15 years ESJ
Special edition

Noise-Induced Hearing Loss Among Greek Solid Waste Landfill Workers

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Doi:10.19044/esj.2025.v21n37p30

Submitted: 22 April 2024
Accepted: 04 July 2024
Published: 15 January 2025

Cite As:
Papastergiou St., Karaiskos C., Damikouka I., Douna E., Koupidis S. & Dounias G. (2025). *Noise-induced hearing loss among Greek solid waste landfill workers*. European Scientific Journal, ESJ, 21 (37), 30. https://doi.org/10.19044/esj.2025.v21n37p30

Abstract

Introduction: Hearing loss at work is currently considered the most common cause of permanent hearing loss in adults and one of the most important health problems with economic and psychosocial consequences. The present study has the aim to investigate the prevalence and the determinants of hearing loss among solid waste workers. **Material and methods**: Eight-three (83) solid waste workers underwent audiometric test in

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

the facilities of the Integrated Solid Waste Management Facility (OEDA) in the area of Attica, Greece. To assess hearing, an occupational history was first taken, followed by an otoscopy and audiogram. The findings of the audiograms were initially assessed as normal and pathological and then classified using diagnostic criteria (NIOSH, OYDOS). **Findings**: Statistical analysis has shown that 23% of solid waste workers had sensorineural hearing loss located mainly at 4000 Hz. Multivariate analysis confirmed that the intensity of occupational exposure to noise appears to be the strongest predictor of noise-induced hearing loss (p=0.02326) followed by the years of work (p=0.02728). Particularly, the analysis with the NIOSH criterion (probability of having a positive NIOSH criterion in at least 1 of both ears) increased by 1.33 times/year or 32.84%/year on average. Finally, no univariate statistically significant associations were found with any of the two criteria and smoking, BMI, hypertension or tinnitus Estimating exposure through self-reported data is not sufficient and accurate and in fact workers who are exposed to higher risk measures tend to underestimate the risk. **Conclusion**: Our findings indicate that solid waste workers are occupationally exposed to high levels of noise, and present high rates of noise-induced hearing loss (NIHL). It is necessary to estimate the noise exposure with appropriate measurements in the work environment (individual sound exposure of employees and environmental measurements in the workplace) and take appropriate measures.

Keywords: Noise, occupational exposure, solid waste workers, hearing loss

Introduction

Landfill workers are doing a heavy, arduous and unhealthy job that is absolutely essential for public health. They are exposed to a variety of risks, present at all stages of management from collection to final treatment. These risks include respiratory diseases from exposure to dust and airborne pollutants, exposure to biological agents, cardiovascular disease, musculoskeletal diseases, exposure to heavy metals and noise-induced hearing loss (NIHL).

NIHL is one of the most common occupational diseases and characterized as a permanent bilateral sensorineural hearing loss caused by degenerative and atrophic changes in the outer hair cells of the organ of Corti and the auditory nerve. It develops slowly, gradually, one would say in an insidious way, and this is because the peculiar form of reduction in acoustic acuity which initially concerns the high frequency spectrum (3000-6000Hz) with a characteristic selective drop at 4000Hz, makes it difficult for the affected person to perceive the problem since the frequency range of everyday

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

speech is lower. Gradually with the gradual progression of this disease, the decrease in hearing acuity extends to the lower frequencies below 3000Hz. [1,2] In Greece, occupational diseases in the past were defined on the basis of article 40 of the I.K.A.'s [Insurance Institute] Occupational Disease Regulation, where, in order for a disease to be classified as an occupational disease, worker must be affected by acute or chronic poisoning or a disease included in the tables of article 40 and more:

- be employed in the work incriminated in the occupational disease for the minimum period of time prescribed by law.
- the disease must be diagnosed within this minimum period of employment or, if the work is interrupted, within the maximum period of time laid down by law for each occupational disease after the interruption.

