Ponencia de Ana Toro, sobre el propuesto **Código de Orden Público del Municipio de San Juan** (2023). Residente de la comunidad de Hato Rey, cercano al Coliseo de Puerto Rico, José Miguel Agrelot (CPR).

Todos estamos conscientes que somos, 'la jurisdicción más ruidosa de Estados Unidos de América', según el Nuevo Día, 24 de junio de 2023. Se hace imperativo controlar estos ruidos por nuestra salud física y mental.

Como residente de la comunidad de Hato Rey cercano al Coliseo de Puerto Rico, José Miguel Agrelot (CPR) y a 24Marketplace, he observado un incremento exponencial del ruido desde hace casi tres años. La mayoría de los conciertos en el CPR provocan un caos vehicular antes y después de los eventos, incluyendo, bocinazos, "voceteo" y pirotecnia; en el estacionamiento de 24Market Place, contiguo a varios edificios residenciales, se han celebrados conciertos al aire libre, algunos con el permiso del Municipio de San Juan, culminando entre la 1:00 AM a 2:00 AM, con fuegos artificiales, exceso de personas en las calles aledañas y basura. Las distancias desde la tarima del estacionamiento a los condominios son (según Google Maps): Atrium Plaza (154 m), Egida La Morada (287 m), Galería I (270 m), Egida de Abogados (352 m); en la Calle O'Neill también se ha celebrado en enero/2023 un concierto "pop up" hasta casi las 4:00AM. (Ver vídeos)

Voceteo 2AM, un lunes: https://www.facebook.com/anatorocollazo/videos/303837598394503

Fuegos artificiales, 15/Oct/2022,
1AM: https://www.facebook.com/anatorocollazo/videos/595319609007326

Concierto contiguo a
condominios: https://www.facebook.com/anatorocollazo/videos/532970062008987

Basura: https://www.facebook.com/anatorocollazo/videos/1273277466861095

Lo particular de nuestra comunidad es que, aunque es parte de Hato Rey, está excluida del Modelo de Paz Ciudadana del Sector de Hato Rey, el cual explícitamente prohíbe poseer y consumir bebidas alcohólicas en las vías públicas o sitios públicos, al igual que prohíbe su venta y/o expendio con este propósito. *Me parece que este modelo es más restrictivo ya que mantiene a las personas dentro de los establecimientos sin perturbar a los residentes aledaños y; por ende, la música debe limitarse al interior.*

El CPR contrata a la Policía de Puerto Rico Estatal para servir sus necesidades durante sus eventos; es decir, procurar que un vehículo no impacte a un transeúnte y manejar el flujo de tránsito. Estos policías no atienden los ruidos de bocinazos, los "voceteos" ni las pirotecnias. Cuando los conciertos llenan, despejar el tránsito toma dos horas—dos horas que perdemos de sueño. Varias ciudades altamente ruidosas están utilizando sensores en las vías las cuales identifican los ruidos sobre ciertos decibeles y expiden boletos: París, Linares (Jaen), Toronto, Philadelphia y Nueva York. Este sistema se podría utilizar para identificar los ruidos antes mencionados sin la intervención de los policías. (Ver enlaces siguientes:)

https://www.semanticscholar.org/paper/Medusa%2C-a-new-approach-for-noise-management-and-in-Mietlicki-Bruitparif/865459c9b435a11e30e1cfe65bf0bc241dedc595

Con relación al ruido hay un componente que no se está considerando: las frecuencias bajas audibles altamente amplificadas (high intensity / low frequency sound). La música moderna ofrece una experiencia multisensorial: el objetivo es provocar sensaciones auditivas y físicas; utiliza bandas muy bajas (casi infrasonidos) cuyas características crean un problema serio para los que no quieren sentirlas ni escucharlas; provocan resonancia en el cuerpo humano, atraviesan objetos (cemento), por lo cual, viajan lejos, el sonido es uno vacío (no graba). Un vehículo puede pasar por al lado de mi apartamento con el volumen tan bajo que no se escucha la música, sin embargo, los "bajos" retumban en las paredes y en mi cuerpo. Estar en presencia de estas frecuencias provocan efectos en la salud humana, incluyendo ansiedad, cardiovascular y neurológicos, entre otros.

En el artículo *Infrasonic Music*[1], adjunto, se hace referencia a cómo se están utilizando las frecuencias bajas audibles para crear una experiencia mulitisensorial en la música. Es muy interesante porque ofrece una mirada a las características de estas frecuencias, lo que se desea provocar con su uso y cómo se usan--es su tema de tesis doctoral.

Hay cantidad de literatura relacionada a los efectos a la salud de las frecuencias bajas audibles (Araújo Alves J, Neto Paiva F, Torres Silva L, Remoaldo P., 2020). En resumen, se han encontrado las siguientes afecciones, entre otras: 'trastornos del sueño (11.7%), malestar, sensibilidad e irritabilidad al ruido (10%), molestia (13.3%), estrés (6.7%), pérdida de audición (8.3%), reducción del rendimiento/fatiga (5%), ritmo cardíaco/enfermedades cardiovasculares (10%), tensión y presión arterial (6.7%), ansiedad (1.7%), depresión (3.3%), desequilibrio/desorientación (3.3%) y rendimiento mental (6.7%)' [2].

Me parece que este es el componente que más está contribuyendo a la contaminación ambiental por ruido, recientemente.

