



White Noise and Its Potential Applications in Occupational Health: A Review

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Abstract

Background: White noise (WN), because of its unique behavior and characteristics, has different applications in different sciences. Nevertheless, the results of studies and reviews of the literature on occupational safety and health found that this type of noise is often used as a noise source to assess the effects of hearing and its physical characteristics. Its possible applications in this area have not received as much attention. The present review study aimed to answer the question, "Can WN be used as a means of promoting occupational safety and health at the workplace?"

Methods: In this review, we reviewed the articles published in reputable databases from 1990 to 2020. Our study included 33 articles from 120 that were searched in full text and followed the inclusion and exclusion criteria.

Results: Various applications were examined, including noise masking, white noise therapy, cognitive functions, and sleep. WN can enhance the work environment and meet occupational safety and health objectives based on the study's results. The results of this study will provide a basis for continuing research into the use of WN in the workplace as an engineering and management control method.

Conclusion: WN is being used in various fields that may hold promise for its application in occupational health sciences and maintaining the well-being of workplace workers.

Keywords: Occupational health; Safety; White noise; Workplace improvement

Introduction

Usually, noise is known as a harmful physical factor. Noise, referred to as White noise (WN), is a type of sound whose energy is equal across differential bands due to the combination of sounds at different frequencies. A WN's spectral density is flat, and its intensity is the same within the

human audible frequency range (20 Hz to 20,000 Hz). If all the sounds an individual can hear are combined, we will have WN. Therefore, WN has unlimited bandwidth and a linear spectrum (1, 2). Among continuous spectrum noises, WN is a crucial example. Simple and tangible examples of



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WN are the sound of the sea crashing, the rain, the air conditioner, the fan, and the static television (2-4).

In different areas of science, WN has different applications due to its unique characteristics and behavior. For example, sometimes its masking property has been used to mask annoying sounds, and sometimes its soothing property has been utilized (2, 5). A fan helps you to sleep and rest well when you are relaxing at a hotel, and the sound of the adjacent rooms disturbs your peace of mind. Alternatively, you will have a better night's sleep when the air conditioner runs at noon in the summer. Furthermore, you will feel calmer by listening to the sound of rain or sea waves. The fan and air conditioner remove or mask unwanted noises by creating WN. In other words, a fan or air conditioner creates thousands of different audio frequencies so that the human brain cannot follow the surrounding noises and stops them from penetrating the brain (unless they are excessively loud) (3, 6). In addition, the same feature of WN is sometimes used in emergency vehicle sirens to make it easier for people to locate police cars, ambulances, and fire engines (2).

An examination of the literature and research on WN, especially by occupational health researchers, reveals that most of these studies focus on the physical and auditory effects of WN (7, 8). As a source of noise, this type of noise has often been used at high intensities to assess its effects (9-11). In other fields, however, such as health sciences, medicine, psychology, and engineering, reviews of published literature have shown that WN has positive effects or applications (12-14). As a result, the question of whether WN is used in occupational health only to evaluate its effects or whether its positive effects may contribute to the advancement of safety and health in the workplace remains unanswered.

We conducted the present review to summarize the applications of WN and introduce its possible application, especially in occupational health fields. The results of this study will provide a basis for continuing research into the use of WN in

the workplace as an engineering and management control method.

Methods

WN applications were identified by compiling a list of WN applications in various fields, specifically occupational health, and a thorough review of articles published in reputable databases. The search focused on several practice areas, including noise masking, WN therapy, cognitive functions, sleep, and subcategories. The initial search with the keyword "White Noise" for articles related to the research topic was performed on Google Scholar, Science Direct, PubMed, Scopus, Scientific Information Database (SID), Magiran, and Iranian Research Institute for Information Science and Technology (IranDoc) databases in a period of 30 years from 1990 to 2020. For further empirical evidence, a secondary search was executed using the equivalent keywords "soothing noise" and the combined keywords "noise AND cognitive function", "noise AND ADHD", "noise AND sleep", "noise AND treatment" and "noise AND noise-masking". We also, conducted ancestry searches through the references section of all papers found. Figure 1 describes the process by which we searched for and selected articles.

