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ORIGINAL RESEARCH PAPER

Effect of small boat engine noise on hearing loss of fishermen and efficiency of small boat engine silencer

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ABSTRACT

BACKGROUND AND OBJECTIVES: The fishery workers are affected by the noise produced by motorboats, which is caused by long-term (more than 7 hours per day), exposure to high frequencies and hazardous noise levels. The detrimental impact of the loud noise emitted by small boat engines affects the hearing abilities of fishermen in Thailand has been well-documented. In light of this, the primary aim of the present study was to assess the potential hazards associated with noise exposure and develop an effective silencer that can effectively mitigate the noise generated by fishing boats. The study was conducted in Songkhla Lake, located in Thailand, providing a suitable setting for the current study.
METHODS: During an 8-hour work period, 300 sample fishers were monitored using sound-level and noise-dose meters. Their response to noise was evaluated through an audiometry test and a questionnaire. Furthermore, a silencer was engineered to decrease the noise emissions from boat engines. Utilizing the solid work technique, the exhaust silencer was designed based on a model of the internal exhaust pressure. The sound level at the end of the exhaust silencer pipe was determined by employing a sound meter and recording it at a speed of 4,000 revolutions per minute. The designed silencer was installed on the exhaust pipe of the boat engine to align with the current operation of the engine. The objective was to measure the variation in noise levels before and after the installation of the silencer. The sound level meter of type I, equipped with a weighted circuit incorporating an A network (weight A), closely resembles the auditory response of the human ear to sound. Prior to assessing the noise produced by the engine, it was ensured that the engine had been running for a minimum of 5 minutes. The sound level of the small boat's engine was then measured using a type I sound-level meter positioned at a 45-degree angle behind the engine, and at a distance of 0.5 meter.
FINDINGS: The results indicated that evaluating the risks associated with being exposed to high levels of noise from boat engines had an impact on the auditory capacity of fishermen. The right ear was more severely damaged than the left at frequencies of 6,000 (23 people) and 8,000 (20 people) Hertz at sound levels of 85 decibels A and above. This data is valuable for the development of a silencer aimed at mitigating sound pressure levels that impact the loudness of sound across different frequency levels, considering a boat engine's maximum acceleration of 4,000 revolutions per minute through the application of solid design principles. Subsequently, the silencer will be tested on Thai fishermen who are regularly exposed to noise, demonstrating a reduction in engine noise of over 23 decibels A within the frequency range of 100 to 10,000 Hertz.
CONCLUSION: The auditory abilities of fishermen are adversely impacted by the intensity and high pitch of the noise emitted by small boat engines. The solid design technique is employed to create a silencer for a boat engine with a maximum acceleration of 4000 revolutions per minute, operating at frequency levels of 2000, 3,000, 4,000, 6,000, and 8,000 Hertz. Exposure to loud noise can pose a significant risk to the hearing health of fishermen. However, their safety can be ensured by implementing effective measures to reduce the loudness by more than 23-42 decibel A. By employing such work practices, the noise levels experienced by fishermen can be kept below the hazardous threshold of > 85 decibels A.

NUMBER OF REFERENCES
40

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7

NUMBER OF TABLES
6

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INTRODUCTION

Noise-induced hearing loss (NIHL) can be caused by long-term hazardous workplace exposure to high frequencies and high noise levels (NIOSH, 2016). Illness related to hearing loss caused by loud noise has been documented in the fishery industry. Studies on fishery workers have determined the effects of the noise produced by motorboats (Barcelo-Serra *et al*., 2021). This information is utilized in medical evaluations within hospitals or in occupational health documentation to establish a diagnosis of noise-induced illnesses among individuals working in the fishing industry (Alberti *et al*., 2023). The fishery industry exists in every coastal area around the world, involving approximately 40,399,000 people. In 2016, reports of noise-related illness had increased 25 percent (%) (FAO, 2019). The hearing capacity of fishers is compromised due to the hazardous noise levels they encounter. To gain a comprehensive understanding of the impact of their work environment, it is essential to measure the noise levels and evaluate their current working conditions. This assessment is the first step in identifying workplace risks. ccurately measuring noise levels and classifying them is crucial for assessing the potential risk of hearing loss among fishers. Despite limited research on the subject, this study does not address the different factors associated with noise exposure from various boat engine sources. Only a limited number of assessment methods have been employed to ascertain ways to decrease noise exposure. The majority of studies have adopted a task-based measurement approach, wherein the noise level associated with specific job functions is measured based on the duration of work and the length of time spent on the job each day (Giorgio and Lorenzo, 2021). Songkhla Lake is the only lake in Thailand that is adjacent to two provinces. In Phatthalung province, some of the districts adjacent to the lake include Mueang Phatthalung, Pak Phayun, Bang Kaeo, Khao Chaison, and Khuan Khanun. In Songkhla province, the bordering districts are Ranot, Sathing Phra, Krasaesin, Singhanakhon, Mueang Songkhla, Khuan Niang, and Hat Yai. Residents in these areas are mostly engaged in the fishing industry (Pawida and Sekson, 2021). On Songkhla Lake, the local fishers usually use a small, high-frequency engine mounted on a long tail-boat, which has a long tail power shaft with a propeller at the end (Suratsawadee *et al*., 2021). his particular kind of boat is commonly utilized within the member countries of the Association of Southeast Asian Nations (ASEAN), such as Malaysia, Indonesia, and Singapore. According to a survey of the Songkhla Lake fishing communities, 134 boats had broken tails. The report mentioned that the damage to boat bodies or their power shafts occurred as often as twice per year, driven by shaft burnout, which increases engine noise. A fisherman is subjected to engine noise exceeding 85 a-weighted decibel A (dBA) for a duration of 8 hours per day. It is worth noting that these fishermen were unaware of and had never utilized any form of soundproofing assistance. The presence of engine noise presents a significant threat to the overall health and well-being of these individuals (Giorgio, 2022). Tinnitus emerged as the prevailing symptom among the fishermen, with a reported prevalence rate of 48.63%. Engine-room keepers exhibited a greater incidence of hearing impairment. Prolonged tenure in their role, and thus, prolonged exposure to noise over the years, was linked to elevated levels of auditory thresholds (Vachira, 2018). The absence of comprehensive regulations for noise control on small-scale fishing boats remains a pressing issue. Currently, the authorities have only introduced a voluntary program, lacking any specific regulations established by prominent agencies like the International Labor Organization, International Maritime Organization, and the Food and Agriculture Organization (FAO) of the United Nations. Some guidelines were established for ship owners/operators (Burella *et al*., 2019) in the United States, by the National Institute of Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and United States Coast Guard. The recommended maximum noise thresholds for an 8-hour duration of noise exposure on commercial fishing vessels are 90, 85, and 90 dBA (NIOSH, 2018). Noise levels surpassing 85 dBA have the potential to pose a significant risk to human health. The effects are contingent upon the length of time one is exposed to frequencies exceeding 3,000 Hertz (Hz). The level of danger and potential harm to an individual is influenced by factors such as gender, ethnicity, susceptibility, as well as unique physiological, chemical, and biological characteristics (Adrea *et al*., 2016). Work-related NIHL is another health issue inevitably experienced by small-scale fishers, which is caused by loud boat engine noise