En conclusión, el nuevo Código de Orden Público del Municipio de San Juan debe:

a. Incluir del Modelo de Paz Ciudadana del Sector de Hato Rey: [Artículo 16.05: Prohibición de venta y/o expendio de bebidas alcohólicas para el consumo en sitio o vía pública. Artículo 16.06: Prohibición de poseer y consumir bebidas alcohólicas en las vías públicas o sitios públicos. Artículo 16:07 Prohibición de consumir o poseer bebidas alcohólicas por conductor o pasajero en vehículo de motor. Artículo 16:08 Prohibición de venta y/o expendio de bebidas alcohólicas desde vehículos de motor, carritos y/o neveritas.]

b. En la sección de ruidos, incluir la prohibición de pirotecnia.

c. En la sección de ruidos, prohibir la amplificación de los "sub-bajos".

d. En la sección de ruidos, prohibir el "voceteo".

e. En el Artículo 2.101 Horario de Venta y Expendio de Bebidas Alcohólicas, reemplazar 1:00 AM por 11:00 PM y 2:00 AM por 12:00 AM.

Adjunto en PDF:

[1]Hope, C. (2009). *Infrasonic Music.* Leonardo Music Journal *19*, 51-56. https://www.muse.jhu.edu/article/363700. Recuperado de: https://www.researchgate.net/publication/49279725_Infrasonic_Music

[2]Araújo Alves J, Neto Paiva F, Torres Silva L, Remoaldo P. *Low-Frequency Noise and Its Main Effects on Human Health—A Review of the Literature between 2016 and 2019*. Applied Sciences. 2020; 10(15):5205. Recuperado de: https://doi.org/10.3390/app10155205

applied sciences

MDPI

Review

Low-Frequency Noise and Its Main Effects on Human Health—A Review of the Literature between 2016 and 2019

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Abstract: This paper summarizes the presently available knowledge about the association between low-frequency noise and its effects on health. A database was constructed with a total of 142 articles published between 2016 and 2019 regarding low-frequency noise exposure and its effects on health. A total of 39 articles were analysed in depth. The articles were divided into categories according to the effects on human health addressed. Regarding the emitting source, there was a greater number of articles addressing issues related to sources of environmental noise and noise from wind turbines. As for the effects generated on human health, there was a greater number of articles referring to the effects on sleep disorders, discomfort, sensitivity to and irritability from noise, annoyance, hearing loss, and cardiovascular diseases, and these effects are analysed in more detail in the present article.

Keywords: low-frequency noise; human health; impacts; environment; literature review

1. Introduction

At the worldwide level, there is a large number of studies on health impacts due to occupational and environmental exposure to noise. However, there are still few studies focusing exclusively on health impacts and discomfort due to low-frequency noise (Figure 1). One of the main reasons for this is the low sensitivity of the human auditory system to low frequencies. On the other hand, this type of noise has very particular characteristics and causes much more discomfort and long-term, non-auditory effects [1–3].

In the 1920s, research on the subject focused on occupational exposure and generally reported physiological changes such as pain in the hands, swelling, and increased vascular tone [4–6]. Until the 1930s, it was believed that the effects of noise on health were restricted only to hearing loss. In a study published in the Journal of the Acoustical Society of America, Jüichi Obata et al. [7] concluded that the effects of noise on human health went beyond hearing loss.

After the low contribution to the improvement of this scientific field in the 1960s, the 1970s were marked by the emergence of a series of studies addressing annoyance caused by environmental noise [1].

Consequently, during the 1970s and 1980s, studies started focusing on the impacts due to exposure to environmental noise [8,9]. The 1990s were marked by research aimed at more specific impacts on human health and reported discomfort due to noise [9–11]. Furthermore, these studies correlated exposure to noise with the onset of cardiovascular diseases [12,13].

In the 1990s, the World Health Organization (WHO) published documents on the subject, such as the Guidelines for Community Noise, in 1999. Regarding the studies published during the 2000s, the most important are those directed at specific environments, such as schools and residential areas [14,15]. These studies used a comparison of the noise level measured by using reference curves with the aim of assessing noise discomfort and reinforced the fact that the A-weighting filter is not ideal to evaluate the non-auditory effects of low-frequency noise (LFN) [1–3]. From 2005, the studies that stand out are oriented to the impacts of low-frequency noise on the quality of sleep [16–18].

In general, these studies were carried out with voluminous samples involving patient reports, the application of questionnaires, the adoption of cross-sectional studies based on databases, and the comparison of environmental noise levels measured using criteria curves.

In fact, these studies reinforced the fact that low-frequency noise is a powerful stressor. The most cited effects on human health refer to emotional changes such as annoyance [19,20], agitation, and distraction [2,21,22], in addition to the association of low-frequency noise with cognitive alterations [23], the development of cardiovascular diseases [24,25], sleep disorders [26], and high blood pressure [27], and, more recently, the effects of industrial low-frequency noise on dental wear [28,29].

In the field of occupational medicine, there is a large number of studies that claim that low-frequency noise is an agent that interferes with the performance of work tasks [22,30]. In addition to these changes, noise can be an agent that affects mental and physical health.

In this sense, the effects of noise pollution comprise "auditory effects", which directly affect the human auditory system, and "non-auditory effects", i.e., the impact of noise on physiological functions. As regards "non-hearing effects", discomfort has been reported as the most frequent effect caused by exposure to low-frequency noise in humans [1,31,32].

In addition, the discomfort may vary from individual to individual and depends not only on the recorded noise pressure levels but also on the exposure time as well as the low-frequency components present in the measured sound levels. Thus, noise that contains low-frequency components tends to be more annoying than noise without them [1,33–35].

