitian ini bertujuan menganalisis hubungan antara intensitas dan durasi paparan bising dengan fungsi pendengaran serta stabilitas postural pada pekerja industri. Studi observasional analitik dengan desain potong lintang dilakukan pada 35 pekerja laki-laki di sebuah fasilitas industri di Sumatera. Fungsi pendengaran dinilai menggunakan audiometri nada murni dan DPOAE, sedangkan stabilitas postural dievaluasi melalui serangkaian uji klinis, dengan instabilitas ditentukan jika terdapat minimal satu hasil abnormal. Tingkat kebisingan berkisar 85–99 dB dengan seluruh subjek memiliki masa kerja lebih dari 10 tahun. Prevalensi gangguan pendengaran mencapai 42,9% dan instabilitas postural 77,1%. Analisis Spearman menunjukkan tidak terdapat hubungan signifikan antara intensitas maupun durasi paparan bising dengan fungsi pendengaran dan stabilitas postural (p > 0,05), serta tidak ditemukan asosiasi antara gangguan pendengaran dan instabilitas postural (p = 0,147). Tingginya prevalensi gangguan diduga tidak disertai korelasi linear akibat homogenitas tingkat dan durasi paparan pada subjek penelitian.

ABSTRACT

The Impact of Occupational Noise Exposure On Auditory Function and Postural Stability: A Cross-Sectional Study in an Industrial Facility In Sumatera. Chronic industrial noise exposure is an occupational health risk that can affect both the auditory and balance systems. This study aimed to analyze the relationship between noise intensity and duration of exposure with hearing function and postural stability among industrial workers. An analytic observational study with a cross-sectional design was conducted on 35 male workers in an industrial facility in Sumatra. Hearing function was assessed using pure-tone audiometry and DPOAE, while postural stability was evaluated through a series of clinical tests, with instability defined as at least one abnormal result. Workplace noise levels ranged from 85–99 dB, and all subjects had more than 10 years of service. The prevalence of hearing impairment was 42.9%, while postural instability reached 77.1%. Spearman correlation analysis showed no significant relationship between noise intensity or duration of exposure with hearing function and postural stability (p > 0.05), and no association was found between hearing impairment and postural instability (p = 0.147). The high prevalence of both conditions without significant linear correlation may be influenced by the homogeneous range of noise exposure and duration among the study subjects.

INTRODUCTION

Occupational noise is a pervasive environmental stressor that triggers chronic health impairments, specifically targeting the auditory and posturo-vestibular systems.[1,2] While the pathophysiology of Noise-Induced Hearing Loss (NIHL) due to cochlear hair cell damage is well-established, emerging evidence suggests that the vestibular labyrinth—sharing embryonic origin, anatomical proximity, and vascular supply with the cochlea—is equally vulnerable to acoustic trauma.[3,4] Mechanisms such as mechanical disruption of the saccule and utricle and noise-induced oxidative stress are hypothesized to disrupt postural equilibrium.[5,6]

In Indonesia, although the prevalence of hearing impairment in industrial sectors is high, research often focuses on auditory or vestibular functions in isolation.[7,8] Current data in Sumatera indicates significant correlations between noise exposure and sensorineural hearing loss, yet integrated studies evaluating the simultaneous impact on both systems remain scarce.[9,10] In many large-scale industrial facilities, noise levels frequently reach and exceed 85 dB, the established regulatory limit for an 8-hour workday.[11,12] This hazard is often compounded by inconsistent adherence to Personal Protective Equipment (PPE), creating a critical need for an integrated diagnostic approach to detect early signs of postural instability.[13,14]

The knowledge gap addressed by this study is the lack of a comprehensive analysis of the simultaneous correlation between noise metrics (intensity and duration) and both auditory function and clinical signs of postural instability in a single industrial study.[15,16] Therefore, we tested the a priori hypotheses that higher noise intensity and longer cumulative exposure duration would significantly correlate with increased hearing thresholds and a higher prevalence of postural instability.[3,17] This study aims to provide a framework for improving occupational health policies by simultaneously analyzing these two interconnected systems through standardized clinical screening tools.[1,18]

METHODS

This study employed an analytical observational approach with a cross-sectional design. It was conducted between August and September 2025 at a large-scale industrial facility in Sumatera. To maintain institutional confidentiality, the facility's specific identity is withheld. A proportional purposive sampling technique was used to recruit 35 male workers. Inclusion criteria were age 30–55 years and at least 10 years of occupational noise exposure. Exclusion criteria included pre-existing middle or inner ear pathologies, a history of central or peripheral vestibular disorders (e.g., BPPV, Meniere’s disease, or stroke), or recent use of ototoxic medications.