Under this article 40 noise was described : "…Diseases due to natural causes: ....., to sound and noise (e.g. reduction of hearing acuity-occupational hearing loss)....". The legislation currently in force is shown in the table below.[3]

Table 1: Hearing loss

Hearing loss or deafness due to harmful noise	
Acute	Sensorineural hearing loss
	Ruptured eardrum - Bleeding
Chronic	Sensorineural hearing loss

In general the effects of noise can be classified into two categories: A) effects on hearing B) non-auditory effects.
The acoustic effects concerning the organ of hearing are characterized by the following functional alterations of a temporary or permanent nature:

a) ***Acoustic fatigue***: Observed after initial exposure to noise and depends on noise intensity. It is temporary and irreversible after a short period of time after the sound stimulus is removed. The drop in acoustic acuity is particularly relevant to the high frequency range of 3000-4000Hz.
b) ***Acute auditory trauma***: It is the acute burden of hearing which is due to a single exposure of the hearing system to a very strong and short-term sound stimulus such as e.g. an explosion It is characterized by a decrease in acoustic acuity in the 4000Hz frequency range.

Non-auditory effects mainly concern the nervous system, mental functions, circulatory, gastrointestinal, and endocrine systems. It is known that workers exposed to noise have symptoms such as physical fatigue, irritability, bad mood, digestive disorders, poor cognition, headaches and sleep disorders.

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Also exposed to noise has been associated with higher morbidity and mortality of cardiovascular disease [4,5,6,7,8]

Primary health care focuses mainly on the frequencies of human speech and takes little or no account of high frequencies, which are mainly of interest to occupational health, since noise-induced hearing loss (NIHL) follows the typical characteristics as described in the literature: bilateral occurrence within a narrow frequency band (mainly between 4-6 kHz).

Materials and methods

A survey was carried out of a sample of 83 exposed to noise landfill (OEDA) workers [19%] of the total number [±430] in the area of Attica, Greece . For the assessment of hearing, the findings of the audiograms were evaluated, first by assigning a diagnosis to the pathological findings and then using various diagnostic criteria. The process was considered necessary as there are a variety of approaches in the literature to classify audiograms, both from a primary and occupational health care perspective.

Noise measurement is made with suitable instrument (audiometer) with the help of electronic circuits - filters, such as the alpha weighting circuit (A), simulate the sensitivity of human hearing. Also, a suitable audiomerer was used to measure the "dose" of noise received by a worker. This instrument determines the total sound energy received by the worker during his shift (8 hours), reducing it to a percentage (dose) of the predetermined permissible Limit Value for 8-hour exposure.

Measurements were taken[1] with a portable Otometrics Aurical Aud portable audiograph. The range of frequencies tested for each worker was 250 Hz to 8000 Hz in steps as follows: 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000 Hz. In some cases, however, due to lack of time, the frequencies 750, 1500 and/or 3000 Hz were not measured. At each frequency the air acoustic oud was tested by means of a warble tone, and additional measurements of the bone acoustic oud were also carried out as indicated. The equipment used was calibrated. Etymotic Research's ER2 intra-aural hearing aids were used for the measurements, which offer:

a) greater accuracy at high frequencies, i.e. the frequency range associated with noise-induced hearing loss
b) greater protection from background noise during measurements. It should be noted that there is no special soundproof room for conducting audiological tests therefore the choice of in-ear headphones offered the maximum possible sound protection and ensured equal testing conditions for all employees.

[1] (*) special acknowledgements to the expert audiologists *: Athanasopoulos C, Dimopoulos A & Christoforidis D*

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c) health protection, provided that disposable sponges were used

Before taking an audiogram, a clinical examination, for abnormal signs or the presence of alveoli, was carried out with an otoscope. The measurements were carried out in quiet, isolated office spaces. Based on the audiogram, the degree of hearing loss for each worker was determined and classified by type of hearing loss:

a) conductivity
b) sensorineural
c) mixed type
d) Bineural hearing loss and
e) auditory trauma.