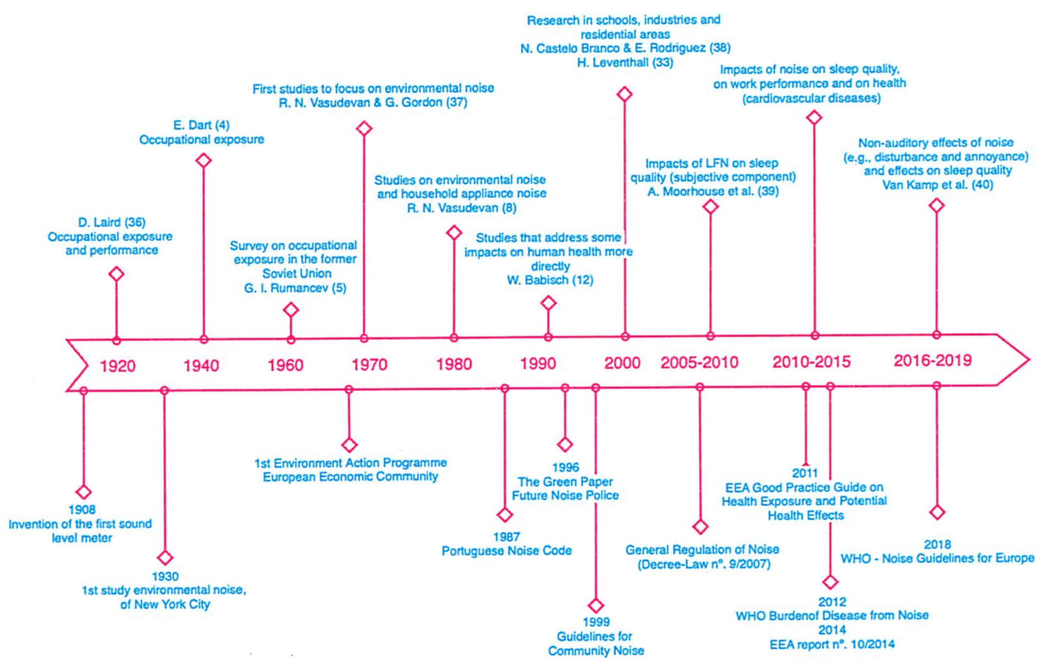

Figure 1. A summary regarding health effects due to low-frequency noise exposure. Source: own elaboration based on several authors [4,5,8,12,36–40].

Since 2000, the WHO has recognized low-frequency noise as an environmental problem. In addition, the health impacts of low-frequency components on noise are estimated to be more severe [1,33–35].

The WHO published its most recent noise pollution guidelines for Europe in 2018. This publication states that further research into the health impacts from wind turbine noise is needed, namely, the low-frequency component [35].

In fact, a systematic review of the up-to-date, peer-reviewed, epidemiological literature has been performed on the association between low-frequency noise and its effects on human health. The present paper aims to fill this gap in the literature.

The paper is structured into four sections. After the introduction, the methodology is outlined. A systematic review regarding scientific articles about low-frequency noise and its impacts on human health is presented in Section 3. The article concludes by highlighting the main conclusions of an in-depth analysis of 39 articles published between 2016 and 2019, some limitations of the research, and recommendations for further studies.

2. Materials and Methods

Database Collection

The original papers were identified by a literature search between October and December 2019 of all of the principal accessible journals and databases (PubMed, Web of Science, and Scopus) concerning the theme and using the following keywords: "low-frequency noise"; "low-frequency noise and its effects on health"; "noise pollution and health". A database was constructed with some variables, e.g., sample results and main noise sources. A total of 142 articles published between 2016 and 2019 was found (Supplementary Materials). Only studies were included in which it was mentioned in the title or abstract that the association between the low-frequency noise and effects concerning health or well-being was studied.

The 142 papers selected for the period from January 2016 to December 2019 were grouped into 9 categories: reviews; health effects due to noise and noise pollution; low-frequency sound/infrasound; health LFN case studies (small population); health LFN case studies (large population); LFN case studies (animals); laboratories studies, simulation studies, and computational case studies; and not relevant. A total of 39 articles published between 2016 and 2019 and grouped in the categories "health LFN case studies (small population)", "health LFN case studies (large population)", and, finally, "LFN case studies (animals)" were selected for in-depth evaluation. The evaluation carried out focused on the impacts on health, highlighting the incidence of studies aimed at human health and others aimed at carrying out tests on animals that may lead to a future study on humans. Additionally, the 39 articles evaluated used similar techniques (e.g., questionnaires; data previously collected in other studies; cognitive, physiological, and psychological tests based on medical and auditory equipment; noise measurements and audiometric assessments; and experimental tests based on noise exposure). The 39 articles evaluated were carried out mostly in Asian and European countries and were based on small samples.

3. Results and Discussion

This section presents the main results obtained from the analysis of articles published on low-frequency noise and its impacts on human health between 2016 and 2019. The results and discussion are structured in five sections on the main effects of low-frequency noise exposure on human health. Each section begins with a description of the methodologies used, followed by the main results achieved in the studies analysed.

3.1. Low-Frequency Noise Exposure and Its Main Health Effects

Table 1 presents a synthesis of the 39 articles based on three of the categories listed in the methodology section. These categories were as follows: cases of low-frequency noise studies in a small population, in a large population, and in a population of animals.