Inclusion and exclusion criteria

The review initially focused on articles that were indexed as original, case-control, and review articles and was accessible through comprehensive databases to ensure the validity of the studies. However, the review team decided to include studies indexed as letters to the editor and short reports due to the low number of research studies and the authors' intention to conduct a comprehensive study with high-quality empirical evidence. We did not include materials such as letters to authors, author notes, news articles, and general texts. The inclusion criteria were having at least one of the keywords in the title, abstract, and keywords. We could accomplish this goal by reading the title, abstract, and keywords and se-

lecting relevant articles. Only articles published in full text in Persian or English were examined in this study.

As part of the screening process, studies of WN addressing climate extinction/extinction, weather, climate changes, and ecosystems were excluded from consideration. In addition, no studies were examined on topics such as computer-based analysis of stochastic stability of mechanical structures driven by WN, extraction of colored noise from WN signals, and providing sophisticated algorithms for generating or investigating WN. We did not examine studies that evaluated WN as a source of noise to assess its effects on human or animal hearing (above 90 dB), like (15, 16).

Following summarization and selection from 120 articles in full text, 33 articles were included in the study based on inclusion and exclusion criteria. Three of these were reviews, short reports, and letters to the editor. Other papers evaluate the use of WN in different contexts with original experiments, quasi-experiments, or interventional studies. In order to qualify, articles had to include at least one case of how WN affected a particular outcome or its application, such as sleeping, learning, memory, noise masking, verbal stimulation, cognitive functions, treatment of tinnitus, anxiety, stress, pain relief, and perception, improvement of Attention deficit hyperactivity disorder (ADHD), and stochastic resonance (SR), etc.

Data extraction

Each article that was eligible for inclusion in the study and discussed some of the applications or effects of WN was evaluated according to 4 criteria (Type of study, Participants, Source, and Scope) to extract information. Authors analyzed each of these criteria separately, while another author reviewed each assessment for accuracy during the review process. Through this process,

an agreement was reached on each of the articles. Detailed information on the criteria for each study is given in Tables 1-4. After analyzing the results, the potential applications of white noise in occupational health sciences were discussed.

Literature Review and Results

Tables 1 to 4 summarize the categorical presentations of the studied factors such as type of study, subjects, source of WN generator, the decibel intensity, scope of application, and results related to WN effects.

Of the 33 studies reviewed, 18.2% covered the years before 2000, 15.2% covered the years between 2000 and 2010, and 66.7% covered the years from 2010 to 2020. This topic indicates a growing interest in WN among researchers in the past decade, particularly from the perspective of the application areas examined. In addition, 87.8% of the studies studied employed experimental-interventional approaches with clinical trials, 9% used quasi-experiments, and just one (3%) was reviewed. Participants in the studies ranged from 2 to 167. Participants ranged in age from 2-day-old infants to adults. Among the participants were children, students, healthy adults, people with ADHD, Autism Spectrum Disorders, Panic disorder, Tinnitus disorder, cardiovascular disease, and inpatients. Only one animal study was done with macaques. Different audio generators in the form of devices and software running on Windows produced WN at different intensities from 50 to 86 decibels. Depending on the purpose of the studies and the physical characteristics available, each audio generator produced WN in the desired frequency range. In some studies, recorded sounds of sea waves and rain were used as a source of WN. Based on general classification, the range of applications of white voice can be divided into four categories, discussed in turn.