Several types of audiometers are available for purchase, ranging from handheld screening audiometers to those with full diagnostic capabilities extending to higher frequencies. Screening audiometers for office use, for example, generally test at frequencies in the speech range of 500 to 4,000 Hz. Support personnel can be trained to perform audiometry in formal courses lasting 20 hours.[9] In the absence of state or local requirements, guidelines for the use of support personnel to perform audiometry https://www.aafp.org/pubs/afp/issues/2013/0101/p41.html#special-considerations-affecting-audiometry-interpretation

Table 2 : Classification of employees by job position

	OEDA workers position
1	Facility Operation Supervisors/Managers
2	Weighing/microscopic checks/radioactive material control (main tasks at the gate)
3	Electrical and plumbing work
4	General duty workers
5	Drivers of official vehicles inside and outside the construction site
6	Operators of special machines (propellers/compressors/presses, etc.)
7	Workers in the vehicle/machinery workshop
8	Office workers (secretarial support/ IT accounting/ cleaning etc.)

Results

Of the participants in the research, 77.1% were men and 22.9% were women. The majority of workers were smokers (36.6%) or ex-smokers (18.1%) and only 24.1% had a normal BMI. 22.9% of employees had sensorineural hearing loss.

To classify the results of the audiograms of 83 solid waste workers were used 2 different diagnostic criteria, NIOSH and OYDOS.

About hearing assessment [audiometer[statistical analysis identified a univariate correlation between the NIOSH criterion and years of work but not between the OYDOS criterion in relation to years of work. More specifically,

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a problem in both ears was identified in 4 individuals 2 of whom worked more than 20+ years at the landfill. The OYDOS criterion also identifies a higher proportion of workers with a problem in both ears with 20+ years of work, without being supported by statistical significance.

Table 3: OEDA workers' audiological tests

Cases		%
14	Bilateral noise-induced hearing loss	16.8
5	With a tendency to bilateral hearing loss	6
15	Unilateral hearing loss due to auditory trauma	18
9	With a tendency to unilateral hearing loss due to hearing trauma	10
18	With sensorineural eterolateral or bilateral hearing loss, such as presbycusis	9.6
1	Bilateral hearing loss of mixed type (patient wore hearing aids)	1.2
2	Conductive hearing loss	2.4
19	Non-pathological findings	10.8
83	TOTAL	100

In the multivariate analysis, the OYDOS criterion did not show any correlation with years/job in the sample. The analysis with the NIOSH criterion (probability of having a positive NIOSH criterion in at least 1 of both ears) increased by 1.33 times/year or 32.84%/year on average ($p<0.05$). A similar trend for a correlation of NIOSH with years of work was observed in the 2nd analysis using only those workers who had a problem in both ears. ($p<010$).

In relation to the working position, it is worth mentioning some observations obtained from the distributions of pathological findings on the audiometry, especially for bilateral lesions:

Both with the NIOSH criterion and with the OYDOS criterion, the jobs with a higher percentage of bilateral pathological findings on the audiogram relate to positions 1, 5 and 7(i.e. supervisors/plant operators, service vehicle drivers and vehicle/machine workshop workers.

Table 4: Cut-off values for assessment of hearing loss at initial examination

Age (A) years	Frequency [kHz]				
	1	2	3	4	6
A≤ 30	15	15	20	25	25
30 <A ≤ 35	15	20	25	25	30
35 <A ≤ 40	15	20	25	30	35
40 < A ≤ 45	20	25	30	40	40
A < 45	20	25	30	45	50

Table 5: Audiometry Distribution of Workers (83 Workers Participated)

Occupation Years	(5 - 10]		(10 - 15]		(15 - 20]	(20 - 30.7]		total
	41% (34)		38.6%(32)		12% (10)	8.4% (7)		83
Age group	(30 - 40]		(41 - 50]		(51 - 60]	(>60]		
	25.3%(20)		37.3%(31)		32.9%(26)	7.6% (6)		83
Gender	Male				Female			
	77.1% (64)				22.9% (19)			83
work position	1	2	3	4	5	6	7	8
	9.6% (8)	16.9% (14)	3.6% (3)	18.1% (15)	3.6% (3)	18.1% (15)	10.8% (9)	19.3% (16)
PPE			Using PPE			Not Using PPE		
			77.1% (64)			22.8% (19)		
Smoking habit		Non - smokers		Smokers		Ex-smokers		
		25.3%(21)		56.6% (47)		18.1% (15)		
BMI	(18.5 - 25]		(25 - 30]		(30 - 35]	(35 - 40]		(>40]
	24.1% (20)		43.4% (36)		18.1% (15)	9.6% (8)		4.8% (4)