Of the 39 articles that were included in the evaluation of this article, it was observed that the main effects on human health are more prevalent in aspects such as sleep disorders (11.7%), discomfort, sensitivity and irritability to noise (10%), annoyance (13.3%), stress (6.7%), hearing loss (8.3%), reduced performance/fatigue (5%), heart rate/cardiovascular diseases (10%), tension and blood pressure (6.7%), anxiety (1.7%), depression (3.3%), imbalance (3.3%), and mental performance (6.7%).

There were also other effects on human health but with an incidence in very specific aspects (13.3%), such as the frequency of chromosomal aberrations in bone marrow cells, excess bilirubin, peptic ulcers (gastric and duodenal), effects on the cerebral blood barrier, haemodynamic events, irreversible imbalance with structural damage to the otoconial membrane, tinnitus and sound reconversion therapy, and vocal disorders and effort.

Only the effects on human health related to sleep disturbance, noise discomfort, annoyance, hearing loss, and cardiovascular disease were analysed, as these were the themes where a greater number of articles were observed, thus allowing a better comparison and evaluation between the various articles.

3.2. Sleep Disturbance

Sleep disturbance is one of the effects on human health that is due to exposure to noise, in particular, low-frequency noise. Long-term exposure to low-frequency noise from wind energy is a major factor in sleep disturbances in residents who live near wind farms. Abbasi et al. [41], Morsing et al. [42], Ishitake [43], Pohl, Gabriel, and Hübner [44], and Poulsen et al. [45] evaluated exposure to low-frequency noise due to proximity to wind turbines. The methodology adopted included the measurement of sound levels and, after the exposure of participants to wind turbine noise, an assessment of sleep disturbances.

The studies [41–43] applied questionnaires to participants to assess the disturbances they felt after exposure to noise. In the study by Abbasi et al. [41], in addition to the questionnaire, Pearson's correlation, analysis of variance, and multiple regression tests were applied for data analysis using software. Morsing et al. [42] evaluated the impact of noise on sleep as measured by polysomnography, after participants were exposed to wind turbine noise for three consecutive nights. Finally, Ishitake [43] assessed sleep disorders using the Athens Insomnia Scale method, based on the responses of participants when exposed to noise.

In the study designed by Pohl, Gabriel, and Hübner [44], the methodology of stress psychology with noise measurement was adopted, ascertaining the physical and psychological symptoms referenced by residents that participated in the study (general mental indisposition, performance and reduced work capacity, lack of concentration, fatigue, tension, nervousness, negative mood, dizziness, irritability, indisposition, reduced sleep quality, and annoyance) caused by exposure to noise from wind turbines. Moreover, Poulsen et al. [45] evaluated the evolution of medical prescriptions related to anxiolytics and antidepressants ingested by the populations living near the wind turbines, in an analysis that lasted two years (2012 to 2014).

Sleep disturbances may also be due to exposure to noise from oil and gas operations, namely in the construction and drilling of wells in residential areas [46]. Blair et al. [46] evaluated the impacts of these operations on human health, including sleep disorders. Sleep disturbances can also be linked to exposure to railway noise, as studied by Smith et al. [47]. They [47] evaluated the effects on physiological sleep resulting from the exposure of participants to railway noise for five consecutive nights, using polysomnography and questionnaires.

As for the results, Abbasi et al. [41] evaluated the effects of noise from wind turbines on the health of employees, divided into three groups (maintenance, safety, and administration). The group with the greatest exposure to noise was the maintenance team, who were considered as a reference group. Maintenance workers were subject to a higher sound level because they are in the vicinity of wind turbines, and higher GHQ (The General Health Questionnaire) scores were also recorded (the health assessment tool for individuals used in the study). Therefore, compared to those on management and safety staff, the harmful health effects of wind turbine noise are stronger on maintenance workers.

The questionnaire was divided into four sections, including somatic symptoms, anxiety and insomnia, social dysfunction, and depression. Based on the results obtained in this study, only the equivalent sound level had a significant effect on the general state of health and in some of its sections. The negative impact of noise exposure of 60 and 66 dBA on general health was approximately six and four times less than that of 83 dBA, respectively. The adverse effect of 60 dBA noise exposure in the anxiety and insomnia section was 1.6 times less than that in the 83 dBA exposure group. The effect of the experiment in the anxiety and insomnia section was 0.2 times greater than that of the 83 dBA noise exposure. This result indicates that the worst health status is due to working conditions and chronic exposure to occupational risk factors, such as noise. The results show that the effect of exposure to noise of 66 dBA in the social dysfunction section was 2.3 times less than that of 83 dBA noise. It was concluded that exposure to noise is significantly correlated with all subsections of general health, except depression. As a general evaluation of the article, the low-frequency noise from the turbines can cause harmful effects on the health of workers who are very close to the turbine, due to the reception of very intense noise [41]. By convention, a frequency A-weighting filter is used in low-frequency noise evaluation [3]. As a matter of fact, the A-weighting filter is not suitable for assessing the effects of low-frequency noise because this filter drastically reduces the low-frequency levels measured [3].

The results obtained by Morsing et al. [42] are due to the measurement of the effects of night noise from wind turbines on sleep measured physiologically in the laboratory. During nights with noise from the turbines, there was some incidence of participants with frequent awakening, less deep sleep, reduced continuous sleep, an increase in sleep disorders self-reported by the participants, and morning tiredness after the nights of noise exposure compared to nights without exposure to noise. Some evidence was observed in the study in which amplitude modulation and rotational frequency were varied; deeper sleep was negatively affected due to higher frequency and strong amplitude modulation while light sleep increased with high frequency and acoustic beat [42].

