LITERATURE REVIEW

Literature Review:

OCCUPATIONAL NOISE INDUCED HEARING LOSS

Oleh:

dr. Dewi Indah Lestari, MKK, Sp.OK

FAKULTAS KEDOKTERAN
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Background

Occupational noise-induced hearing loss (ONIHL) is a leading cause of acquired hearing impairment worldwide, particularly among workers in manufacturing, mining, and construction. Early detection is critical for effective intervention and prevention, yet conventional screening methods, such as pure-tone audiometry, are resource-intensive, require specialized personnel, and are often inaccessible in low-resource or remote settings.[1–5]

In countries like Indonesia, the impact is particularly acute, where approximately 16.8% of the population experiences hearing loss, leading to substantial declines in quality of life, social isolation, and economic productivity. Traditionally, the gold standard for diagnosis, pure-tone audiometry, requires specialized equipment, soundproof rooms, and trained audiologists, resources that are often inaccessible and unaffordable in low- and middle-income regions. The emergence of website-based and mobile hearing screening applications offers a promising alternative, leveraging digital platforms to deliver scalable, cost-effective, and potentially more accessible screening. These tools employ methodologies ranging from speech-in-noise tests to mobile audiometry and machine learning-based risk prediction, aiming to overcome the limitations of traditional approaches and facilitate early identification of ONIHL.[2,3,6–8]

In response to these challenges, digital health innovations have led to the development of alternative hearing screening modalities, including smartphone- and web-based audiometric tools. Web-based hearing screening tools offer potential advantages in terms of scalability, accessibility, and cost-effectiveness, making them attractive options for preliminary hearing assessment in occupational contexts. Such tools are generally designed for screening rather than diagnostic purposes, aiming to identify individuals who may require further evaluation using conventional audiometry.[3,4,9]

International occupational health frameworks, including those developed by the International Labour Organization (ILO) and the National Institute for Occupational Safety and Health (NIOSH), emphasize comprehensive hearing conservation programs as a cornerstone of NIHL prevention. Central to these programs is periodic hearing surveillance to detect early threshold shifts and prevent further deterioration through timely intervention. Early identification of hearing impairment is therefore critical for effective risk management among noise-exposed workers. Screen-H is one example of a web-based hearing screening tool developed to assess hearing thresholds at frequencies relevant to occupational NIHL.

Hearing Anatomy, Physiology and Pathology

Noise-induced hearing loss (NIHL), the most common occupational auditory disorder, results primarily from damage to cochlear outer hair cells caused by excessive acoustic stimulation. Chronic or repeated exposure to hazardous noise levels induces mechanical stress and metabolic injury, leading to oxidative damage, hair cell dysfunction, and eventual irreversible cell loss. Early NIHL typically manifests as high-frequency sensorineural hearing loss, often with a characteristic notch at 4–6 kHz, reflecting the vulnerability of the basal cochlear region. From an occupational health perspective, NIHL is insidious and often asymptomatic in its early stages, progressing gradually until speech frequencies are affected. This pathophysiological progression underpins the emphasis placed by international guidelines on early detection through periodic hearing surveillance. Screening tools focus on identifying frequency-specific threshold shifts indicative of early cochlear damage, particularly in noise-exposed populations. In the context of this systematic review, understanding the anatomical and physiological basis of hearing is essential for interpreting the performance of web-based hearing screening tools. Such tools aim to detect functional consequences of cochlear pathology rather than structural abnormalities. Their validity therefore depends on accurate assessment of hearing thresholds at frequencies most susceptible to noise-related damage. Synthesizing evidence on these tools requires careful consideration of how well screening outcomes reflect underlying auditory pathology when compared with pure-tone audiometry as the reference standard.[10,11]

