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A Review of Vibroacoustic Noise on Psychological and Physiological Stress and Mitigation Practices in Occupational Environment

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Abstract

This paper presents a narrative literature review examining the multifaceted impacts of vibroacoustic noise exposure on workers' physiological health, psychological well-being, and safety performance in occupational environments. Drawing on research from occupational health, environmental psychology, and physiology, the review synthesizes evidence showing that chronic exposure to 70–100+ dB noise activates the sympathetic-adrenal-medullary (SAM) stress axis, elevating stress hormones, impairing immune function, and degrading cognitive performance. These outcomes contribute to increased error rates, unsafe behaviors, and workplace accidents. The paper also evaluates existing mitigation strategies and regulatory standards, revealing that current frameworks insufficiently address combined noise and vibration exposures. This work's unique contribution is its integrated cross-domain perspective and its identification of this synergistic gap, providing a foundation for developing targeted noise-vibration mitigation strategies and real-time stress monitoring tools in high-risk workplaces.

Keywords

Vibroacoustic noise, mental stress, workplace safety, occupational health, productivity, noise mitigation

1. Introduction

Vibroacoustic noise (noise) causes physiological and psychological short term and long-term stress effects. Many industrial, construction, and open-plan office environments, while often treated as a background nuisance, noise have been shown to induce mental stress, impair decision-making, and compromise safety. Recent studies including humans and mice have reported that environmental noise, particularly chronic exposure to moderate to high (70dB-100dB and above) can trigger the sympathetic-adrenal-medullary (SAM) axis, a key component of the body's stress response system [1,2,3,4,5,6,7,8,9,10,11,12]. This system, also known as the sympathetic-adreno-medullary system, plays a crucial role in maintaining and restoring physiological homeostasis in response to various stressors. When exposed to environmental noise, especially loud or intermittent sounds (e.g., traffic noise, construction noise, aircraft noise), the brain perceives this as a potential threat or stressor. This triggers the activation of the sympathetic nervous system (SNS), initiating a cascade of physiological responses aimed at dealing with the perceived threat or returning the body to a balanced state. In addition, these studies also revealed increases in weight gains, disorders such as sleeping depravation, insomnia, many cognitive disorders and every system of the body, leading further muscular skeletal, immune, nervous and even cardiovascular implications.

2. SAM Activation and Hormone Release

A perceived threat activates the SNS (sympathetic nervous system). The SNS sends signals to the adrenal glands, particularly the adrenal medulla, which then releases catecholamines, primarily epinephrine (adrenaline) and norepinephrine (noradrenaline), directly into the bloodstream. These hormones play a crucial role in the "fight or

flight" response, causing a range of physiological changes throughout the body. Catecholamines stimulate the heart to beat faster and stronger, increasing cardiac output and blood pressure [35]. It can cause the narrowing of blood vessels (vasoconstriction) in some areas and widening (vasodilation) in others, redirecting blood flow to muscles and vital organs in preparation for action. Catecholamines also increase blood glucose levels to provide quick energy for the body's response.

3. Potential Health Consequences of Chronic SAM Activation due to Environmental Noise

Prolonged or repeated activation of the SAM axis due to chronic noise exposure can have detrimental effects on cardiovascular health and overall well-being [23]. This sustained stress response can lead to or worsen the development of cardiovascular diseases like hypertension, ischemic heart disease, and stroke. Additionally, chronic noise exposure can disrupt sleep, impair cognitive function, and contribute to psychological issues like anxiety and depression, further impacting the body's ability to cope with stress.

In essence, environmental noise, even at levels below those causing direct hearing damage, acts as a stressor, activating the SAM axis and the release of stress hormones, which can have significant and wide-ranging consequences for physical and mental health.

Environmental noise, even at levels not considered harmful to hearing, is perceived as a stressor by the body. This perception activates the sympathetic-adrenal-medullary (SAM) axis, a rapid stress response system involving the sympathetic nervous system and the adrenal medulla. Activation of the SAM axis causes the release of catecholamines like adrenaline and noradrenaline from the adrenal medulla. These hormones affect physiological processes such as heart rate, blood pressure, and metabolism, helping to maintain the body's balance.