Blair et al. [46] monitored continuous levels of audible and low-frequency noise during the construction and drilling of oil and gas wells in a residential area. The equivalent monthly levels of continuous noise varied between minimum values of 51.5 and 73.1 dBC, and maximum values of 60.2 to 80.0 dBC. On the one hand, Blair et al. [46] found that continuous weighted noise levels above 50 dBA can have effects on health, such as increasing the risk of cardiovascular disease and hypertension. On the other hand, they found that low-frequency noise levels that exceeded the recommended level of 60 dBC caused nausea and headaches. In a general analysis of the article, the average noise levels in an oil and gas well during construction and drilling exceeded the levels associated with annoyance, sleep disturbances, and cardiovascular health effects; that is, they were higher than 50 dBA or 60 dBC [46].

Ishitake [43] conducted an epidemiological study that suggests that the noise generated by wind power generation facilities may be a risk factor for effects on human health, especially sleep disturbances. In this study regarding sleep disturbances caused by infrasound, it was found that the noise level of the wind turbine measured in the lower frequency range is below the human sensory threshold. As mentioned by Ishitake, 63% reported having sleep disturbance; the effect was reduced with increased distance between the source and the receiver [43].

Pohl, Gabriel, and Hübner [44] carried out a study that combined the methodology of stress psychology with noise measurement. They conducted interviews with residents who lived close to a wind farm and assessed their perception of noise from the wind farm and road traffic at two different points in time, first in 2012 and later in 2014. Residents complained of physical and psychological symptoms due to traffic noise (16%) and noise from wind turbines (10% and 7% in 2012 and 2014, respectively). In the study, 12 symptoms caused by exposure to noise were evaluated. It was found that the participants reported more symptoms in 2012 than in 2014 and the most strongly irritated participants considered their overall health in 2014 to be improved. The sleep disorders assessed decreased from 2012 to 2014. Distraction also decreased slightly from 2012 to 2014 for the most irritated residents, while remaining relatively low and/or unchanged in the other groups. However, only a few participants showed evidence of noise from low-frequency wind turbines: in 2012, 8.5% reported feelings of pressure related to wind farms and 6.1% reported having felt vibrations in the body; in 2014, these feelings decreased to 6.8% and 3.8%, respectively. The annoyance experienced was very low, and symptoms of dizziness were not observed in this study. Regarding the effects of wind noise stress compared to road traffic noise, there were more reports of symptoms due to traffic (15.8%) than to noise from wind turbines. In 2014, it was observed that about a third (34.9%) of the participants were slightly irritated by traffic noise and 21.2%, by noise from the wind farm [44].

Poulsen et al. [45] determined the numbers of prescriptions for anxiolytics and antidepressants for residents due to prolonged exposure to noise from wind turbines. During the survey carried out between 1996 and 2013, 68,696 adults had recourse to sleeping pills and 82,373 used antidepressants, out of a population of 583,968 and 584,891, respectively. In this study, it was observed that people over the age of 65 years were more affected by the noise of wind turbines, with an HR (hazard ratio) of 1.68 for measuring sleep and 1.23 for antidepressants being found for the group with the greatest exposure. Regarding low-frequency noise due to wind turbines in indoor environments, the risk rate among people aged 65 and over when exposed to noise equal to or higher than 15 dB was 1.37 for anxiolytics and 1.34 for antidepressants. Thus, Poulsen et al. [45] concluded that the combination of high noise levels from wind turbines and the use of anxiolytics and antidepressants can induce sleep disturbance and, in turn, affect the mental health of the elderly [45].

Finally, Smith et al. [47] demonstrated that sleep was significantly affected, both in terms of physiological measures and by self-report, during nights with exposure to 45 dB noise, although the number and size of the effects were modest. Most self-reported sleep measures were adversely affected by terrestrial railway noise. In this study, no significant differences were found in the general sleep structure or disorders and in the subjective quality of sleep between the reference tests and the 35 dB night tests. The results obtained support the value of the Swedish guidelines proposed for the maximum noise level of 35 dB for indoor environments and may be suitable for protection against adverse sleep problems due to terrestrial railway noise [47].

3.3. Discomfort from, Sensitivity to, and Irritability from Noise

Discomfort, sensitivity to noise, and irritability are other effects on human health due to exposure to low-frequency noise.

Huang, Pan, Liu, Hou, and Yang [48] analysed acoustic comfort and developed a noise analysis model for a skyscraper by measuring exterior noise, mainly from road traffic.

Suzuki, Suzuki, Onishi, and Penido [49] performed audiometric assessments on patients with persistent tinnitus, through their perception of sounds of nature and everyday life and their comparison with a pure tone or noise (white noise, narrow-band low frequency and narrow-band high frequency). The assessments considered in the patients were otorhinolaryngological, audiological, Pitch Matching and Loudness, Visual Analogue Scale, Tinnitus Handicap Inventory, and Minimum Masking Level [49].

Lee et al. [50] determined the effects of exposure to transport noise and established a relationship with the blood pressure of residents of residential buildings. They determined noise exposure levels (Lden, Lday, and Lnight) through adjusted linear regression analysis and established the relationship with blood pressure [50]. They also conducted a questionnaire related to the annoyance caused by internal noise, noise sensitivity, and sociodemographic variables [50].

Tao, Wang, Zou, Li, and Luo [51] assessed the irritation from noise in a metro depot and the influence of noise in adjacent residential buildings. They carried out a questionnaire with people working at the metro station and took field measurements, both at the metro station and in the adjacent residential buildings [51].