(Śliwińska-Kowalska and Zaborowski, 2017). The generated noise differs with the type of engine (Albizu *et al*., 2020). Exposure to prolonged loud noise can lead to the occurrence of temporary threshold shift (TTS) and permanent threshold shift (PTS) hearing loss in individuals. This phenomenon is frequently observed in the medical records of hospitals located near fishing areas. TTS and PTS usually substantially impact those aged 50 and older (WHO, 2012). The assessments are required of the noise risk posed by the engines used on fishing boats. Authorities can use this information for ongoing prevention planning and reducing the health risk posed to local fishers, which are both critical to consumers. The implementation of a specially engineered exhaust silencer can effectively lower the noise levels, thereby minimizing the detrimental effects on the hearing of fishers. Additionally, this measure can contribute to the reduction of environmentally harmful emissions of toxic substances (ANSI, 1999). Exhaust silencers have the potential to be custom-designed and analyzed through experimentation in order to investigate the behavior of sound energy. These devices, which generate anti-phase fluids, are well-suited for use as exhaust silencers in muffler systems (George and Raj, 2018). These pipes cause sound to vibrate; sound energy is lost through impingement and inversion in the pipe. The design of a silencer enables the reduction of sound pressure emitted by a boat engine across different frequency levels. By incorporating a maximum acceleration of 4,000 revolutions per minute, the design of the sound pressure inlet and outlet is strategically planned to increase the distance the sound pressure needs to travel. This approach, when combined with a thorough examination using solid design techniques, effectively minimizes noise. The aims of the current study are to assess the hazards associated with noise exposure and develop a suitable noise suppressor to mitigate the noise emitted by fishing vessels. This study has been carried out in Songkhla Lake, in Thailand in 2022 and 2023.

MATERIALS AND METHODS

Sampling and boat monitoring

This study with cross-sectional design by selecting a group of small-scale fishers living in the Songkhla Lake area, southern Thailand (Fig. 1), which covers an area of 1040 squre kilometer (km^2). The climate attributes of Songkhla

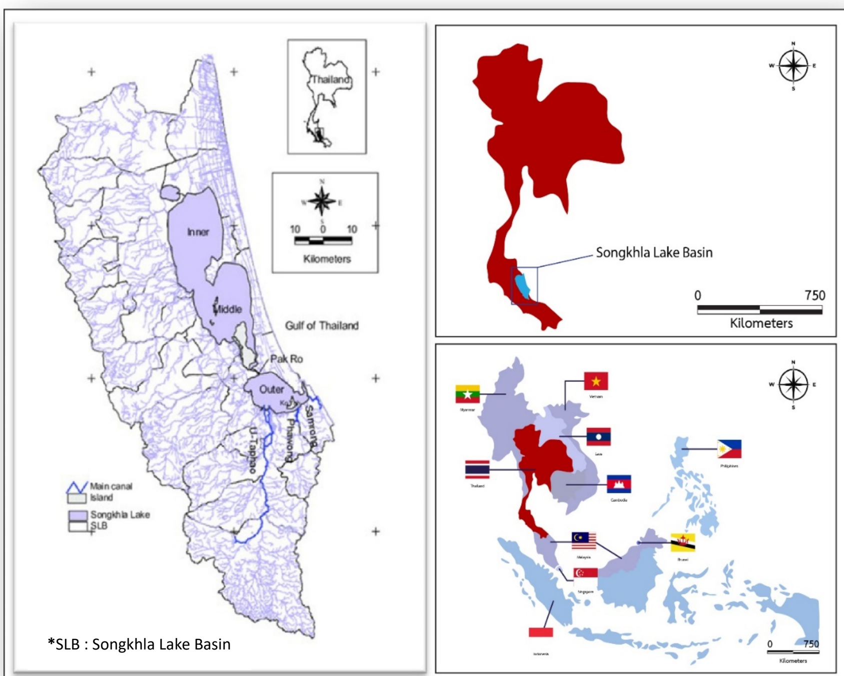


Fig. 1: Geographic location of the study arae in Songkhla Lake area , Southern, Thailand

Table 1: Sound monitoring of samples

Boat Sampler (boat)	Fisherman (person)	Measuring period	Sound Level meter	Noise dosimeter
100	300	06.00-15.00 (>8 h)	Brand: 3M Model: BLN020003	Brand 3M Model: Q-300 NXNO20007

Lake consist of temperatures fluctuating between 27.4 and 33.9 degrees Celsius, relative humidity levels varying from 56 to 95.8%, an average wind speed of 2.2 knots, and an average precipitation of 1,873.8 millimeters annually. Its coordinates are at latitudes 6° 45¢ to 8° 00¢ north (N) and the longitude line 99° 30¢ to 100° 45¢ east (E). A total of 100 boats participated in this study; each boat hosted 3 fishers, for a total sample of 300 (Total population) fishers who were exposed to loud noise and the risk of hearing loss. 2 distinct instruments were employed to gauge the sound level: 1) A noise dosimeter (Q-300 NXNO20007, 3M) was utilized to assess the cumulative noise exposure encountered by each fisherman on board throughout the entire day. This device was affixed to the individuals while they performed their duties on the vessel, capturing the noise data from the beginning till the end of the working day. 2) The researchers utilized a sound-level meter (SLM) of type I, BLN020003, 3M to assess the sound level produced by the 13 Horse power (hp) V13 one-cylinder gasoline engines of the small boats. The data collection took place from 6:00 a.m. (ante meridiem) to 3:00 p.m. (post meridiem) over an 8-hour working period, as detailed in Table 1. Additionally, they employed an audiometer (AC50-B, SIBELMED) to evaluate the hearing capabilities of each fisherman.