Environmental noise intensity was measured using a REED R8050 Class 2 Sound Level Meter (IEC 61672-1 Class 2). The device featured dual ranges (Lo: 30–100 dB; Hi: 60–130 dB) and was calibrated to ensure measurement accuracy. Measurements were performed using A-weighting (dBA) with a slow time weighting setting (1 second) to capture stabilized sound pressure levels. Noise was sampled at strategic production locations at ear level, with three repeats for each location to obtain a representative average. Individual exposure was assigned based on the Time-Weighted Average (TWA). Personal Protective Equipment (PPE) use was quantified via a self-report questionnaire regarding consistency; however, actual noise attenuation was not subtracted from the TWA to reflect the maximum potential hazard.

All clinical assessments were performed in a controlled, low-noise environment (ambient noise <30 dB). Pure-tone audiometry and tympanometry were conducted using an Interacoustics AD528 diagnostic suite, which was recently calibrated by an authorized service. Tympanometry (226 Hz probe tone) was performed to ensure Type A tympanograms, confirming normal middle ear function before proceeding. Air-conduction thresholds were measured at 250–8000 Hz. Hearing loss was defined based on the Fletcher Index, calculated as the average hearing threshold at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The criteria were set as Normal (≤ 25 dB) and Abnormal (> 25 dB). Distortion Product Otoacoustic Emission (DPOAE) was measured using an Interacoustics OtoRead handheld device to evaluate outer hair cell integrity. A "Pass" result was defined by a signal-to-noise ratio (SNR) ≥ 6 dB.

Vestibular Screening: A battery of standardized clinical tests was performed: Head Impulse Test (HIT), Romberg Test, Tandem Walking Test, and Fukuda Stepping Test. Implementation was strictly standardized: participants were barefoot on a firm surface in a well-lit room. To minimize observer bias, the examiner was blinded to the participants' specific noise exposure levels. These tests were utilized as screening tools to identify signs of postural instability. For the purpose of this study, postural instability was defined by an abnormal result in at least one of these four tests. These bedside assessments indicate global postural impairment and are not diagnostic of specific peripheral or otolithic dysfunction, as results may be influenced by non-vestibular factors such as proprioception, musculoskeletal symmetry, and fatigue.

Data analysis was performed using IBM SPSS Statistics version 25 through a three-stage protocol, beginning with Spearman's rank correlation (r) to assess the bivariate relationship between noise metrics and clinical outcomes, followed by a bivariate screening using Chi-Square tests to identify potential confounders such as age, smoking, PPE use, and comorbidities. Variables exhibiting a $p < 0.25$ or established theoretical relevance were subsequently entered into a multivariate analysis using binary logistic regression with the Backward LR (Likelihood Ratio) method to evaluate the simultaneous impact of independent variables while rigorously controlling for confounding factors, with the significance level for all definitive tests set at $p < 0.05$ within a 95% confidence interval.

RESULTS

A total of 35 male industrial workers participated in this study, with a mean age of 36.57 ± 5.34 years (range: 31–55 years). Occupational noise assessment across strategic production units revealed a mean intensity of 90.61 ± 5.88 dB (range: 85.0–99.1 dB), which consistently exceeded the regulatory safety threshold of 85 dB. The subjects exhibited significant long-term exposure, with a mean occupational tenure of 16.40 ± 5.20 years (range: 10–30 years). Potential confounding factors were identified, revealing that 40.0% used personal audio devices, 8.6% were active smokers, and 14.3% had comorbid hypertension. Detailed demographic and risk factor distributions are presented in Table 1.