Moradi et al. [52] studied the effects of noise on the selective attention of university students. They conducted questionnaires to determine students' personality traits; that is, they assessed whether they were extroverted or introverted and analysed their stability or instability [52]. In addition, they also assessed the level of sensitivity to noise using the Weinstein sensitivity scale and the level of selective attention using the DUAF test from the Vienna Test System [52].

Alves, Silva, and Remoaldo [53] analysed the effects of exposure to low-frequency noise pollution emitted by poles and power lines on the well-being of the population, based on a study carried out on "exposed" and "unexposed" populations in two residential areas. Additionally, adapted audiometric tests were carried out to complement the analysis and determine the audibility thresholds of "exposed" and "unexposed" volunteers. To develop the research, Alves, Silva, and Remoaldo [53] used sound level measurements and sound recordings (recordings made at a distance of 5 m from the source), as well as the adapted audiometric performance test [53].

Regarding the results, [48] observed that, due to the effect of the ground, the effect of medium propagation, and the different frequency components, the comfort of the sound does not increase with distance from the ground, that is, on the highest floors. They concluded that low-frequency noise has great potential for the annoyance and discomfort of the residents of the building.

Suzuki et al. [49] identified 181 tinnitus complaints in which pure-tone-type tinnitus was observed in 93 (51%) of the responses (4 low pitch and 89 high pitch) and from noise in 88 (49%) responses (15 low frequency and 73 high frequency). Regarding tinnitus with a low-frequency sensation, 19 responses were determined, while for that with a high-frequency sensation, 162 responses were found. They determined a Visual Analogue Scale average of 5.47 for tinnitus similar to pure tone and 6.66 for that similar to noise, with a higher value for noise. The average loudness of tinnitus similar to pure tone was 12.31 dBNS, and that similar to noise was 10.54 dBNS. For the Tinnitus Handicap Inventory and the Minimum Masking Level, the patients considered in the study were separated into three groups with tinnitus, pure tone, noise, and multiple, with the mean of the largest Tinnitus Handicap Inventory in the group with multiple tinnitus being 61.38. For the Minimum Masking Level, masked noises of the type white noise and narrow band [49] were used.

Lee et al. [50] concluded that general noise (road and rail traffic) and road traffic showed higher associations with systolic blood pressure (SBP) than with diastolic blood pressure (DBP), while rail noise had similar associations with SBP and DBP. They also observed that the closest associations between exposure to noise and blood pressure were estimated for participants who reported higher classifications of annoyance, irritation, and sensitivity to noise. This indicates that the annoyance of internal noise and sensitivity to noise develop regardless of the level of exposure to external noise. They also found that people who were sensitive to noise and participants who were most irritated due to internal noise had significantly higher SBP and DBP than the rest. In addition, the regression coefficients between noise exposure and blood pressure increased slightly in a subgroup that excluded participants exposed to high railway noise [50]. The results established by Lee et al. [50] support the hypothesis that long-term exposure to transport noise is associated with higher blood pressure in adults living in multi-storey residential buildings.

Tao et al. [51] concluded that 96% of respondents feel disturbed by noise and 31% of them feel that the impact of noise is serious. They noted that closing doors in buildings may be a solution, but only a reduction in noise from the low-frequency structure in the range 63 to 125 Hz occurs. They found that there is a problem of annoyance from low-frequency noise. They evaluated that the noise level caused by the fans decreases with the height of the floors. Ventilation noise is one of the dominant noise sources for adjacent buildings, and, therefore, they found that the shorter the distance between the building's fans and ventilation, the more severe the impact of the noise. They also concluded that the noise attenuation rate increases with an increase in the distance to the noise source [51].

Moradi et al. [52] concluded that there were no significant differences in the average time spent on correct answers before and after exposure to noise between extroverted and introverted participants; however, there was a significant difference among extroverts in the average time spent on correct answers before and after exposure to noise. The results showed that introverted participants are more sensitive to noise than extroverts. The most noise-sensitive participants showed greater stimulation during exposure to noise, which led to increases in incorrect responses and a decrease in mental performance. Moradi et al. [52] found that the participants' personal traits are related to their annoyance due to noise. Moradi et al. [52] concluded that stress due to noise improves selective attention in extroverted individuals.

Finally, Alves et al. [53] concluded that the "exposed" area has higher sound levels and, consequently, more problems with well-being and health than the "unexposed" population. Audiometric tests also revealed that the "exposed" population seems to be less sensitive to low-frequencies than the "unexposed" population; that is, the "exposed" group needs a higher sound intensity to perceive noise, especially at lower frequencies. The "exposed" group has a larger number of respondents with health problems (e.g., cardiovascular disease, insomnia, and depression), which can be caused by exposure to low-frequency noise emitted by power poles and lines. On the other hand, the "unexposed" group tends to perceive noise with a slightly lower sound intensity, due to the fact that this residential area is far from the emission source [53].

3.4. *Annoyance*

Annoyance is another effect on human health due to exposure to low-frequency noise.

Boyle et al. [54] assessed how the A-weighted exposure levels differed indoors and outdoors in homes in the vicinity of a natural gas compressor station, where low-frequency noise was found. They performed measurements of the noise levels defined in the A-weighted scale to filter most of the low-frequency noise and in the C-weighted scale to identify the impulse noise (noise measured in less than one second with peak levels 15 dB higher than the background noise) [54].