Workers identified with abnormal results, using the criteria, in relation to occupation years, are shown in tables 6 and 7 (where: none: no damage, single: damage to one ear, both: damage to both ears (P-value>0.05).

Using the NIOSH criteria, a total of 8 workers (out of a total of 83 workers) with abnormal audiometry results are identified (4 workers in one ear and 4 in both ears).

Using the OYDOS criterion, a total of 45 workers (out of a total of 83 workers) with abnormal audiometry results are identified (22 workers in one ear and 23 in both ears). Because the criterion describes bilateral hearing loss, individuals with damage to both ears are considered (to assess the criterion).

Table 6: Audiogram results by occupation years with the NIOSH criterion

Result	occupation years			
	(5-10]	(10-15]	(15-20]	(20-30.7]
None	44% (33)	38.7% (29)	12% (9)	5.3% (4)
Single	25% (1)	50% (2)	0% (0)	25% (1)
Both	0% (0)	25% (1)	25% (1)	50% (2)
83	34	32	10	7

P-value = 0.02728

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Table 7: Audiogram results by occupation years with the OYDOS criterion

Result	occupation years			
	(5-10]	(10-15]	(15-20]	(20-30.7]
None	44.7%(17)	36.8%(14)	15.8% (6)	2.6% (1)
Single	45.5%(10)	40.9% (9)	4.5% (1)	9.1% (2)
Both	30.4% (7)	39.1% (9)	13% (3)	17.4% (4)
83	34	32	10	7

P-value = 0.4209

The distribution of workers, using the criteria, in relation to the work position, is shown in following tables (where none: no damage, single: damage to one ear, both: damage to both ears. P-value>0.05).

Table 8: Audiogram results by job with the NIOSH 2000 HZ criterion

	None	%	Single	%	Both	%
1	7	87.5	0	0	1	12.5
2	14	100	0	0	0	0
3	2	66.7	1	33.3	0	0
4	15	100	0	0	0	0
5	1	33.3	1	33.3	1	33.3
6	14	93.3	1	6.7	0	0
7	7	77.8	1	11.1	1	11.1
8	15	93.8	0	0	1	6.2
83	75		4		4	

Table 9: Audiogram results by job with the OYDOS 4000 HZ criterion

	None	%	Single	%	Both	%
1	3	37.5	2	25	3	37.5
2	8	57.1	5	35.7	1	7.1
3	2	66.7	1	33.3	0	0
4	6	40	5	33.3	4	26.7
5	0	0	1	33.3	2	66.7
6	7	46.7	3	20	5	33.3
7	2	22.2	1	11.1	6	66.7
8	10	62.5	4	25	2	12.5
83	38		22		23	

Table 10: Audiogram results by age group with NIOSH criteria

Result	Age category			
	(30,40)	(40,50]	(50,60)	(60+)
None	26.8% (19)	35.2% (25)	31% (22)	7% (5)
Single	25% (1)	25% (1)	50% (2)	0% (0)
Both	0% (0)	25% (1)	50% (2)	25% (1)
79	20	27	26	6

P-value = 0.6357

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Table 11: Audiogram results by age group with the OYDOS criterion

Result	Age category			
	(30,40)	(40,50]	(50,60)	(60+)
None	29.6% (16)	37% (20)	27.8%(15)	5.6% (3)
Single	50% (1)	0% (0)	50% (1)	0% (0)
Both	0% (0)	0% (0)	50% (1)	50% (1)
54	17	20	17	4