Studies suggest that both intense and everyday environmental noise can increase stress hormone levels, although the specific impact can vary based on factors like the study environment, how used to the noise a person is, and what information the sound conveys (Table 1). One study found that short-term exposure to loud noise increased levels of dopamine, noradrenaline, and adrenaline, while longer-term exposure led to higher noradrenaline, but lower adrenaline compared to control groups [1]. The body’s response to noise appears to be influenced by factors such as the setting of the research, the level of habituation to the noise, and the informational content of the sound. For instance, experimental settings themselves can be stressful, potentially obscuring the effects of noise. The varying release patterns of hormones, particularly cortisol which follows a daily rhythm, can also make research findings challenging to interpret. The release of adrenaline and noradrenaline after noise exposure might also depend on how accustomed someone is to the noise [24].

In summary, environmental noise activates the SAM axis, leading to the release of catecholamines that affect various bodily functions. The specific hormonal response is complex and influenced by several factors, and more research is needed to fully understand the long-term health effects of noise exposure on the SAM axis

4.Noise Exposure and the Immune System

Noise exposure can significantly impact the immune system, with varying effects depending on the intensity and duration of the noise, as well as individual factors like sensitivity. Generally, short-term or low-intensity noise may temporarily enhance immune function, potentially as a compensatory response to stress. However, long-term or high-intensity noise is consistently linked to immune suppression and various health issues. Looking at urban noise studies, it is found that residents near highways or airports show elevated stress hormones and reduced immune markers. Factory or construction workers exposed to higher than 85 dB show higher rates of respiratory infections and fatigue.

5. Effects of Noise on Immune Components

Prolonged noise exposure can lead to decreased levels of important immune substances in the blood (IgG and IgM) and local mucosa (sIgA) [13]. Short-term noise exposure has been shown to increase IgM in mice [13]. Long-term noise exposure can reduce the number and activity of critical immune cells like T-lymphocytes, NK cells, and NKT cells. However, a study showed that short-term heavy traffic noise exposure led to an increase of myelomonocytic cells and natural killer cells in mice [13]. Another study found a decrease in the percentage of NKT cells with increasing road traffic noise [34]. The size and weight of immune organs like the thymus, bone marrow, and spleen can be significantly reduced by long-term noise exposure. Noise exposure may also cause structural abnormalities in the thymus. Noise, particularly low-frequency noise (LFN) at high decibel levels (120 dB or 150 dB), can induce chromosomal aberrations and increase the presence of low molecular weight DNA (lmwDNA) in the blood, indicating potential cell death and DNA damage [14].

6. Noise and Immune-related Diseases

Noise exposure can contribute to auditory and non—auditory categories. Auditory effects can lead to NIHL (Noise induced hearing loss) through the production of autoantibodies such as anti-Hsp70 and anti-Hsp60. Noise exposure has been associated with an increased risk of autoimmune diseases like rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), Hashimoto's disease, and Graves' disease (Non auditory). One study suggested that long-term occupational noise exposure might be a modifiable risk factor for RA [15]. However, another study found that traffic noise levels themselves might not be the primary factor in increased RA risk associated with proximity to highways, suggesting other factors like noise sensitivity, genetics, or sleep disorders might play a role [15]. Studies have shown a correlation between road traffic noise exposure (above 65 dB) and an increased risk of developing Non-Hodgkin Lymphoma (NHL), particularly B-cell lymphoma [16]. The road traffic noise can be at the construction sites as well since the outdoor construction work can expose workers through the road traffic noises.

7. Mechanisms of Noise-induced Immune Dysfunction

In addition, noise acts as stress and results in consequences of SAM, which release stress hormones like cortisol, adrenaline, and noradrenaline. These hormones can directly influence the immune response, with short-term exposure potentially stimulating immunity, and chronic activation leading to immune suppression. Moreover, it can result in oxidative stress and inflammation. Noise exposure can trigger oxidative stress and inflammation, which are closely linked to immune system dysregulation. Oxidative stress can damage cells, including immune cells, while chronic inflammation can exacerbate various diseases and disrupt the normal function of immune cells and organs. According to recent findings, Chronic noise exposure has been shown to alter the composition and function of the gut microbiota, which plays a crucial role in immune regulation. Changes in gut bacteria, such as increased opportunistic pathogens and alterations in inflammatory markers like IgA and TNF-α, are linked to potential increases in inflammatory bowel disease and metabolic disorders like type II diabetes.