Cross-sectional model

The impact of noise exposure on the hearing abilities of fishermen has been assessed for both ears. The participants were small-scale fishers in the Songkhla Lake area, whose hearing loss had been increasing by 10% every year. The study included 100 fishing boats, each of which hosted three fishers, for a total of 300 people in this study group who were at risk of hearing impairment. The study was performed in the Songkhla Provincial Public Health Office. First, asking all participants to answer a questionnaire. As the general information, the questionnaire responses confirmed if the participants had ever had any prior ear injury; if they had any hearing loss at birth; and if they had worked with hazardous chemicals, e.g., toluene, lead, manganese, normal butyl alcohol, trichloroethylene, carbon disulfide, styrene, mercury, or arsenic. The questionnaire was used to ask about taking any medication that could have affected their hearing inability.

Instrument and study tool

The questionnaire was developed by referring to the literature and selecting questions specifically related to hearing loss. It is divided into five parts. Part 1 (personal information) included seven close- and open-ended questions; Part 2 (medical history and illness records related to hearing loss) consisted of five closed ended questions; Part 3 (noise damage prevention behaviors) comprised four closed-ended questions; Part 4 (additional details) comprised 5 open-ended questions, which used to gather any other individual details. The data records of hearing performance tests were acquired in a standard format from the occupational doctor at the Songkhla Provincial Public Health Office in Thailand. The sound level was measured and determined by utilizing the data obtained from the noise dose meter. Experts validated all three study tools, namely the questionnaire, hearing records, and sound level. The interview questionnaires were examined for their alignment with the study objectives, ensuring content consistency. Subsequently, a thorough evaluation was conducted by five experts from diverse backgrounds, including three occupational health and safety officers and two public health professionals specializing in hearing loss. These experts meticulously assessed the language and content of each tool, scrutinizing them for accuracy, comprehensiveness, clarity, and appropriateness. The study conducted an experiment using the survey on 15 fishermen from different regions in order to assess the reliability of the questionnaire. The findings indicated a satisfactory outcome, showing a confidence level of 0.81 (Cronbach's alpha; α = 0.81). The audio meter utilized was the SibelSound 400, with a serial number of 033700. It adhered to the BS EN60645-1 type 3 standard and underwent calibration by a laboratory staffed with professionally qualified individuals. The Audiometric Cabin S40

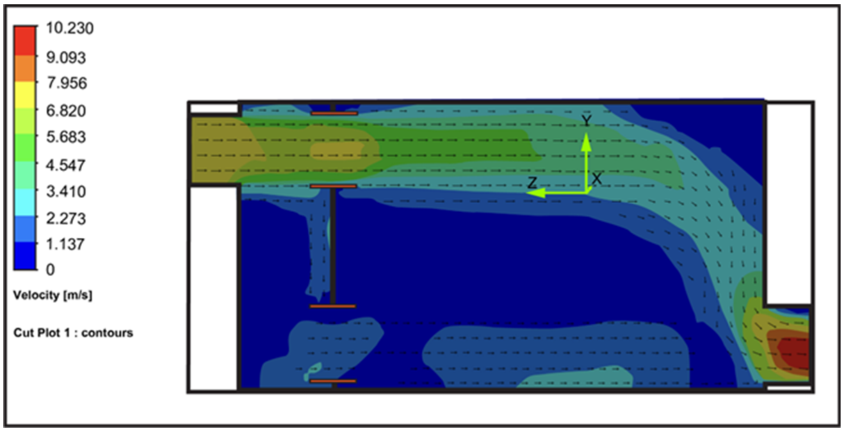


Fig. 2: Sound model using the exhaust silencer by solid work technique

model A was utilized as an auditory test room to regulate noise levels, ensuring compliance with the American National Standard Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms (ANSI S3.1-199128) (Trevorrow and Vasilier, 2008). The sound level was measured in accordance with OSHA standards using a calibrated noise dosimeter (3M, Quest Technologies, type I model) that complied with the American National Standard Institute (ANSI) Standard S1.25-1978, titled "Specifications for Personal Noise Dosimeters". The equipment (adjustment and verification) was then tested before and after each use, to ensure the instrument was suitable for the study application. Before commencing the study, the researchers provided a comprehensive explanation of the study's objectives and data collection procedures to the participants. The fishers were duly informed that their participation in the study was entirely voluntary. It is worth noting that the data obtained during the course of this study were treated with utmost confidentiality. During the process of data collection, the participants' names or addresses were not gathered. All pertinent study information was securely stored in a designated location. The data will be eliminated 1 year after the study has been published. The design principles for off-set silencers involve enhancing the flow distance of sound pressure within the silencer's pores. This deliberate increase in flow distance results in a reduction of sound pressure energy as it traverses through the pores, primarily due to a decrease in kinetic energy. diminishes as a result of simulating the flow of sound pressure. By configuring the sound pressure inlet to be positioned opposite the outlet, the sound pressure is compelled to cover a greater distance, leading to further reductions in sound energy. This phenomenon can be assessed through the implementation of the solid work technique. The exhaust silencer was constructed by analyzing the noise emitted from the end of the exhaust silencer pipe with a sound meter while the boat engine was running at a speed of 4,000 revolutions per minute (rpm) (Fig. 2). This process was carried out to replicate the actual operating conditions of the boat engine before installing the silencer onto the exhaust pipe. The alteration in volume was assessed by measuring the difference in loudness prior to and subsequent to the installation of the specifically engineered silencer (Fig. 3). The type I SLM with a weighted circuit with an A network (weight A) is the most similar to the human ear response to sound (Measure sound loudness at 2,000, 3,000, 4,000, 6,000 and 8,000 Hz) frequency levels. Prior to conducting the engine noise measurement, the engine underwent a warming-up process for a minimum duration of 5 minutes. Subsequently, the sound level of the long-tail boat engine was assessed using a Type I Sound Level Meter (SLM) positioned behind the engine at a 45-degree angle and at a distance of 0.5 meters (Gassmann *et al*., 2017).