Table 1. Demographic, Occupational, and Potential Confounding Factors (n=35)

Characteristic	**Mean ± SD (Range)**	**Category**	**Frequency (n)**	**Percentage (%)**
Age (years)	36.57 ± 5.34 (31–55)	30–40	27	77.1
		41–55	8	22.9
Noise Intensity (dB)	90.61 ± 5.88 (85.0–99.1)	≤ 90 dB	21	60.0
		> 90 dB	14	40.0
Years of Service (years)	16.40 ± 5.20 (10–30)	≤ 16 years	20	57.1
		> 16 years	15	42.9
Education Level	-	High School / Vocational	14	40.0
		Diploma / Bachelor / Master	21	60.0
PPE Use	-	Routine	22	62.9
		Inconsistent	13	37.1
Personal Audio Use	-	Yes (Headset/Earphone)	14	40.0
		No	21	60.0
Smoking Habit	-	Yes	3	8.6
		No	32	91.4
Comorbidities	-	Hypertension	5	14.3
		Diabetes Mellitus	1	2.9

This table summarizes the demographic and occupational characteristics of 35 male workers, showing a predominant age group of 30–40 years and a high rate of consistent PPE use. **Abbreviations:** SD: Standard Deviation; PPE: Personal Protective Equipment.

Auditory function was evaluated using a multimodal approach to ensure diagnostic validity. Pure-tone audiometry indicated a mean hearing threshold of 23.57 ± 8.65 dB in the right ear (AD) and a significantly higher mean of 26.27 ± 9.61 dB in the left ear (AS), with thresholds ranging from 6.2 dB to 58.8 dB. Based on the Fletcher Index, the prevalence of Sensorineural Hearing Loss (SNHL) was 37.1% in the right ear and 54.3% in the left ear. To rule out middle ear pathologies as a source of measurement error, tympanometry was performed, confirming normal middle ear function (100% Type A tympanograms) across the study. Furthermore, outer hair cell integrity assessed via DPOAE yielded "Refer" results in 42.9% (AD) and 45.7% (AS) of the subjects. The comprehensive auditory data per-ear are summarized in Table 2.

Table 2. Comprehensive Auditory Assessment Results (n=35)

Parameter	Category	Right Ear (AD) n (%)	Left Ear (AS) n (%)
Hearing Threshold (dB)	Mean ± SD	23.57 ± 8.65	26.27 ± 9.61
	Range (Min–Max)	6.2 – 47.5	11.2 – 58.8
Hearing Interpretation	Normal (≤ 25 dB)	22 (62.9)	16 (45.7)
	SNHL (> 25 dB)	13 (37.1)	19 (54.3)
Tympanometry	Type A (Normal)	35 (100)	35 (100)
DPOAE (OAE)	Pass	20 (57.1)	19 (54.3)
	Refer	15 (42.9)	16 (45.7)

This table presents the auditory profiles of participants, highlighting a higher prevalence of sensorineural hearing loss in the left ear compared to the right ear despite universal normal middle ear function. **Abbreviations:** AD: Auricula Dextra (right ear); AS: Auricula Sinistra (left ear); SNHL: Sensorineural Hearing Loss; DPOAE: Distortion Product Otoacoustic Emission.

The clinical screening battery demonstrated a high rate of abnormalities in postural stability, particularly during dynamic balance assessments. The Fukuda Stepping Test was the most frequent indicator of instability, identifying abnormalities in 62.9% of subjects, followed by the Tandem Walking Test (34.3%) and the Romberg Test (8.6%). Notably, the Head Impulse Test (HIT) yielded normal results for all participants (100%), suggesting preserved vestibulo-ocular reflex function within this study. Overall, 77.1% of the workers exhibited at least one abnormal sign of postural instability. When integrating both clinical systems, 45.7% of the participants presented with combined auditory impairment and postural instability.

Table 3. Results of Postural Stability Screening and Combined Sensory Status (n=35)

Assessment	Category	Frequency (n)	Percentage (%)
Head Impulse Test	Normal / Abnormal	35 / 0	100.0 / 0.0
Romberg Test	Normal / Abnormal	32 / 3	91.4 / 8.6
Tandem Walking Test	Normal / Abnormal	23 / 12	65.7 / 34.3
Fukuda Stepping Test	Normal / Abnormal	13 / 22	37.1 / 62.9
Overall Postural Stability Status	Normal / Abnormal	8 / 27	22.9 / 77.1
Sensory Profile	Normal (Both Systems)	7	20.0
	Postural instability Only	13	47.14
	Auditory Impairment Only	1	2.85
	Combined (Auditory + Vestibular)	15	42.85