Van Kamp, Breugelmans, Van Poll, Baliatsas and Van Kempen [40], and Lee et al. [50] presented questionnaires to assess issues related to annoyance due to noise. Van Kamp et al. [40] surveyed complaints due to low-frequency noise using existing data and by means of a questionnaire determining participants' annoyance due to noise from road, rail, and air traffic sources, low-frequency noise, construction noise, and noise sensitivity; the residential satisfaction index; and a survey of measures applied in the residence to avoid noise. As for the study by Lee et al. [50], the methodologies adopted are referenced in Section 3.3.

The methodologies adopted by Blair et al. [46] and Pohl, Gabriel, and Hübner [44] are referenced in Section 3.2 However, according to [46], noise levels above 50 or 60 dBA can cause annoyance.

Ishitake [43] assessed the level of annoyance regarding the source of low-frequency noise generated by wind energy and road traffic noise, by conducting a questionnaire to obtain these perceptions.

According to Hansen et al. [55], the presence of amplitude modulation in wind farm noise results in increased annoyance and possible sleep disruptions. The developed study investigated the prevalence of this characteristic in homes close to the wind farm [55]. In the article by Hansen et al., several important variables were considered, namely, the receiver-source distance, meteorological conditions, and proximity to reflective surfaces, among others.

Moradi et al. [52] assessed the level of selective attention through the DUAF test (test of selective attention, performance capacity, and general performance) and the level of annoyance based on the ISO15666 (International Organization for Standardization, 2003), based on the study sample referenced in Section 3.3.

As for the results, Boyle et al. [54] found that houses located close to a compressor station have higher average noise levels, both indoors and outdoors, than houses located at a distance greater than 300 m. The authors also found that noise levels during the day were higher than those recorded at night and that the residents of residences located less than 300 m from the station were exposed to low-frequency noise. In this study, they established the relationship of the results with the daytime and nighttime noise levels recommended for the prevention of hearing loss and annoyance, established by the WHO [56,57], and found that the average noise levels determined exceeded these guidelines [54].

Table 1. Studies selected and health effects related to low-frequency noise.

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2016	Zeitooni, Mäki-Torkko and Stenfelt [66]	27	Binaural hearing capacity	Evaluation of binaural auditory capacity in adults with normal hearing when bone conduction stimulation is applied bilaterally in the bone conduction hearing aid implant position, as well as in the audiometric position in the mastoid.	Exposure to low-frequency noise (400 to 600 Hz) and high-frequency noise (3000 to 5000 Hz).	The results confirmed that the binaural auditory processing with bilateral bone conduction stimulation in the mastoid position is also present in the bone conduction hearing aid (BCHA) implant position. This indicates the capacity for binaural hearing in patients with good cochlear function when using bilateral BCHAs.
2016	Walker, Brammer, Cherniack, Laden and Cavallari [63]	10 (male)	Heart rate variability and stress	The authors conducted a sound monitoring campaign between February 2015 and February 2016 across the city of Boston, MA. Boston occupies an area of 124 square kilometres with an estimated population of close to 700,000 individuals. To identify potential monitoring sites, the authors divided the city of Boston into 500 × 500 m grid cells using ArcGIS. They constructed a list of all accessible potential sites (n = 525), and 400 site locations were randomly selected for monitoring by time of day. Convenience sampling was also conducted in certain areas of the city to ensure adequate coverage of varied land use and urban activity. The participants underwent an outpatient electrocardiogram. Blood pressure measurements and saliva samples were collected before, during, and after exposure to noise.	Low-frequency noise (31.5 to 125 Hz at 75 dB (A)); high-frequency noise (500 to 2 kHz at 75 dB (A)); 50 dB (A) "noise-free" exposure.	During exposure to noise, reductions in heart rate variability of 19% (−35; −3.5) with low-frequency power and 9.1% (−17; −1.1) were observed according to the quadratic difference average between adjacent normal heartbeat intervals. During exposure to low-frequency noise, reductions in heart rate variability of 32% (- 57; −6.2) with high-frequency power, 34% (−52; −15) with low-frequency power and 16% (−26; - 6.1) according to the standard deviation of the adjacent normal heartbeat intervals. During exposure to high-frequency noise, reductions in heart rate variability of 21% (−39; −2.3) with low-frequency power compared to that with exposure to noise.
2016	Liu, Young, Yu, Bao and Chang [67]	1002	Hypertension and blood pressure	Personal noise measurements and environmental analysis of octave bands were carried out to divide workers into similar exposure groups based on the similarity and frequency of the tasks they performed in the company, thus creating a high exposure group (≥80 dBA), another of medium exposure (75–79 dBA), and another of low exposure (<75 dBA).	Noise at frequencies of 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz during the working period.	Participants exposed to ≥80 dBA for 8 years had a higher relative risk of hypertension (relative risk = 1.38, 95% confidence interval: 1.02, 1.85) than those exposed to <75 dBA. Significant exposure–response patterns were observed between incident hypertension and the stratum of exposure to noise at frequencies of 250 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz. The strongest effect was found at the frequency of 4 kHz, and a 20 dBA increase in noise exposure at 4 kHz was found to be associated with a 34% higher risk of hypertension (relative risk = 1.34, confidence interval of 95%: 1.01, 1.77).
2016	Selander et al. [58]	1,422,333	Hearing dysfunction in children due to noise during pregnancy	Occupational noise exposure during pregnancy, according to the prospective cohort study, FENIX (foetal noise exposure), based on births between 1986 and 2008.	Low-frequency noise (<75 dBA); high-frequency noise (≥85 dBA); medium-frequency noise (75–84 dBA).	In the sample, in a mixture of part-time and full-time workers during pregnancy, HR adjusted for hearing impairment associated with exposure to maternal occupational noise ≥85 vs. <75 dB LAeq, 8 h was 1.27 (95% CI: 0.99 1.64; 60 exposed cases). When restricted to children whose mothers worked full time and had less than 20 days of absence during pregnancy, the HR was 1.82 (95% CI: 1.08, 3.08; 14 exposed cases).