P-value = 0.1511

Table 12: Audiogram results by gender with NIOSH criteria

Result	Gender	
	male	female
None	73.2% (52)	26.8% (19)
Single	100% (4)	0% (0)
Both	100% (4)	0% (0)
79	60	19

P-value = 0.5312

Table 13: Audiogram results by gender with OYDOS criterion

Result	Gender	
	male	female
None	62.9% (22)	37.15% (13)
Single	76.25(16)	23.8% (5)
Both	95.7%(22)	4.3% (1)
79	60	19

P-value = 0.01293

Table 14: Audiogram results according to NIOSH noise exposure

Result	Exposure to noise	
	Yes	No
None	83.1% (59)	16.9%(12)
Single	75% (3)	25% (1)
Both	50% (2)	50% (2)
79	64	15

P-value = 0.1714

Table 15: Audiogram results according to OYDOS noise exposure

Result	Exposure to noise	
	Yes	No
None	80% (28)	20% (7)
Single	76.2%(16)	23.8% (5)
Both	87% (20)	13% (3)
79	64	15

P-value = 0.6655

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Table 16: Audiometry results according to NIOSH noise exposure intensity

	Noise exposure intensity	
Result	Little exposure to noise (Low)	High exposure to noise (high)
None	27.1%(16)	72.9%(43)
Single	100% (3)	0% (0)
Both	0% (0)	100% (2)

P-value = 0.02326

Table 17: Audiogram results according to OYDOS noise exposure intensity

	Noise exposure intensity	
Result	Little exposure to noise (Low)	High exposure to noise (high)
None	32.1% (9)	67.9%(19)
Single	43.8% (7)	56.2% (9)
Both	15% (3)	85% (17)

P-value = 0.1616

The distribution of workers, using the criteria and the correlation with exposure to vibrations (35 workers - out of 83 workers - report exposure to vibrations, are shown in following tables (where none: no damage, single: damage to one ear, both: lesion in both ears. P-value>0.05)

Table 18: Audiogram results according to NIOSH vibration exposure

Result	Exposure to vibrations	
	YES	NO
None	46.5% (33)	53.5% (38)
Single	25% (1)	75% (3)
Both	25% (1)	75% (3)

P-value = 0.6264

Table 19: Audiogram results according to OYDOS vibration exposure

Result	Exposure to vibrations	
	YES	NO
None	37.1% (13)	62.9% (22)
Single	57.1% (12)	42.9% (9)
Both	43.5% (10)	56.5% (13)

P-value = 0.369

The distribution of workers, using the criteria and the correlation with the use of PPE (35 workers - out of 83 workers - report exposure to vibrations, are shown in following tables). (where none: no damage, single: damage to one ear, both: lesion in both ears. P-value>0.05)

Table 20: Audiogram results according to PPE use with NIOSH criteria

Result	use of PPE	Not use of PPE
None	78.9% (56)	21.1% (15)
Single	75% (3)	25% (1)
Both	75% (3)	25% (1)

P-value = 1

Table 21: Audiogram results according to PPE use with the OYDOS criterion

Result	use of PPE	Not use of PPE
None	80% (28)	20% (7)
Single	61.9% (13)	38.1% (8)
Both	91.3% (21)	8.7% (2)

P-value = 0.066

Discussion

The percentage of bilateral sensorineural hearing loss attributed to noise is 22.9% in the present study. The results of the hearing test are consistent with the results of other studies in the literature. [10, 11, 12,13, 14].

In spite of the size of the sample the number of workers with some form of NIHL is strikingly high. With regard to NIHL or the tendency towards it, which is the subject of the present epidemiological study, the incidence rate among workers is also very high (22.9%). If we also take into account that a proportion of hearing injuries and tendencies towards hearing injury are also the result of exposure to noise in the work environment, the rate becomes even higher. For example, cases can be cited of workers who work in areas with high levels of impact noise and have been diagnosed with suspected hearing trauma or even auditory trauma and the diagnosis was for the ear that is constantly exposed to the source of the noise. [15]

The NIOSH and OYDOS diagnostic criteria show a correlation between them. More specifically, all those who have a problem in both ears according to the NIOSH criterion are confirmed as having problem in both ears by the OYDOS criterion. Also the 4 workers who had problem in one ear by NIOSH have problem in one or both ears by the OYDOS criterion. Therefore, a positive NIOSH diagnosis is contained within the positive OYDOS diagnosis, but a positive OYDOS diagnosis is not contained within the positive NIOSH diagnosis.