This table presents the results of postural screening, showing that although all participants passed the Head Impulse Test, the majority exhibited postural instability, primarily detected via the Fukuda Stepping Test. **Note:** Combined sensory status refers to the simultaneous presence of both auditory impairment and postural instability

Due to the non-normal distribution of the data, Spearman's rank correlation was employed to analyze the relationship between noise metrics and clinical outcomes. Daily noise exposure was constant at 8 hours for all participants; therefore, cumulative duration (total years of work) was used as the primary temporal metric.The analysis showed that noise intensity had a very weak positive correlation with hearing thresholds in both the right ear (AD) ($r = 0.215$) and left ear (AS) ($r = 0.101$), which was not statistically significant ($p > 0.05$).

Similarly, neither noise intensity nor cumulative duration showed a significant correlation with postural instability

Table 4. Correlation of Noise Intensity and Cumulative Duration with Clinical Outcomes

Variable	Auditory Threshold AD (r)	p-value	Auditory Threshold AS (r)	p-value	Postural Instability (r)	p-value
Noise Intensity	0.215	0.216	0.101	0.563	-0.154	0.378
Cumulative Duration	-0.033	0.851	0.160	0.357	0.115	0.510

This table displays the Spearman correlation analysis, revealing that neither noise intensity nor cumulative duration had a statistically significant relationship with auditory thresholds or postural stability. **Abbreviations:** AD: Auricula Dextra; AS: Auricula Sinistra; r: Spearman's correlation coefficient; p: probability value

Bivariate screening using the Chi-Square test indicated that for the right ear (AD), no variables significantly met the criteria for multivariate entry ($p < 0.25$). For the left ear (AS), the final logistic regression model identified age as the primary remaining factor, with a trend toward increased risk ($p = 0.078$, Exp(B) = 4.074), though this was not statistically significant. Regarding postural stability, bivariate analysis initially showed that age ($p = 0.009$), cumulative exposure duration ($p = 0.013$), and employment duration ($p = 0.048$) were significantly associated with instability. However, in the final multivariate model (Step 5), no variables remained statistically significant.

DISCUSSION

The environmental noise assessment in this study revealed a mean intensity of 90.61 ± 5.88 dB, which consistently exceeds the regulatory safety threshold of 85 dB established for an 8-hour workday.[1,11] With a range reaching up to 99.1 dB, workers in these production units are exposed to a significant potential hazard that may impact both auditory and non-auditory systems.[9,12] The participants in this study represent a group with chronic exposure, evidenced by a mean occupational tenure of 16.40 years. This long-term duration is critical, as the cumulative effects of noise on the inner ear structures—specifically the hair cells of the cochlea and the sensory epithelium of the vestibular labyrinth—often manifest after years of persistent exposure.[19,20] Furthermore, while 62.9% of workers reported routine use of Personal Protective Equipment (PPE), a notable 37.1% remained inconsistent in their adherence.[13,21] This inconsistency, combined with an average intensity of 90.61 dB, likely contributes to the high prevalence of clinical impairments observed despite existing safety regulations. Other potential confounders, such as age distribution (predominantly 30–40 years) and comorbidities, including hypertension (14.3%), provide a comprehensive context for evaluating subsequent auditory and postural stability outcomes.

The auditory evaluation revealed a significant prevalence of hearing impairment, with 54.3% of workers exhibiting sensorineural hearing loss (SNHL) in the left ear (AS) and 37.1% in the right ear (AD).[10,22] The higher mean hearing threshold observed in the left ear (26.27 ± 9.61 dB) compared to the right ear (23.57 ± 8.65 dB) is a notable finding. This asymmetry in noise-induced damage is frequently documented in occupational health literature. It is often attributed to the "shadow effect" of the head or to specific industrial spatial configurations, in which noise sources may be positioned closer to one side.[18,22] Additionally, the Distortion Product Otoacoustic Emission (DPOAE) results, which showed a "Refer" rate of 45.7% (AS) and 42.9% (AD), further confirm that the damage has extended to the outer hair cells (OHCs) of the cochlea, which are typically the first structures affected by chronic acoustic trauma.[13,19]