Data collection

Hearing test

The tests were conducted by an audiologist on the 300 fishermen who were consistently exposed to

Fig. 3: silencer on the boat engine's exhaust pipe

engine noise from the 100 various boats. The team collaborated with the fishers involved to communicate the goals and seek their cooperation. The Songkhla Provincial Public Health Office was involved in the study as the sponsoring organization. In order to conduct the hearing test, participants were instructed to cease their exposure to loud noise for a minimum of 14–16 hours before the test to avoid TTS). Prior to commencing the test, participants took a minimum of 15 minutes to rest. The participants underwent ear examinations, which involved the use of an otoscope to examine the external auditory canal and tympanic membrane. Prior to each examination, the hearing specialist ensured that the equipment settings and installation were properly checked and pretested the instrument. Subsequently, the hearing tests were conducted. The examination encompassed audiometry using air conduction at different frequencies, namely 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. Following this, the information was recorded. The assessment of hearing function was established by evaluating the auditory capacity in both ears based on the mean of the air conduction outcomes. During the bone conduction examination, vibrators were positioned on the auditory ossicles. During each test, a sound of a specific frequency was emitted at varying levels of volume. The volume of the sound was then systematically reduced until reaching the minimum threshold at which the participants were able to detect it. The classification of hearing disability in terms of NIHL is based on six levels, determined by the quietest sound that can be heard. These levels are as follows: 1) Normal hearing, ranging from -10 to 25 dBA. 2) Mild hearing loss (slight), ranging from 26 to 40 dBA. 3) Moderate hearing loss (moderate), ranging from 41 to 55 dBA. 4) High hearing loss (high), ranging from 56 to 70 dBA. 5) Severe hearing loss (severe), ranging from 71 to 80 dBA. 6) Profound hearing loss (deaf), exceeding 90 dBA.

interviews to obtain personal background information sigh questionnaire

The interviews were carried out with the participants in order to inquire about their individual experiences with high levels of noise and the specific hearing protection devices they utilized. The interviews took place subsequent to the participants completing their hearing assessments.

Sound-level measurement

The sound exposure level experienced by the fishers was determined by utilizing a noise dosimeter, which was installed on every fishing boat. This determination was made in accordance with the ANSI Standard S1.25-1978, titled "Specifications for Personal Noise Dosimeters," in order to calculate the cumulative sound level. he OSHA standards were meticulously adhered to for the collection method, which involved individual measurements of sound levels at different frequencies produced by the boat engines using an SLM (3M, S/N BLN020003) (HSE, 2022). The sound level generated by 100 boat engines running at 4,000 rpm was assessed by utilizing a type I SLM positioned 0.5 meters away from the exhaust silencer pipe of the boat engine at a 45-degree angle. The accuracy of the obtained results was fine-tuned with a sound calibrator, aligning the readings with sound test values of 94 and 114 dBA. The sound of each boat was calibrated using a sound calibrator in accordance with the International Electrotechnical Commission

Table 2: Individual factors of the sample

Type	Amount (Persons)	Percentage (%)
1. Individual factors		
Male	211	70.3
Female	89	29.7
2. Age (y)		
≤30	18	6.0
31-40	16	5.3
41-50	108	36.0
>51	158	52.7
3. Education level		
Primary	173	57.7
Junior high school	67	22.3
Senior high school	53	17.7
Diploma degree	7	2.3
4. Years of work in fishery (y)		
≤ 10	43	14.3
11-20	67	22.4
21-30	138	46.0
31-40	52	17.3
41 -50	-	-
5. Noise exposure duration per day (h)		
1-2	-	-
3-4	-	-
5-6	47	15.7
7-8	253	84.3
9-10	-	-

(IEC) 60942 standard. Sound levels were recorded for a duration of 5 minutes for each boat, both prior to and subsequent to the installation of the exhaust silencer. Measurements were taken at frequencies of 2,000, 3,000, 4,000, 6,000, and 8,000 Hz to evaluate the effectiveness of the silencer in reducing noise.

Statistical analysis

The impact of cumulative sound exposure on the participants' hearing ability was assessed through a rigorous analysis of descriptive statistics and analysis of variance using the Statistical Package for the Social Sciences (SPSS).

RESULTS AND DISCUSSION

Individual factors

The data collected through a survey from 300 fishermen in the Songkhla Lake region between July 1, 2022, and May 1, 2023, was analyzed. Of the 300 participants, 211 were men (70.3%) and 89 were women (29.7%). The age distributions under 30 years old were 18 people (6.0%), 16 aged 31–40 (5.3%), 108 aged 41–50 (36.0%), and 158 aged 51 or older (52.7). Regarding educational level, 173 (57.7%), 67 (22.3%), 53 (17.7%), and 7 (2.3%) had primary, junior high school, senior high school, and diploma education. In terms of years working in fishery, 43 (14.3%) had less than 10 years of experience, 67 persons (22.4%) had worked for 11–20 years, 138 (46.0%) had 21 -30 years of experience, and 52 persons (17.3%) had 31–40 years of experience. A total of 47 participants (15.7%) were exposed to 5–6 h of loud noise per day and the remaining 253 (84.3%) to 7–8 h/d. All information is listed in Table 2.

RESULTS AND DISCUSSION

Individual factors

The analysis involved examining the data obtained

Table 3: Medical records and hearing illness of participants

Types	Amount (Persons)	Percentage (%)
1. Has the participant made a hearing test before?		
Yes	-	-
No, never	300	100.0
2. Have the participant got a hearing treatment?		
Yes	-	-
No, never	300	100.0
3. The recurrence of an earache, tinnitus, or deaf		
Very frequently	-	-
Often	87	29.0
Sometimes	163	54.3
Rarely	50	16.7
Not at all	-	-
4. The irritation of noise inside ears		
Very frequently	-	-
Often	36	12.0
Sometimes	134	44.7
Rarely	103	34.3
Not at all	27	9.0
5. Requesting others to speak up louder		
Sometimes	97	32.3
Rarely	33	11.0
Not at all	170	56.7