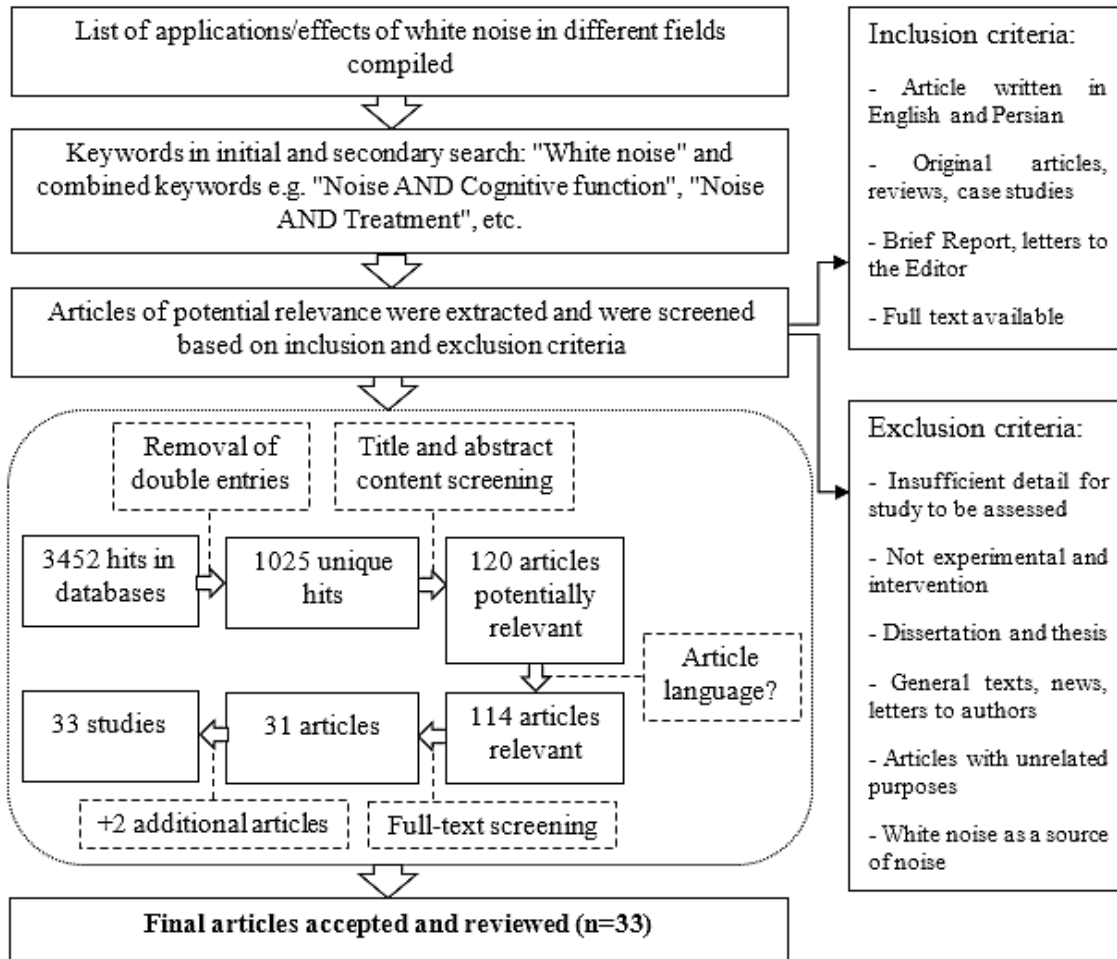


Fig. 1: A descriptive overview of the search process and selection of articles

White noise and sleep

The results of sleep and WN studies, which account for 15.2% of the studies, are summarized in Table 1. White noise (50 to 75 dB) has demonstrated positive and improving effects on the sleep and wake cycle of participants in all the studies in which it was used as an intervention (17-21). As a result of these studies and comparisons between target and control groups, WN has proven to be effective in reducing the number of infants awakening during nighttime sleep, improving their sleep quality, and helping them

sleep better. Children with ASD also reported fewer sleep onset delays and fewer night wake-ups following this intervention (20). Meanwhile, a study on healthy adults found that when WN is used, the difference between background noise and peak noise is decreased, increasing the arousal threshold in people to the noise. As a result, it leads to complete sleep and less arousal during sleep (21). In short, WN is a promising intervention for improving sleep that can be investigated further.