Noise Exposure and Occupational Noise-Induced Hearing Loss

Noise exposure refers to the presence of unwanted or excessive sound that may cause adverse health effects, particularly when exposure occurs at high intensity and over prolonged periods. In occupational settings, noise is commonly generated by machinery, tools, engines, and industrial processes. Sound intensity is measured in decibels (dB). which reflects the frequency sensitivity of the human ear. Occupational Noise-Induced Hearing Loss (ONIHL) is defined as a partial or complete hearing loss in one or both ears as the result of one's employment; it is a function of continuous or intermittent noise exposure and usually develops slowly over several years.[12,13] ONIHL is different from the acoustic trauma, which is characterized by a sudden change in hearing as a result of a single exposure to a sudden burst of sound, such as explosive blasts, gunfire, and attendance at loud concerts.[12–14] Although there is increasing evidence that asymmetrical hearing loss occurs among individuals with ONIHL,[15] typically, ONIHL is a sensory neural phenomenon involving injury to the inner ear. It is bilateral and symmetrical, usually affecting the higher frequencies at 4 kHz, with spread to neighboring frequencies of 3 and 6 kHz, and some hearing recovery at 8 kHz.[13] ONIHL is proposed to be on average no higher than 75 dB in the high frequencies and no higher than 40 dB in the lower frequencies. Four grades of hearing impairment are classified by the WHO: slight (audiometric ISO value 20-40 dB), moderate (41-60 dB), severe (61-80 dB), and profound (81 dB or greater).[13]

The Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) provided the standard exposure levels of noise. For OSHA,[12] the permissible exposure limit (PEL) in the occupational noise exposure standard (29 CFR 1910.95) is 90 dBA, for an 8-h time-weighted average (TWA) with a 5-dB exchange rate (increase or decrease in dB corresponding to doubling or halving the noise dose). An action level of 85 dBA, for an 8-h TWA (50% of PEL) was added in the 1983 Hearing Conservation Amendment (HCA), in which a hearing conservation program must be made available to workers whose exposures equal or exceed the action level. In addition, an 80-dB threshold level in the computation of noise dose was proposed in the OSHA-HCA criteria. By including sound energy doses from 80-90 dBA, the noise dose measured under the OSHA-HCA criteria is typically higher than the corresponding compliance measurement.

For NIOSH, an 8-h time-weighted average exposure limit of 85 dBA and a 5-dB exchange rate were recommended in the 1972 Criteria for a Recommended Standard: Occupational Exposure to Noise. These criteria were further revised in 1998. The recommended exposure limit (REL) remains at 85 dBA, but the 5-dB exchange rate has been replaced with a 3-dB exchange rate. Therefore, under this requirement of an exchange rate of 3-dB, a 4-h of exposure at 88 dBA is as equally hazardous as 8 h at 85 dBA. Furthermore, all workers exposed to noise levels above the REL are recommended to be enrolled in a hearing loss prevention program (HLPP).[12]

In addition, individual demographic factors such as age, preexisting sensorineural hearing loss, chronic diseases (e.g., hypertension and diabetes mellitus), history of smoking, and use of ototoxic medications may influence the degree of damage to the inner ear caused by noise injury. The human auditory system is composed of the outer ear, middle ear, and inner ear. The outer ear gathers sound energy and transmits it to the middle ear through the ear canal and the tympanic membrane and then transmits the vibrations to the inner ear through the three tiny bones (malleus, incus, stapes) in the middle ear.[17] Activation of MT channels is initiated by tension in extracellular tip links bridging adjacent stereocilia, and they can respond within microseconds to nanometer displacements of the bundle, facilitated by several steps of Ca2+-dependent adaptation. The vibrations are converted by the inner hair cells into electrical impulses, and the impulses are delivered to the brain through the auditory nerve.

Continued exposure to excessive noise may lead to impaired transmission of both low- and high-frequency sounds to the brain. Furthermore, the cochlear blood flow may be poor; hair cells bear stereocilia on the apical surface and these can become a fused, splayed, or missing stereociliary bundle arrangement after significant noise exposure, hair cells and supporting structures disrupt hearing function; and ultimately, even nerve fibers that innervate hair cells disappear.Changes in the stria vascularis are likely to decrease endocochlear function, thus decreasing the cochlear amplifying function for auditory signals and increasing the auditory threshold. Along with the degeneration of cochlear nerve fibers, there is simultaneous degeneration within the central nervous system. Because hair cells in mammalian species do not regenerate, once hair cells are destroyed, ONIHL is present permanently, regardless of the pathway of hair cell destructions.