from a survey conducted among 300 fishermen residing in the Songkhla Lake area during the period from July 1, 2022, to May 1, 2023. Out of the total participants, 211 were male, accounting for 70.3% of the sample, while 89 were female, making up 29.7% of the sample. The age distribution of the participants revealed that 18 individuals (6.0%) were below 30 years old, 16 individuals (5.3%) fell within the age range of 31 to 40, 108 individuals (36.0%) were aged between 41 and 50, and 158 individuals (52.7%) were 51 years old or above. In relation to educational attainment, the distribution was as follows: 173 individuals (57.7%) had primary education, 67 individuals (22.3%) had junior high school education, 53 individuals (17.7%) had senior high school education, and 7 individuals (2.3%) had diploma education. With regards to the duration of employment in the fishery sector, 43 individuals (14.3%) had less than 10 years of experience, 67 individuals (22.4%) had worked for 11–20 years, 138 individuals (46.0%) had 21-30 years of experience, and 52 individuals (17.3%) had 31–40 years of experience. Table 2 presents the data indicating that out of the total 47 participants, which accounts for 15.7% of the sample, were subjected to 5-6 hours of loud noise exposure on a daily basis. Conversely, the majority of participants, comprising 253 individuals or 84.3% of the sample, were exposed to 7-8 hours of loud noise per day.

Medical records and hearing illness

A total of 300 local fishermen underwent hearing tests, with none of them having previously undergone any form of hearing treatment. In terms of the prevalence of earache, tinnitus, or deafness, 87 individuals (29%) reported experiencing these symptoms often, 163 individuals (54.3%) reported experiencing them sometimes, and 50 individuals (16.7%) reported experiencing them rarely. The frequency of occurrences of inner ear noise irritation yielded the following results: often = 36 (12%), sometimes = 134 (44.7%), rarely = 103 persons (34.3%), and never = 27 (9.0%) persons. Of the respondents, 24 (8.0%), 146 (48.7%), 97 (32.3%), and 33 (11.0%) persons reported very frequently, often, sometimes, and rarely having to ask others to speak up louder. The findings are reported in Table 3. The Standard hospital contact ratio for NIHL was reported as 119 (95% confidence interval 85-162 decibel A). Additionally, the standard hospital contact ratio for NIHL, tinnitus, and early signs of NIHL, with a prevalence ranging from 19% to 67%, was identified

Table 4: The hearing performance of the right ear for participated fishermen in Songkhla Lake

Frequency (Hz)	Hearing performance (hearing loss)					
	Normal (persons),(%)	Mild (persons),(%)	Moderate (persons),(%)	High (persons),(%)	Severe (persons),(%)	Profound (persons),(%)
2,000	207(69.0)	63(21.0)	22(7.3)	0(0.00)	8(2.7)	0(0.00)
3,000	187(62.3)	74(24.7)	19(6.33)	12(4.0)	8(2.67)	0(0.00)
4,000	166(55.3)	87(29.00)	13(4.3)	23(7.7)	11(3.7)	0(0.00)
6,000	198(66.0)	32(10.7)	34(11.3)	13(4.3)	23(7.7)	0(0.00)
8,000	127(42.4)	73(24.3)	46 (15.3)	34(11.3)	20(6.7)	0(0.00)

as one of the most prevalent otoneurological symptoms, followed by otalgia (Arumugam *et al*., 2015). Mansi *et al*., (2019) conducted a study which indicated that individuals who are involved in working with boat engines are at a higher risk of experiencing adverse effects due to noise exposure. The primary physical health concern associated with prolonged exposure to loud noises is hearing loss. Additionally, exposure to excessive noise levels can result in both sensorineural and conductive hearing loss. Engines room workers exhibited a sorineural hearing loss prevalence of 26% (Albizu *et al*., 2020). The study recorded the noise level and frequency of fishing boat engines on Songkhla Lake at sound pressure levels of 86.8, 87.8, 88.4, 88.8, 89.1, 89.5, 90.4, 90.8, and 91.4 dBA at frequencies of 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. The noise produced varying health issues in the participating fishers because the sound field generated by boat engines varies with the frequency and angle of the boat (Zhu *et al*., 2022). When a boat is on water, its propeller is 2–3 m below the surface. Thus, the sound transmission reflecting to the water surface produces a strong downward noise pattern (Bramhall *et al*., 2019). The noise emitted by the boat and reflected by the air generates a dipole radiation pattern in physical terms, resulting in the transmission of boat noise deep into the ocean. However, the transmission of noise along the horizontal plane near the sea surface is significantly diminished as a result of destructive interference caused by the reflection and original sources. According to the findings, it was discovered that a significant proportion (46.7%) of individuals aged 40 and above, who were subjected to prolonged exposure of loud noise exceeding 8 hours per day, faced a considerable risk of experiencing hearing impairment (Yadav *et al*., 2023).

Hearing performance

The audiometric evaluations of the fishermen were conducted by the healthcare professionals at Songkhla Hospital utilizing an audiometer from July 1, 2022, to May 1, 2023. Each month, 30 fishermen underwent hearing assessments, resulting in a total of 300 participants over the course of 10 months. The hearing results (Table *4*.) indicated highest severe hearing loss in the right ear in 23 persons (7.7%) at 6,000 Hz and in 20 persons (6.7%) at 8,000 Hz.

The left ear hearing results showed hearing loss as; 7 (2.3%) at 2,000 Hz, 10 (3.4%) at 6,000 Hz, and 10 (3.3%) at 8,000 Hz, as shown in Table 5. In contrast to the noise exposure encountered by workers in a wood factory, the left ear has demonstrated a slightly higher susceptibility to it compared to the right ear (Boger *et al*., 2009). Harger and Barbosa–Branco (2004) conducted a study that revealed the average frequencies ranging from 3,000 to 8,000 Hz. It was observed that each frequency range had a corresponding sound pressure level measured in decibel A. In the metallurgical facilities, the frequency band of 8,000 Hz stands out as the primary source of excessive noise (85.4 dB), prevailing within the environment and posing the greatest threat to workers. This heightened exposure significantly elevates the risk of hearing impairment among individuals. Participants who were exposed to high frequencies of 2,000–8,000 Hz experienced elevated levels of hearing loss in this study. The results indicated that hearing loss in both ears rose as sound pressure and frequency increased. The participants exhibited a higher prevalence of hearing impairment in their right ear compared to their left ear across all frequencies due to the fact that fishermen typically sit in a sideways position while using the motor, causing their right ear to be exposed to the engine noise (Song *et al*., 2016). The concurrent presence of engine noise, propeller noise, and noise reverberating off the water posed a hazard as a result of prolonged exposure to high levels of noise (sound pressure level (Lp) exceeding 85 dBA for 8 hours)