Despite the high prevalence of SNHL, tympanometry showed 100% Type A tympanograms, confirming intact middle ear function across all participants. This indicates that the hearing deficits observed are purely sensorineural, specifically cochlear in origin, and are not confounded by conductive hearing loss.[10,18] The presence of such a high rate of auditory impairment in a relatively young cohort (mean age 36.57 years) underscores the progressive and permanent nature of noise-induced damage, which often begins as subclinical OHC dysfunction before manifesting as measurable threshold shifts on pure-tone audiometry.[2,21]

The evaluation of postural stability revealed a high prevalence of clinical abnormalities, with 77.1% of workers exhibiting at least one abnormal sign across the test battery.[6,13] Among the four tests conducted, the Fukuda Stepping Test had the highest abnormality rate at 62.9%, followed by the Tandem Walking Test at 34.3%. The high failure rate in the Fukuda Stepping Test suggests significant postural instability in this noise-exposed population.[4,17] However, as noted in the study's limitations, these findings should be interpreted as global postural impairment rather than definitive evidence of peripheral vestibular or otolithic pathology, as the Fukuda test is a screening tool sensitive to non-vestibular influences such as proprioceptive input, musculoskeletal symmetry, and physical fatigue.[17,20]

A particularly striking finding was that the Head Impulse Test (HIT) yielded 100% normal results for all participants. This discrepancy between the high instability rate in dynamic tests (Fukuda and Tandem Walking) and the perfectly preserved result in the HIT provides valuable clinical insight. The HIT primarily evaluates the vestibulo-ocular reflex (VOR) mediated by the semicircular canals. The normal HIT results suggest that the high-frequency VOR remains intact in this study.[20,23] In contrast, the instability observed in the Fukuda and Tandem tests may point toward an earlier or more pronounced disruption of the vestibulospinal reflex (VSR) or potential saccular/utricular dysfunction, which are hypothesized to be more vulnerable to acoustic trauma than the semicircular canals.[3,6] This reinforces the need to use a multi-test battery to capture different aspects of the posturo-vestibular system during occupational screenings.[16,17]

The statistical analysis revealed no significant linear correlation between noise intensity or cumulative exposure duration and either auditory thresholds or postural stability. This lack of significance, despite the high prevalence of impairment, is primarily due to the homogeneity of the exposure data in this study.[24,25] All participants were exposed to noise levels within a relatively narrow range of 85–99.1 dB and possessed long-term work tenures exceeding 10 years. Such uniformity reduces the statistical variability required to establish a clear dose-response relationship, as the study population likely represents a "ceiling effect" where chronic damage has already stabilized.[18,21] In the multivariate analysis, although age, cumulative duration, and years of service initially showed significant associations with postural instability in the bivariate screening, these factors did not maintain their significance in the final logistic regression model. The final model identified age as the most prominent remaining factor, showing a trend toward increased risk, yet it remained statistically non-significant ($p = 0.998$). This suggests that while age and long-term exposure are theoretically linked to sensory-neural decline, the small sample size (n=35) of this study limits the statistical power to detect these associations as independent predictors.[23,24]

This study has several limitations. First, the small sample size (n=35) and cross-sectional design limit statistical power and preclude the establishment of definitive causal relationships. Second, the homogeneous exposure range (85–99 dB) and long-term tenure (>10 years) among participants reduce the variability needed to observe a clear dose-response gradient. Third, individual noise exposure was based on environmental sampling rather than personal dosimetry, which may not capture fluctuating individual levels. Lastly, reliance on clinical screening tools, such as the Fukuda Stepping Test, indicates postural instability rather than confirmed vestibular pathology, as results may be influenced by non-vestibular factors, such as fatigue and proprioception.[4,17] Future longitudinal studies with larger cohorts and advanced diagnostics (e.g., VEMP or vHIT) are warranted.[6,20]

CONCLUSION

This study observes a high prevalence of auditory impairment (42.9%) and postural instability (77.1%) among industrial workers exposed to chronic noise levels (85–99.1 dB). While no statistically significant linear correlation was found between noise metrics and the severity of clinical outcomes—likely due to the homogeneity of the long-term-exposed cohort—the findings highlight a substantial burden of multisensory impairment. Notably, the high frequency of postural instability, compared with the preserved vestibulo-ocular reflex, suggests that equilibrium screening should be integrated into routine occupational health assessments alongside audiometry.[1,16]

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