Table 22: maximum NIHL at frequencies

Frequency (Hz)	2000	3000	4000	6000
Noise-induced hearing loss cases	2	8	33	3
Percentage of all (%)	4,35%	17,67%	71,74%	6,52%

Statistical analysis revealed a gender split. Specifically, in the univariate analysis with the OYDOS criterion, a correlation with gender was shown and, in particular, a problem in both ears was more frequent in men than in women. Also in the multivariate analysis, the same correlation appears in both two criteria, namely an average woman is less likely to have an ear problem than an average man, giving women a lower probability of having a hearing problem. This correlation is the result of job segregation, as women work mainly in office jobs with little exposure to noise, while men work in outdoor jobs with greater exposure to noise. Finally, no univariate statistically

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

significant associations were found with any of the two criteria and smoking, hypertension or tinnitus.

The results of the hearing screening are consistent with the literature. Occupation years and noise level were associated with abnormal audiogram results and interesting observations emerged for work location, where locations with estimated high noise levels concentrated the highest percentages of workers with abnormal audiogram findings. The critical case-control frequency for noise-induced hearing loss was 4000 Hz.

Prevention measures include technical prevention based on the removal of the generative causes of risk and reduction noise level at its source. This is achieved by replacing the noisy production process with a less noisy one, following the instructions for the installation and maintenance of the machines, as well as by reducing the transmission of noise both at the source (caging of noise sources) and at the work environment (construction materials with a suitable sound absorption coefficient, sound curtains, etc.) [16,17,18]. Personal Protective Equipment (PPE) is the last defense line against noise and their use must be temporary. Medical and organizational prevention based on organizational interventions aimed at reducing the time of exposure of workers to the harmful agent and on the medical monitoring of workers exposed to noise.

The recognition of the role of noise exposure as a harmful factor emphasizes the importance of early interventions as part of comprehensive worker assistance programs. Investigating innovative architectural designs, soundproofing and technological solutions can help reduce noise pollution and promote a more comfortable workplace. Ultimately, cultivating a culture of awareness and education about the potential consequences of noise exposure empowers workers to actively participate in protecting their well-being. This research adds to the growing body of evidence on the multifaceted health effects of noise, while providing robust insights that have the potential to reshape workplace policies and interventions to promote worker well-being in the face of escalating noise pollution.

Conclusion

The incidence rate of NIHL or the tendency towards it among solid waste workers is very high. To document NIHL, initial screening of workers immediately after recruitment and periodic monitoring over time is required. The audiogram recording must be complete and include all frequencies. The use of any diagnostic criteria must be complementary to the initial evaluation of the audiograms and be part of an algorithm (eg the NIOSH algorithm). Estimating exposure through self-report data is not sufficient and accurate and indeed workers exposed to higher levels tend to underestimate risk. It is necessary to assess the noise exposure with appropriate measurements in the

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

work environment (individual noise exposure of workers and environmental measurements within the workplaces) and take appropriate control and preventive measures.

Audiometric testing can be of value in the identification of hearing loss. Occupational hearing loss is preventable through a hierarchy of controls, which prioritize the use of engineering controls over administrative controls and personal protective equipment. The Occupational and Environmental Medicine (OEM) physician plays a major role in the prevention of NIHL.

Declaration for Human Participants: The study has been approved approved by the Scientific and Ethical Committee of the National School of Public Health (No 3288/13-03-2018) and the principles of the Helsinki Declaration were followed.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

Funding Statement: The authors did not obtain any funding for this research.

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