Table 5: The hearing performance of the left ear for participated fishermen in Songkhla Lake

Frequency (Hz)	Hearing performance (hearing loss)					
	Normal (persons),(%)	Mild (persons),(%)	Moderate (persons),(%)	High (persons),(%)	Severe (persons),(%)	Profound (persons),(%)
2,000	(0.27)162	(4.12)46	(3.2)7	(0.2)6	(3.7(2	(0)0
3,000	(7.57) 272	(3.41)34	(3.5)16	(7.4)41	)0.0)0	(0)0
4,000	(0.63)891	(3.20)16	(9.0)27	(3.4)31	(4.3)10	(0)0
6,000	(7.48)461	(0.82)48	(0.9)27	(0.11)33	(3.3)10	(0)0
8,000	(0.27)162	(4.12)46	(3.2)7	(0.2)6	(3.7(2	(0)0

(Manar *et al*., 2019). Furthermore, the participants' average daily noise exposure was evaluated through full-day measurement (FDM) using a dosimeter to determine noise exposure levels. The FDM approach is considered reliable, with a tolerance of <1 dBA due to the variations in the Standard Class 1 microphone utilized during the assessment (Shi *et al*., 2016). Overexposure to loud noise can lead to a TTS. Long-term overexposure to such noise can permanently damage the synapses between the inner hair cells and auditory nerve fibers (Bramhall *et al*., 2019). Noise exposure has different impacts on the auditory nerve system depending on the environment and individual physical characteristics. Some hearing loss is caused by synaptic loss above 4 kHz (Priya and Hohman, 2023). Auditory nerve fibers, with low spontaneous rates and high thresholds, are a key component in sound coding, especially in the presence of background noise (Lee *et al*., 2021). Functional changes in noise-induced cochlear synaptopathy, including decreased peak I amplitude in the compound action potential and the auditory brainstem responses (Lucus *et al*., 2020), produce hearing defects, which found that individual factors e.g., sex, age, fishery employment duration, and length of exposure to engine noise were statistically significantly correlated with NIHL at the 95% confidence level in those aged 41 and above. Elderly fishermen who commenced their careers in fishing at a young age faced potential hazards from prolonged exposure to loud noise. Roughly 10% of these fishermen started to encounter hearing loss between the ages of 40 and 49. The research revealed that 6.66% of the participants exhibited severe hearing loss without any previous indications such as ear pain, ringing in the ears, or deafness. Furthermore, individuals aged 40 and above were more susceptible to hearing impairment compared to younger fishermen. The implementation of an exhaust silencer significantly altered the direction of noise flow, decreased the sound pressure level, and attenuated the noise intensity at higher frequencies; the utilization of an indented filling extended the flow distance and modified the noise flow direction in contrast to employing a straight pipe, particularly during elevated engine revolution scenarios (Gryboś *et al*., 2021).

Comparision of hearing loss

Fig. 4 compares the hearing loss between the left and right ears of the 300 fishers at different frequencies.

Relationship Between noise level and hearing loss in left and right ears at different frequencies

Fig. 5 illustrates the impact of different noise frequencies on hearing loss in both the left and right ears. The study revealed that as the sound pressure level (SPL) increased, so did the hearing loss in both ears. Furthermore, a positive correlation was observed between noise level and high frequency sound, leading to an increase in hearing loss. Based on the data, it was observed that when the noise level surpassed 85 dBA across all frequencies, more than 30 individuals engaged in fishing encountered hearing impairment. The study aimed to examine the auditory capabilities of individuals exposed to occupational noise in both conventional and high frequencies. It specifically evaluated those exposed to noise levels exceeding 90 dBA, while also considering individuals without any history of noise exposure or hearing difficulties. The findings indicate that as the frequency, age, and duration of noise exposure increase, there is a corresponding impact on the results obtained (Porto *et al*., 2004).

Based on the assessment of environmental noise sources, it was observed that within each industry examined, distinct outcomes were identified in relation to the environmental noise spectrums. These

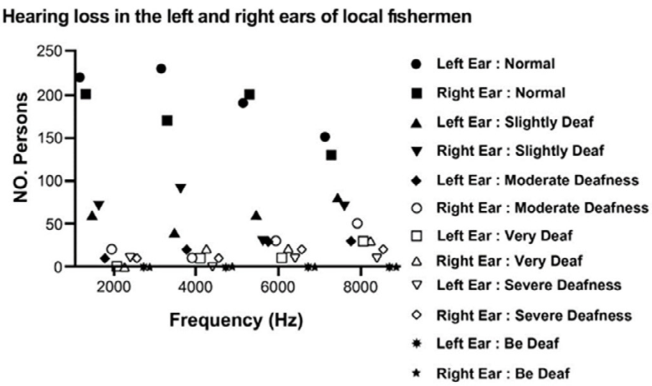


Fig. 4 : Comparison of Hearing Loss on left and right ears of the participated Fishermen