Further, noise exposure can indirectly affect and impact many other disorders and behaviors and complicate the recovery processes. Noise-induced sleep disruption can suppress the activity of regulatory T cells (Tregs) and increase levels of inflammatory cytokines, increasing the risk of autoimmune diseases. Studies suggest that noise exposure, particularly in industrial settings, may increase smoking behavior, which in turn can lead to higher levels of autoantibodies and promote the development of autoimmune diseases [17].

8. Mental Stress Induced by Acoustic Noise

Many studies have attempted to find the causes of construction accidents and one cause consistently identified is workers' unsafe behaviors [28]. Unsafe behaviors are decisions made by workers that increase their risk of injury which can be caused due to cognitive performance levels. Cognitive performance has greatly influenced unsafe

behavior. Noise is a critical factor that negatively influences most cognitive dimensions, including memory, attention, response time, judgement, decision making and perception [27]. In the construction industry, the impacts of noise on cognitive performance are of great concern because noise pollution is prevalent on most construction sites. It is the most frequent pollution in construction activities.

[31] investigated the combined effects of task difficulty and noise exposure on mental workload using three assessment methods: behavioral performance, subjective assessment, and EEG (Electroencephalography) analysis. The results showed that there is a significant combined effect of task difficulty and noise exposure on perceived mental workload. The main findings from this study are that there was a positive linear relationship between task difficulty and mental workload and low-frequency noise had a more negative impact on mental workload compared to high-frequency noise. One study suggested that music promoted accuracy whereas the medium level of mechanical noise impaired the accuracy. The cognitive performance by EEG indicators revealed that music affected concentration but also reduced stress. Another of the study compared the annoyance scores with noise level. Below 70 dB, the annoyance score was lower but after 75dB, the annoyance score rose sharply from 4.6 to 9.4 on a 11-point scale. Another study looked at EEG data to explore the effects of different types and levels of construction noise on emotions. It showed saw and jackhammer may create significantly higher negative emotion compared to bulldozer and pile driver noise types. The operators of saw and jackhammer may feel vibration and noise pollution combination which can create a higher negative emotion compared to bulldozer which may not be creating enough vibrations but more noise. A combined effect of the vibration and noise should be studied in more detail.

Prolonged exposure to noise elevates stress hormone levels such as cortisol and adrenaline. This can result in cognitive overload, reduced memory retention, irritability, and long-term psychological fatigue. Studies demonstrate a clear correlation between chronic noise exposure and increased rates of anxiety and burnout in high-noise environments. In addition, recent studies with mice exposed to higher levels of noise showed morpho functional changes in their brain cell which is alarming and thus could cause permanent mental disorders due to brain cell permanent changes [1].

9. Sources and Characteristics of Occupational, Industrial and Traffic Noise

Noise in the workplace, traffic and industrial setting can be continuous, intermittent, or impulsive. Continuous noise can be constant and steady like running motors or HVAC systems. Intermittent noise can be start and stops at intervals such as alarms or machinery cycles. Impulsive noise can be sudden and brief such as hammering and or explosions.

Key characteristics influencing its impact include frequency, intensity (measured in dB), and duration of exposure. Also, seasonal effects can be observed with environmental and human activities. Environmental can be open windows in summer may increase exposure to outdoor noise, snow in winter can dampen sound whereas human activity examples can be construction tends to peak in warmer months and traffic patterns shift with school schedules and holidays. Noise levels can fluctuate based on the time of the day as well where higher traffic and daily chaos can be in some particular times of the day like mornings or evenings as compared to afternoons.

10. Safety Implications

Noise-induced stress can diminish situational awareness, delay reaction times, and mask critical auditory signals like alarms or verbal warnings. These effects substantially increase the likelihood of workplace accidents, especially in high-risk environments like construction and manufacturing.