Pure tone audiometric testing is used to detect and quantify the degree of ONIHL.This provides a subjective measurement of hearing loss in individuals exposed to occupational noise and requires a voluntary response on the part of the person being tested.[12] The main characteristics of ONIHL are that most noise exposures are symmetric and display typical signs of notching at high frequencies of 3000, 4000, or 6000 Hz with recovery at 8000 Hz in audiogram testing. This notch presents at one of these frequencies and does not actually influence neighboring frequencies but once a notch occurs, additional frequencies may demonstrate notches, and the prominence of this notch may be affected by age-related hearing loss. Therefore, ONIHL needs to be differentiated from age-related hearing loss in older persons.

Typically, ONIHL is bilateral and symmetric. However, there may be some atypically asymmetric presentation in hearing loss, particularly if there is a different degree of exposure to sound between the two ears. When a discrepancy is present, ONIHL is commonly more severe in the left ear, although the reasons for this phenomenon are still unclear.[16]

Except the direct damage on the auditory system, noise also can cause psychological and physiological disorders. Tinnitus, the subjective sensation of sound, is an effect of noise exposure that can be even more bothersome for individuals than hearing loss. Tinnitus often serves as an early sign of auditory injury.60 The severity of tinnitus may be associated with the degree of NIHL. Tinnitus has several etiologies other than noise exposure. However, once hearing loss is noted, the cause of hearing loss is recognized as the cause of tinnitus, unless more evidence proves otherwise.[16]

Biological Exposure Limit

Based on the distribution of sound energy over time, sound can be stable, fluctuating, and intermittent. In general, noise exposure can be classified as follows:[17]

a.Steady Noise

Steady noise is a type of noise that is relatively stable or constant, uninterrupted for the duration of the worker's exposure while performing their job. Exposure patterns can be determined using records of the duration of exposure and noise intensity while the worker is at work. Workplaces that produce such noise include those where noise is generated by rotating machinery or air escaping at high pressure thru narrow channels. This kind of noise can be analyzed for its frequency.

b.Intermittent Noise

Intermittent noise is noise exposure that is found intermittently during work. The noise is not continuous, like traffic noise or airplane noise. To make it easier to assess intermittent noise exposure, a Noise Dosimeter can be used.

c.Impact Noise

Impulsive noise is one or more bursts of sound energy lasting less than one second and striking sharply, typically caused by the impact of a pile driver hammer or a press. A series of cannon explosions is also categorized as impulsive noise. A Sound Level Meter (SLM) is the tool used for this noise. The Noise Threshold Limit Value (TLV) is a value that regulates the average noise pressure or noise level based on the duration of noise exposure, representing a condition where almost all workers are repeatedly exposed to noise without experiencing hearing impairment and can understand normal speech. In accordance with PMK number 70 of 2016 concerning Standards and Requirements for Environmental Health in Industrial Workplaces, the noise TLV for an 8-hour workday is 85dBA. Meanwhile, the noise exposure NAB for specific exposure durations can be seen in the following table:

Unit	Exposure Duration / day	Noise Level (dBA)
Hour	24	80
	16	82
	8	85
	4	88
	2	91
	1	94
Minute	30	97
	15	100
	7,5	103
	3,75	106
	1,88	109
	0,94	112
Second	28,12	115
	14,06	118
	7,03	121
	3,52	124
	1,76	127
	0,88	130
	0,44	133
	0,22	136
	0,11	139

Table 2.1 Threshold Limit Value

Note: Noise exposure must not exceed 140dB, even for a moment.

Source: Ministry of Health Regulation No. 70 of 2016 concerning Industrial Occupational Health Standards.