Table 1: Summary of studies investigating white noise and sleep

<i>First (Reference No.)</i>	<i>Author</i>	<i>Year</i>	<i>Type of Study</i>	<i>Participants (Number)</i>	<i>White Noise Generator</i>	<i>Application</i>
Spencer (17)		1990	Clinical trial	Healthy neonates(n=40)	Babyshh-Egnell-Ameda(72.5,67 dB 500,9kHz)	Sleep induction
Stanchina(21)		2005	Interventional	Human subjects(n= 5)	Recorded ICU noise and a WN(1–22.05kHz, 65dB)	Sleep and Arousal thresholds
Cautilli(18)		2005	Brief Report-Interventional	Neonate and child(n=2)	FamilyCare Air Purifier/Ionizer (model HAP221)	Sleep and wake routines
Forquer(19)		2005	Interventional	Children(n=4)	Tranquil Moments Plus (Brookstone model)(75dB SPL)	Resistance going to sleep and wakings
Knigh(20)		2014	Interventional	Children with ASD*(n=3)	ObusForme Sound Therapy Relaxation(50 and 75dB)	Sleep problems

*ASD: Autism Spectrum Disorders

White noise and noise masking

WN effectively masks Pure Tones and Speech as far back as the 1950s. Masking noise is the addition of a natural or artificial sound to an environment to mask unwanted sounds. Among the most critical properties of WN is noise masking, applied to many areas such as improving the work environment, improving sleep, increasing privacy, controlling annoying noise, treating some disorders, and inducing a sense of calm and comfort, and other matters. Mismatch Negativity (MMN) and its domain changes have also been examined using WN Masking. The amplitude of MMN is reduced significantly under contralateral WN masking (22).

The most common use of WN masking for tinnitus patients is to mask the sounds they hear in their ears. Tinnitus is a form of the disorder that is audible without any external sound source. In his explanation, tinnitus occurs exclusively as the result of the nervous system's activity without any mechanical or vibrational activity in the cochlea and any external stimuli (23). The only study on WN and Tinnitus in 2017 that was available during the study period was a cross-sectional study of 110 adult patients with tinnitus (24), which was an interventional study. The hypothesis of this study was based on previous findings that showed many patients with tinnitus responded better to external sounds with a frequency similar to tinnitus. The results of this study proved the above hypothesis, less intensity is needed to cov-

er tinnitus when the noise used to mask it is as close to the tinnitus frequency. Furthermore, low-frequency tinnitus patients require more intensity when using High-Frequency Narrow Band and WN than those with high-frequency tinnitus (24).

White noise and cognitive function

WN and cognitive function-related studies have been reviewed in two groups. As a group, the first group of studies focused on various aspects of cognitive function(33.4% of studies), while the second group focused on the use of WN to improve the condition of ADHD patients (24.2% of studies); the results of shown in Tables 2 and 3.

According to Table 2, for more than three decades, the effects of WN on cognitive functions such as working memory, long-term and short-term memory, implicit memory bias, recall, learning, attention and selective attention, cognitive and perceptual tasks, semantic priming, and visual working memory have been studied. According to the findings of these studies, which investigated WN at intensities of 60 to 86 dB, WN may be able to reduce distracting factors from the environment, improve attention and concentration, improve learning and memory, and enhance performance in tasks involving sequential short-term memory (25-29). Taking a broad view, one can say that by adding an optimal level of WN in certain situations as an intervention, one can expect

to improve cognitive functions and facilitate information processing in the nervous system. In these experimental-interventional studies, however, the subjects were primarily students, older people, and patients, with one study involving animals. Consequently, the impact of such interventions on the cognitive functions of industrial workers has not yet been studied, so further research is required.

On the other hand, WN can effectively treat some symptoms of ADHD, one of the most common neurodevelopmental disorders in childhood and adulthood (Table 3). Several items such

as improving reading and writing speed, speech recognition, controlling off-the-job behaviors, raising awareness and assisting working memory tasks, and rarely improving the accuracy of tasks have been proven effective in studies. Nonetheless, it has yet to be established whether WN affects the speed of reaction and response to stimuli (30-33). To the same extent as what has been said about cognitive functions, studies have predominantly investigated the effect of WN on ADHD in school-age children and students, so finding its role in adults and employees requires further investigation.