11. Work Performance Degradation

Cognitive tasks requiring focus, memory, and decision-making are significantly hindered in noisy settings. Workers report higher rates of error, lower productivity, and increased dissatisfaction leading to short term and long term physiological and psychological complications. Table 1 shows the noise levels generated with respect to industry and their effects. Higher dB noise levels can create higher accident rates as compared to lower noise level as seen in manufacturing or construction and create higher incidents and accidents rate as compared to office settings.

Table1: Noise levels generic to industry and observed effects

Industry	Noise Level (dB)	Observed Effects
Manufacturing	85–100	Increased error rates in assembly and inspection tasks along with hypertension risk [11,29,35]
Healthcare	60–75	Reduced diagnostic accuracy and slower response times along with reported stress [25,26]
Aviation	70–90	Impaired communication and decision-making in cockpits [11]
Education	50–70	Lower test scores and reduced verbal comprehension [25]
Office Environments	45–65	Decreased productivity and higher reported stress levels [25]

12. Mitigation Strategies - Engineering Controls

There are many mitigating strategies which can be adopted. Installation of sound barriers (physical partition to block or absorb noise), vibration isolation (reduce structure borne noise from machinery), and use of quieter machinery (retrofitting with dampening materials) can help in some mitigation. There can be administrative controls such as rotating shifts, implementing quiet zones, and modifying work schedules to limit exposure. Use of PPE such as use of earplugs or noise-canceling earmuffs with communication compatibility can help as well. There can be training imparted to employees and enhance awareness. Educating employees on the impact of noise and coping mechanisms for stress can give better awareness regarding the detrimental effects of higher noise pollution on the body and work performance. Some studies suggest that antioxidants like lipoic acid, Scoparia dulcis (SD), and vitamins C and E may help mitigate noise-induced changes in the immune system [18,19]. This can help reduce stress. Many research indicate that music can have a positive effect on the immune system, potentially by reducing stress and enhancing the activity of immune cells (rehabilitation in quiet and serine environments) [20]. Some of these mitigating strategies can help reduce the impact of vibroacoustic noise hazards.

13. Standards for Occupational Vibroacoustic Noise Safety

OSHA occupational noise standard started in 1910 and has been amended over the years covers the general guidelines for occupational noise safety. This standard has been the main guidance for the many regions of the world. Standard covers general noise maximum limits with respect to time of exposure. The limits cover the impulse and continuous noise spectrums. The recent findings of noise exposure revealed that the combination effect of the impulse and continuous noise is more severe, and standard can be improved in this section. Also, the levels are not specific to age and gender demographics.

Another closely correlated standard is the ISO 2631 standard with respect to whole body vibrations. Even though it is not a comprehensive standard that covers most of the demographics it provides good guidance. Depending on the complex nature, the generic adoption and application of this standard in most practical cases is difficult. The sever effects of vibration and noise environments of bus passengers are reported in recent publication [21,22]. In addition, limited research has been conducted [36] to investigate into combination effect of acoustic noise and vibration experienced via handheld tools. This research has shown the importance of further investigation and synergetic combined effect.

In addition, recent studies have shown that the combined effect of noise and vibration is more severe than the one factor alone. Moreover, the physical and psychological state of a person plays a critical part since recent research also shows the direct and indirect intricate correlations between noise and vibration on general wellbeing and productivity. Looking at the construction industry, it is found that there are several instances where the combination of vibrations and noise play a combined effect thus more studies related to this effect should be done.

14. Conclusion and Future Work

This review integrates evidence that vibroacoustic noise simultaneously undermines physiological health, psychological well-being, and safety performance in occupational settings. By linking these domains, it reframes noise not as a secondary nuisance but as a core safety hazard. It also highlights a critical gap: the combined effects of noise and vibration on human stress systems, which current standards do not address.

Future research should explore real-time monitoring of stress indicators and more research on adaptive noise-reduction technologies under combine noise and vibration environments, taking consideration the work context and physiological and psychological state of the individual. Addressing occupational noise in this integrated manner is essential for protecting worker health, improving safety, and sustaining productivity in high-risk industries.

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