Hearing Conservation Program

Temporary hearing loss due to short-term noise exposure, normal hearing returns after a period of rest. Generally, prolonged exposure to high-level noise exceeding time limits causes permanent damage. [18,19] OSHA's Hearing Conservation Program is designed to protect workers significantly exposed to noise from hearing loss, even if they are exposed to excessive noise throughout their working lives. According to OSHA's occupational noise standard (29 CFR 1910.95), workers exposed to noise levels of 85 dBA or higher for 8 hours or more must participate in a hearing conservation program (HCP). If engineering and administrative controls do not reduce the noise, each worker must use hearing protection devices such as earplugs or earmuffs to protect their hearing.[18,19]

Noise-induced hearing loss is not curable but can be prevented, therefore workplaces exceeding the PEL must implement an HCP program. According to OSHA, a Hearing Conservation Program includes: noise exposure monitoring; administrative and engineering controls; hearing protection devices; audiometric evaluation and follow-up activities; and management training and education.[18,19]

The HCP program includes noise monitoring, audiometric testing, noise control, hearing protection devices, motivational training, and record keeping.

a.Noise Monitoring The HCP program accurately monitors noise exposure levels to identify workers exposed to noise at or above 85dB averaged over 8 hours of work, or working 8 hours TWA. Companies must monitor all workers exposed to noise equal to or greater than 85dB for 8 hours.[20] The measuring instruments for workplace noise measurement are the Sound Level Meter (SLM) and for personal monitoring, the Noise Dosimeter is used. A sound pressure level meter, sound level meter, or sound meter is an instrument used to measure the Sound Pressure Level (SPL), the intensity of sound at a specific time. This device uses a frequency weighting scale that accounts for differences in human sensitivity to different frequencies. [20]

The unit of sound level used for humans is dB(A), A-weighted decibel (A-decibel measured), calculated using the spectral sensitivity factor (A-filter), which is the sound pressure level measured with frequencies corresponding to the sensitivity of the human ear. Decibels are a logarithmic scale that refers to one unit on the decibel scale. Decibel means one-tenth of a bel. The unit 'bel' itself is taken from the inventor named Alexander Graham Bell, and this unit is used to compare the strength in electrical communication, voltage, or sound intensity. The abbreviation for bel is B and decibel is dB, 10 dB = 1 B.[20] A noise dosimeter is used for personal noise monitoring. Sound level meters can be analog, digital, or available as smartphone applications. A noise dosimeter is similar to a sound level meter, but it can be used to record, store, and calculate sound measurement results over a specific duration, allowing for the average sound level to be calculated. Because a noise dosimeter is used for longer periods and to measure the sound of a single person, it is equipped with a microphone for sound capture. [20]

Audiometry Test

The standard hearing loss examination is an audiometry test. Pure tone audiometry is an OSHA recommendation for NIHL surveillance approaches. Audiometric tests are used to monitor the hearing of workers exposed to noise. This gives workers an advantage regarding their hearing and the need to protect it. Important elements of this program are the baseline audiogram, annual audiogram, and evaluation (follow-up). Workers who need to undergo audiometric testing are those exposed to levels of 85dB or higher, measured over an 8-hour TWA. There are 2 types of audiograms required in the HCP program: baseline and annual audiograms.[18]

1. Baseline audiogram

A baseline audiogram is a reference audiogram that is compared to subsequent audiograms. Workers must have a baseline audiogram within the first 6 months of initial exposure or 8 hours TWA. Workers must not be exposed to noise for 14 hours before the baseline test or use personal protective equipment during that time.