Table 2: Summary of studies investigating white noise and cognitive performance

<i>First (Reference No.)</i>	<i>Author</i>	<i>Year</i>	<i>Type of Study</i>	<i>Participants (Number)</i>	<i>White Noise Generator</i>	<i>Application</i>
Harrison(34)		1990	Interventional	Human subjects	Sony-Nova(52&80 Db)	Cognitive functions and Cardiovascular
Baker(35)		1993	Interventional	Students(n=160)	Grason-Stadler(455C)	Cognitive Task Performance
Amir(36)		1996	Interventional	Panic disorder patients(n=28)	Software(60,64,68dB)	Implicit memory bias
Carlson(29)		1997	Interventional	Macaque monkeys(n=5)	WN generator(80dB)	Working memory
Soderlund(37)		2010	Interventional	School pupils(n= 51)	Software(78,86dB)	Memory performance
Rausch(28)		2014	Interventional	Human subjects(n=66)	Software(20-5000 Hz,70dB)	Learning
Helps(27)		2014	Interventional	Children(n=90)	High quality headphones (65,70,75,85dB)	Performance and attention
Herweg(38)		2015	Interventional	Human subjects(n=167)	Bose Quiet Comfort(70dB)	Cognitive and perceptual tasks
Angwin(25)			Interventional	Students(n=80)	AKG K5(70dB)	New-word learning
Angwin(12)		2017	Interventional	Undergraduate students(n=78)	AKG K550(70,75dB SPL(A))	Direct and indirect semantic priming
Banaieezadeh(26)		2018	Interventional	Students(n=100)	Software(44100 Hz,70dB)	Psychoacoustics

White noise therapy

Besides what has already been discussed above - treatment of ADHD symptoms, the literature review suggests that WN has also proven helpful in treating depression, anxiety, stress, schizophrenia, dementia, relieving pain, improving vital signs, and sucking success in newborns (Table 4). Accordingly, WN reduced verbal agitation in pa-

tients in nursing homes with dementia, decreased behavioral and psychological symptoms in patients with schizophrenia with dementia, improved depression and anxiety symptoms, decreased heart rate in elderly patients admitted to the CCU, reduced pain during vaccination, and helped develop sucking behaviors in newborns (14, 43-45).

Table 3: Summary of studies investigating white noise and ADHD

<i>First Author (Reference No.)</i>	<i>Year</i>	<i>Type of Study</i>	<i>Participants (Number)</i>	<i>White Noise Generator</i>	<i>Application</i>
Soderlund(30)	2007	Interventional	Children with ADHD(n=42)	WN generator(81dB)	Cognitive functions in ADHD
COOK(39)	2013	Interventional	Male students with ADHD(n=3)	Brookstone Tranquil M-Junior, MDR-E818LP (75dB)	Off-task behavior (ADHD)
Allen(32)	2015	Interventional	Children with ADHD(n=33)	Sleep Machine iPhone application	Selective attention and visual search (ADHD)
Batho(40)	2015	Interventional	Adolescents With ADHD(n=52)	Background noise and WN(70dB)	Reading and writing speed (ADHD)
Baijot(41)	2016	Interventional	Children with ADHD(n=30)	Etymotic(model ER-3A) (77dB)	ADHD in children
Söderlund(42)	2016	Interventional	Secondary school boys(n=49)	A noise generator(65dB)	Speech recognition (ADHD)
Söderlund(13)	2016	Interventional	Children with ADHD(n=40)	WN generator(80dB)	Cognitive task performance (ADHD)
ÿPickens(33)	2019	Review	Literature Review	Not required	ADHD in children