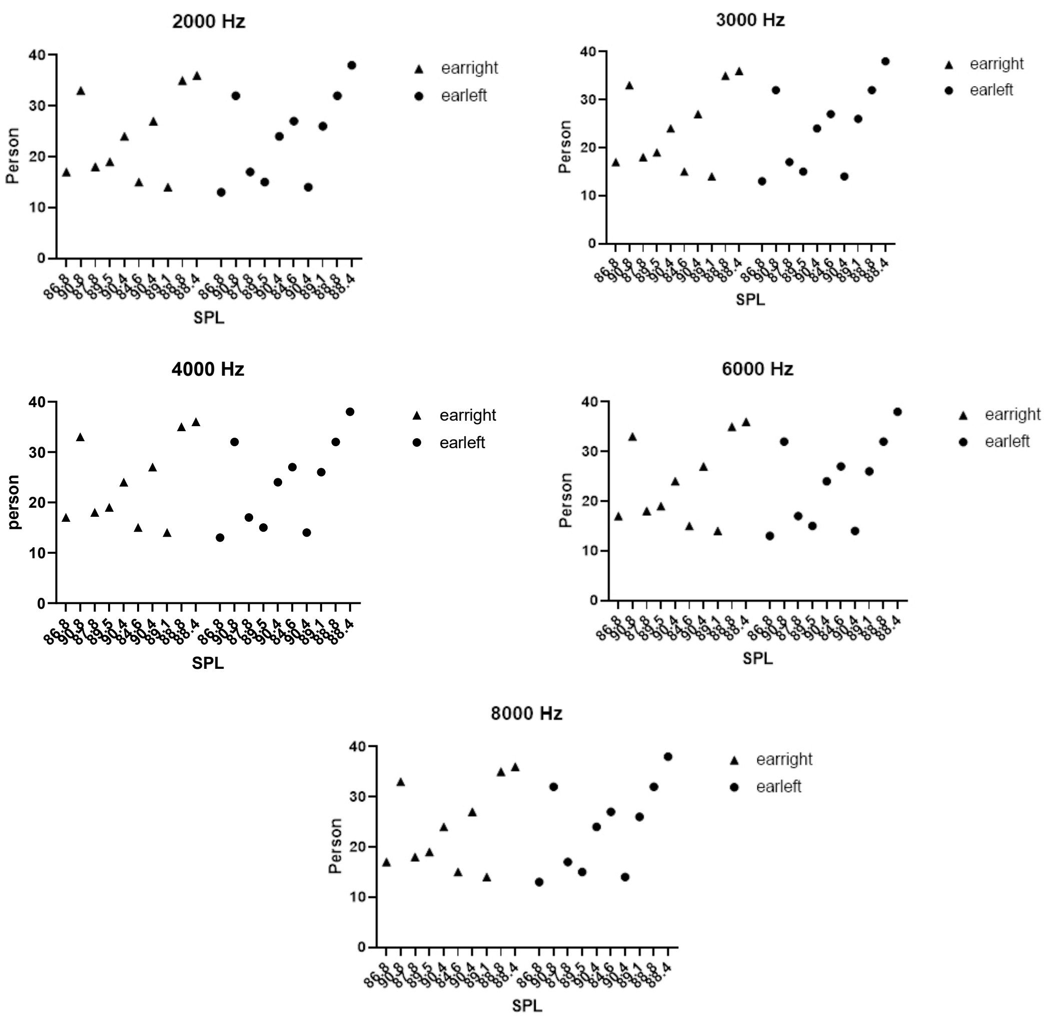
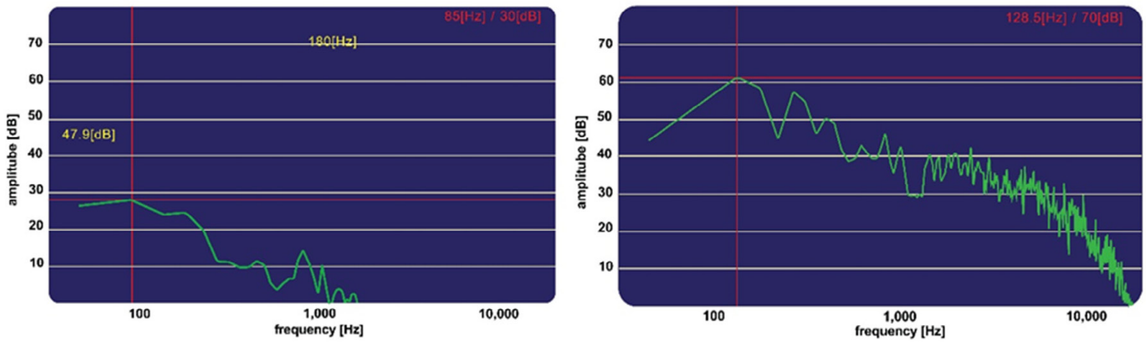


Fig. 5 : The sound pressure level (SPL) and hearing loss on the left and right ears at different frequencies (Into 2,000, 3,000, 4,000, 6,000 and 8,000 frequencies)



(A) (B)

Fig. 6 : Volume reduction at different sound frequencies before (A) and after (B) using an exhaust silencer

Table 6: The hearing performance of the right ear for participated fishermen in Songkhla Lake

Frequency (Hz)	Sound pressure level before using the muffler (dBA)	Sound pressure level after using the muffler (dBA)	Reduced sound level (dBA)	p-value
2,000	110	68	42	
3,000	110	75	35	
4,000	110	79	31	0.04*
6,000	110	83	27	
8,000	110	87	23	

* Mean value with a significant difference ≤ 0.05

findings indicated that each frequency band had a varying impact on the development of noise-induced hearing loss (NIHL) in individuals

Efficacy of exhaust silencer in reducing noise level at different frequencies

present the variations in sound levels across various frequencies prior to and post the implementation of the exhaust silencer on 100 boat engines, demonstrating a statistically significant difference ($p \leq 0.05$). Notably, the frequencies of 42 dBA at 2,000 and 8,000 Hz exhibited the most substantial attenuation. Furthermore, the recorded minimum of 23 dBA aligns with the anticipated noise reduction model curve as illustrated in Fig. 7, showcasing the efficacy of the designed offset silencer in diminishing noise levels within the range of 100 to 10,000 Hz. This indicates an enhancement in sound level attenuation achieved through the silencer, which designed to allow the movement of sound through a porous model that allows it to absorb sound. The pores in the silencer will cause the noise passing through the pores to lose energy from the pressure inside the silencer. Prior to the design phase, a simulation was conducted to analyze the sound pressure distribution within the silencer pipe in order to determine the maximum sound pressure loss. This simulation involved utilizing the solid work technique to flow pressure. The indented pipe, known as the porous pipe, is specifically engineered to facilitate the flow of pressure. It is designed in such a way that the pressure enters from the top and then travels horizontally through the pores. This unique design effectively diminishes the energy of sound pressure, preventing it from escaping on the opposite side and consequently leading to a reduction in noise levels. Laffay *et al.* (2018) conducted an experimental study focusing on the noise reduction and characteristics of high-pressure exhaust flow through diaphragms and perforated plates. The study highlighted the effectiveness of porous materials in reducing noise levels within general silencers, which are frequently utilized as readily accessible sound-absorbing materials (Gama *et al*., 2018). The porous substance utilized in the newly designed silencer demonstrated exceptional effectiveness in decreasing the noise intensity at moderate and elevated frequencies (Yuan *et al*., 2021).