2. Annual audiogram

Annual audiogram for workers whose TWA >85dBA. This is important for assessing workers' hearing by identifying any potential hearing loss. This allows workers to begin protecting and following up before hearing loss progresses. Annual audiograms are compared to baseline audiograms to determine if the audiogram is valid and whether workers have experienced a decrease in hearing ability or meet the criteria for a Standard Threshold Shift (STS). According to OSHA, an STS is an average shift of 10 dB or more in one ear at 2000, 3000, and 4000 Hz.[11]

a. Noise Control

An effective step for preventing hearing loss is to control the source of the hazard by eliminating, substituting, engineering, and administering. In planning/engineering control, ensure you select equipment with the lowest noise effect. Keep machines with high noise intensity away from areas with many workers. If the machine is still noisy after installing barriers, install sound dampeners if necessary, or consider total or partial enclosure. For administrative control, the following measures can be taken: designate the area as restricted, allow only trained workers to enter, and use hearing protection. Adjust work schedules according to the NAB, for example, 85dBA for 8 hours, 88dBA for 4 hours, and so on.

b. Hearing Protection Devices

Workers must use Hearing Protection Devices for an 8-hour TWA noise exposure of 85dB or higher. Workers need HPDs before hearing impairment occurs. Workers who must use hearing protection devices are those who have been exposed to noise of 85dB or more for over 6 months from the first time they were exposed to noise for 8 hours TWA, since receiving their baseline audiogram; if they experience STS showing susceptibility to noise; or if they are exposed to noise exceeding the Permitted Exposure Limit (PEL) of 90dB for more than 8 hours TWA.[20,21] The company must provide a variety of earplugs and earmuffs for workers. The company needs to train people on how to use it.

The size and type of HPD must be suitable for the working environment. HPD should be comfortable to use and protective to prevent hearing loss. The HPD must sufficiently reduce the noise level in the workers' environment. Many workers use the Noise Reduction Rating (NRR) to represent the ability of the APP to reduce noise under ideal workplace conditions. Workers must adjust the NRR to reflect the noise reduction in the actual work environment. Workers must evaluate the appropriate PPE; if workplace conditions change, the tool must provide sufficient protection. If the noise level increases at work, the company provides employes with more effective hearing protection. Hearing protection devices can reduce noise levels from 90dB to 85dB when STS has already occurred in the worker's hearing.

Examples of PPE include earplugs, which are inserted into the ear canal until they seal tightly, preventing sound from reaching the eardrum. Earplugs can reduce noise by up to 30dB. Earmuffs cover the entire external ear and are used to reduce noise by up to 40 dB, at frequencies of 100 Hz – 8000 Hz. Helmets cover the entire head and are used to reduce noise by a maximum of 35 dBA at 250 Hz to 50 dBA at high frequencies. Selection of hearing protection:

- Earplugs when noise is between 85 dBA and 100 dBA.
- Earmuffs when noise is above 100 dBA.

Each hearing protection device has an NRR (Noise Reduction Rating). The important thing about this app is to provide proper user training.[20] Factors to consider when choosing hearing protection are: it can protect workers from noise; it is comfortable to wear and efficient; it is compatible with other personal protective equipment such as helmets and glasses; and it still allows for communication while in use, as excessive use can lead to other dangers such as not being able to hear signals or warning sirens.

c. Motivational training

Training from the company is very important. Workers who understand the HCP program can be motivators for using Hearing Protection Devices and Audiometric Testing. Workers must be educated about 8-hour TWA noise exposure or more, the purpose, advantages, and disadvantages of various types of hearing protection devices, the selection, fit, and maintenance of hearing protection devices, and the purpose and procedures of audiometric testing. Training using visualization methods is an effective way to explain things to workers.[18] Workers should also be educated about the consequences of noise and how to prevent it, that no one is immune to noise, by providing information from audiometric medical record data and workplace area measurement data. Training using visualization methods is an effective way to explain things to workers.

d. Record Keeping

Noise exposure measurement records for 2 years and audiometric test data for the duration of employment must be kept. Also, audiometric test data including the worker's name and job, date, examiner's name, date of last calibration, measurements of the audiometric test room level, and the company's latest noise exposure measurements must be stored. Data on workplace measurements, employe audiometric tests, and periodic evaluations must be kept. Technical efforts for work areas with noise levels exceeding the NAB must also be implemented.[20]

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