Table 4: Summary of studies investigating white noise therapy

<i>First Author (Reference No.)</i>	<i>Year</i>	<i>Type of Study</i>	<i>Participants (Number)</i>	<i>White Noise Generator</i>	<i>Application</i>
Burgio(46)	1996	Interventional	Elderly demented people(n=9)	Audiotapes(ocean/ mountain stream)	Verbally agitated
Kaneko (45)	2013	Letters to the Editor	Chizophrenia Patients(n=6)	Tinnitus control instrument,MJ)(60dB)	Dementia patients with schizophrenia
Akca(44)	2014	Semi-experimental	Newborns(n=127)	Album Colic, Osman (55dB)	Sucking success of newborns
Ilkkaya(47)	2014	Clinical- controlled trial	Patients(n=75)	CD containing Pure WN, Windsor	Sedation and anxiety
Karakoc(43)	2014	Interventional	Healthy infants(n=120)	Album Colic, Osman(55dB)	Pain perception in newborns
Farokhnezhad-Afshar(14)	2015	Quasi-experimental	Cardiovascular patients(n=90)	Ocean waves (50-60dB)	Psychoacoustics and Depression
Farokhnezhad-Afshar(48)	2016	Quasi-experimental	Cardiovascular patients(n=59)	Ocean waves (50-60dB)	Medical(The vital signs of elderly patients)
Kucukoglu(49)	2016	Interventional	Premature infants(n=75)	Album Colic, Osman(55dB)	Relieving vaccination pain

Discussion

WN is being used in various fields that may hold promise for its application in occupational health sciences and maintaining the well-being of workplace workers. By involving long-term memory structures, such as the hippocampus, and by enhancing learning capacity, WN simplifies and im-

proves the learning process for new vocabulary (25, 26).According to polysomnographic studies, adding mixed-frequency WN to the ambient noise led to a significant reduction in sleep-induced arousal and sleep disturbance since the difference between background and peak sounds was significantly reduced. Thus, WN promotes more profound and more restful sleep (18-21).

Additionally, it can improve sleep-wake cycles and reduce the delay in falling asleep (17). WN can reduce distractions by reducing the number of noise changes in the surroundings and bringing a sense of privacy when working (33). WN facilitates information processing in the nervous system, which can benefit specific (but not all) aspects of cognitive function such as learning, memory, attention, and concentration (26, 31, 41).

However, WN can have different effects on people with different attention levels. WN can lead to better cognitive tasks for certain people, such as those with ADHD (30). In this way, WN helps people with such disorders compensate for low basal dopamine levels, often resulting from dopamine transport disorders. However, it has the opposite or no effect on individuals with normal or high levels of attention (37). The differential benefits of WN in people with ADHD have yet to be fully understood. However, the Moderate Brain Arousal (MBA) model has been proposed, which might provide some explanation for this (33). The MBA model of dopamine states that people with ADHD have lower tonic levels of dopamine, which makes their phasic release more prone to hyper activation via environmental stimuli. According to the MBA model, low tonic dopamine levels correlate with low levels of neural activity in people with ADHD, reducing signal-to-noise ratios (SNRs) and performance (33, 41). Thus, the model suggests that the perception of external noise can also influence internal noise in the neural system, so there should be an optimal level for cognitive performance.

Though the exact mechanism of WN's benefits has not been discovered, scientists agree that the sum of WN's positive and healing effects can be attributed to two well-known and possible phenomena: stochastic resonance and noise masking. These two phenomena could explain WN's observed benefits, but there is little data on either, and more studies are needed to draw any significant conclusions.

Stochastic resonance (SR) is a well-documented phenomenon in psychophysics that has been suggested as the mechanism behind the beneficial

effects of noise therapy. SR is caused when a signal with too low a power to be detected can be amplified by adding noise. Accordingly, random noise enhances neural communication via the phenomenon of SR. SR increases the SNR of transmission, making the signal easier to detect (in this case the detector would be the auditory system) (33, 40, 41). In summary, an increase in the level of unpredictable noise, such as WN, results in a higher level of signal transmission or signal detection, or to put it simply, a higher SNR. The SR effect appears to be highly sensitive to both the level of the signal and the amount of noise; this relationship follows an inverted U-curve function, where performance peaks at moderate noise levels. Accordingly, moderate levels of WN are beneficial for performance. In contrast, too little WN does not add the power necessary to bring the signal over the threshold, and too much WN overpowers the signal, deteriorating the ability to pay attention and perform (28, 33).