Fig. 7 illustrates that upon installation of the

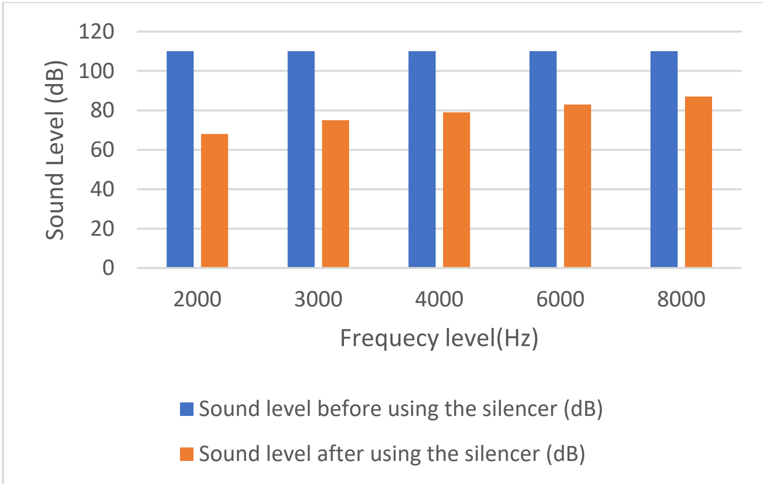


Fig. 7: Compare the noise level before and after using the silencer

silencer, there was a significant reduction in sound levels within the frequency range of 2,000–8,000 Hz. The average decrease exceeded 23 dBA, ensuring that the sound level did not surpass 85 dBA across all frequencies. These findings validate the outcomes of the study, suggesting that the implementation of guidelines can effectively address the issue of excessive noise emitted by small boats, which adversely affects the fishermen in the Songkhla Lake region.

CONCLUSION

This study found that the hearing loss of local fishers was related to noise exposure in the 2,000–8,000 Hz range, noise levels 85 dBA or above, and noise exposure of over 7 h/d. Which will lead to the birth of Noise-Induced Hearing Loss (NIHL), which is a disease in the group Sensorineural Hearing Loss (SNHL) is caused by exposure to excessively loud sound for a long enough period to cause the disease. Hearing loss can be attributed to exposure to excessively loud sounds, leading to mechanical damage that results in the destruction of hair cells located within the cochlea. This condition is recognized as a significant occupational hazard and has the potential to result in disability. Given the proximity of the right ear to the engine, the motor, gearbox, and propeller collectively produce a high level of noise. The rapid combustion of fuel within the engine cylinder results in small explosions, leading to the continuous loud noise emitted by the motor through its shafts and rotating gears. The rotation of the propeller occurs as the boat moves through the water. A significant amount of air bubbles will form in the water due to cavitation. The creation of these bubbles is known as cavitation. An audible noise is produced when these bubbles implode. The rapid rotation of the propeller is what causes the boat to accelerate. The experiment resulted in the generation of a high-frequency noise and the formation of air bubbles within the water. The maximum frequency reached was 20,000 hertz. A majority of the subjects reported greater hearing impairment in their right ear compared to their left ear, attributed to the closer proximity of the right ear to the engine based on their operational positioning. The majority of participants reported a greater degree of hearing impairment in their right ear compared to their left ear. This discrepancy can be attributed to the proximity of the right ear to the engine, given its operational placement. It is important to note that this pattern of hearing loss differs from the prevalence of hearing impairment in the left ear, which is more commonly observed among workers in various industries such as wood factories and iron foundries. The majority of the individuals involved in the project were male fishermen, while those who were over 41 years old experienced a higher incidence of hearing loss. Interestingly, the medical records of these fishermen revealed that most of them did not exhibit any early indicators of hearing loss, such as earache, tinnitus, or difficulties in their everyday interactions. Following prolonged exposure to consistently high levels of noise for 21 years, 6.6% of individuals suffered from significant and irreversible hearing impairment. Consequently, efforts have been made to address this issue by investigating sound pressure distribution patterns in order to develop diverse strategies aimed at mitigating noise pollution. Through the application of Solid work technique, the sound flow characteristics in different silencers were simulated in order to investigate the most effective method. The results revealed that the design of the silencer with off-set pores effectively diminishes the intensity of loud noise at high frequencies ranging from 100 to 10,000 Hz. This study specifically focused on the noise level emitted by a boat engine operating at speeds ranging from 1,000 to 4,000 rpm. The exhaust silencer effectively lowers the noise level to a range of 23–42 dBA, ensuring that it falls below the necessary safety standards. By maintaining the noise level at or below 85 dBA, it prompts local authorities to implement proactive measures aimed at minimizing noise exposure for nearby fishermen. In order to address the issue of hearing protection for fishermen operating small boats exposed to high-frequency noise, it is essential to establish regulations. This can be achieved through the collaboration of various stakeholders, including groups of fishermen, local authorities, regional agencies, and researchers. By working together, these entities can develop standards and regulations pertaining to the installation of silencers in fishing boats. This proactive approach will help safeguard the hearing health of fishermen and mitigate the potential risks associated with prolonged exposure to high-frequency noise.

AUTHOR CONTRIBUTIONS

S. Sinworn designed the field experiment, organized the study, discussion, and manuscript preparation. N. Viriyawattana as the corresponding author was involved in the study design, data collection, and interpretation of results and contributed to manuscript preparation and article approval.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

ABBREVIATIONS

%	Percent
a	Cronbach' s Alpha
a.m.	Ante meridien
ANSI	American National Standard Institute
ASEAN	Association of Southeast Asian Nations
BS	British Standard
dBA	A-weighted decibel
E	East
FDM	Fully – day measurement
FAO	Food and Agriculture Organization
IEC	International Electrotechnical Commission
h	Hour

h/d	hours per day
hp	Horse power
Hz	Hertz
kHz	Kilo-heartz
km²	Square kilometer
Lp	Noise pressure level
m	Meter
min	Minute
N	North
NIHL	Noise induced hearing loss
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
p.m.	Post meridiem
PTS	Permanent threshold shift
rpm	Revolution per minute
SLM	Sound level meter
SPL	sound pressure level
SPSS	Statistical package for the social sciences
TTS	Temporary threshold shift
Weight A	Frequency weighting A

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