As part of its task, the central nervous system distinguishes between the signal, the information it carries and noise (i.e., meaningless neural inputs that interfere with the signal). The modulation of neural synchronization enables particular brain regions subserving specific functions to form transient networks that allow perception, cognition, or action to occur (28). As a result, random noise enhances the sense of weak sensory signals and is explained by SR. The concept of SR attempts to explain the paradox that the brain seems to utilize WN to differentiate the signal in the targeted stimuli from non-target noise.

Noise masking occurs when a noise obscures the detection of another sound. WN can be used as a mask to reduce the recognition of other background noises by blocking them. Masking by noise works on the principle that the brain actively processes only recognizable patterns, such as speech, and ignores sounds that are not identifiable as patterns, such as static sounds. In essence, noise-masking works by introducing low-level random background noises (usually WN) into the workplace that correlate with human speech frequencies. Meanwhile, controlling the decibel level

and frequency of noise added to the environment is crucial. Because the noise must be loud enough to interfere with the understanding of conversations at a predetermined distance, the human brain will not be able to ignore the noise if it is too loud, eventually interfering with other processes. The WN can do this well since it can cover speech without distracting or irritating the listener (1, 33).

Nowadays, workplaces often include "open spaces," where many employees work in spaces usually separated by barriers. In this work environment, ideas are shared, creativity is fostered, collaboration is emphasized, and productivity at work is increased. Therefore, it is often preferred to have such work environments. Nevertheless, everyone cannot work efficiently and effectively in these environments because of noise pollution and the distraction it causes. To maintain the advantages of an "open spaces" layout in the workplace and to maintain employee attention and focus, systems need to mask ambient noise and improve employee concentration. WN-based systems that mask disturbing ambient noise play an essential role in such environments. Offices, organizations, institutions, and academic environments, as well as telecommunications, police, and emergency services centers with telephone systems, etc., can benefit from using these systems to improve productivity and comfort. Moreover, it can facilitate speech privacy, allowing employees to be more productive and concentrate.

Most jobs in today's society are associated with shift work due to socio-economic conditions and market demands. For example, firefighters, manufacturing workers, health care professionals, security guards, and physical security guards work shifts with short rest periods. Sleep delay and difficulty falling asleep are usually the most common problems of shift workers with certain personality traits (50). WN devices can prove to be an effective intervention for shift workers suffering from sleep disorders. WN also improves sensory integration and sleep (21).

Maintaining focus and attention while working and reducing distractions and reactions to environmental stimuli is essential when performing

high-risk jobs or jobs requiring high levels of precision, such as assembly and manufacturing industries. WN has been found to affect various aspects of cognitive function (33) empirically. Due to this, the authors of the present study believe that WN is an effective option, especially for those with poor concentration or attention problems in the workplace.

Tinnitus is a well-known disorder in occupations with high noise levels (24). Historically, tinnitus was believed only caused by changes in the auditory nerve and cochlea. However, imaging or EEG examinations have shown that central mechanisms and various brain functions may be involved (51). In the literature, several treatments have been reported to treat tinnitus, including acupuncture, cranial stimulation, and pharmacotherapy (24). Nevertheless, none of these have reached a consensus and are only helpful in certain circumstances. This may be due to the differences between the different types of tinnitus and a lack of standardization (52). On the other hand, WN may prove more beneficial for different types of tinnitus because of its wide band of frequencies and the possibility to mask different sounds with different frequencies. Thus, using a Tinnitus Masker, which continually generates specific sound frequencies, often WN, and which reduces the patient's perception of sounds in the ear, may be a successful treatment option for many types of tinnitus.

Finally, this study was conducted to address the potential for future research about white noise in occupational health. Nevertheless, the main limitation of this study was the lack or unavailability of results of studies related to occupational health and the improvement of working conditions related to white noise.

Conclusion

Studying WN to determine if it can improve and enhance the occupational health status of workers showed that, despite the viewpoint that noise is destructive and disruptive, WN can be beneficial and even health-enhancing. WN can enhance

the work environment and meet occupational safety and health objectives based on the study's results. The results of this study will provide a basis for continuing research into the use of WN in the workplace as an engineering and management control method.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

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