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2016	Abbasi et al. [41]	53	General health; somatic symptoms; anxiety; insomnia; social dysfunction; depression	Study of the effect of wind turbine noise on the general health of employees at a wind farm, with workers divided into three groups: maintenance, security, and office workers. Equivalent sound levels were measured for each group. The individuals' health data were assessed using a 28-item questionnaire. Pearson's correlation, analysis of variance, and multiple regression tests were performed for data analysis using software.	In the maintenance team, an LAeq of 83 dBA was considered, an LAeq of 66 dBA was considered in the security team, and an LAeq of 60 dBA, in the administration team.	Exposure to noise is significantly correlated with all subscales of general health, except depression. The low-frequency noise from the turbines can cause harmful effects on the health of workers who are very close to the turbine and receive very intense noise.
2016	Wang et al. [59]	2700	Cardiovascular diseases; hearing loss.	The authors carried out the study in the metropolitan area of Taichung, Taiwan and set up 50 monitoring stations to collect related information on noise measurements, traffic flow rates, speed limits, and meteorological data. The 50 monitoring stations included 4 agricultural areas, 6 green-land areas (e.g., parks, forests, and mountains), 2 conservation areas, 8 culture-educational areas (i.e., schools, temples, and churches), 11 residential areas, 4 industrial areas, 1 stream-channel area (e.g., harbours), 7 commercial areas, 6 governmental areas (i.e., governmental agencies and institutes), and 1 recreational area. Determination of exposure to traffic noise by measuring the average equivalent noise levels A (LAeq, 24 h) in 50 monitoring stations (25 road traffic stations and 25 non-commercial ones) covering 10 different types of land use.	Equivalent continuous sound levels (Leq, 24 h) in the range of 30–130 dBA; noise levels with the time-weighted average (TWA) at frequencies of 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.	The Leq annual average, 24 h in Taichung was 66.4 ± 4.7 dBA, exceeding the threshold for cardiovascular disease prevention. The mean annual Leq, 24 h in the flow and commercial channel areas was 71.2 ± 1.0 and 70.0 ± 2.6 dBA, respectively, revealing a potential risk of hearing loss among residents. The noise levels at 125 Hz had the highest correlation with total traffic and the highest forecast in multiple linear regression.
2017	Vasilyeva, Bespalov, Semenov, Baranenkoand Zinkin [68]	96 rats	Frequency of chromosomal aberrations in bone marrow cells; levels of low molecular weight DNA (lmwDNA) in blood plasma.	Exposure to single or multiple LFN from male Wistar rats and their comparison with those in the control group. The control group rats were not subjected to any impact. Measurement of the frequency of chromosomal aberrations in bone marrow cells and the levels of lmwDNA in blood plasma.	Frequency below 250 Hz; simple LFN with sound pressure levels (SPL) of 120 dB; multiple LFN with 150 dB SPL.	Blood plasma lmwDNA levels measured the following day after a single exposure to LFN were significantly higher (7.7 and 7.6 times, respectively) than in the control group (11.0 ± 5.4 ng/mL), and these levels were higher (4.8 and 2.1 times, respectively) in the week after a single exposure of LFN to the SPL of 120 and 150 dB, respectively, than in the control group (18.8 ± 1.6 ng/mL). Similar results were obtained in the group with multiple exposures to LFN (36.4 and 22.4 times, respectively) compared to the control group (17.7 ± 1.7 ng/mL) and suggest an increase in cell apoptosis as a result of impact of the LFN.
2017	Boyle et al. [54]	11	Noise disturbance from natural gas compression stations.	Assessment of how A-weighted exposure levels differ indoors and outdoors in homes near the natural gas compressor station, where low-frequency noise was found. Measurement of noise levels defined in the A-weighted scale to filter out most of the low-frequency noise and in the C-weighted scale to identify the impulse noise.	-	Houses located close to a compressor station have higher average noise levels, both indoors and outdoors, than houses located more than 300 m away. Noise levels during the day were higher than at night. Residents of residences located less than 300 m from the station were exposed to low-frequency noise. The daytime and nighttime noise levels recommended for preventing hearing loss and annoyance were exceeded.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2017	Van Kamp, Breugelmans, Van Poll, Baliatsas and Van Kempen [40]	3972	Annoyance due to low-frequency noise	Survey of complaints due to low-frequency noise, based on analysis of existing data. Conducting a questionnaire with participants addressing aspects such as annoyance and sensitivity to noise, sources of emission, and residential satisfaction, among others.	-	The level of background noise, sensitivity to noise, and dissatisfaction with the residential situation were strongly associated with higher levels of annoyance. The lower the background noise levels, the greater the annoyance due to tinnitus. Low-frequency noise is particularly a problem in places with low levels of background noise.
2017	Ohgami, Oshino, Ninomiya, Li and Kato [60]	Rats	Hearing loss; imbalance	Conducting an experimental study in which wild type rats were exposed to similar low-frequency noise and the assessment of noise-induced hearing loss and determination of the rats' imbalance.	Low-frequency noise (70 dB, 100 Hz)	The authors observed that a sound stimulation at 375 Hz at a frequency lower than the audible range of the rats causes a hearing reduction in wild type rats, and in rats with an abnormal otolytic morphology, this hearing loss was not observed.
2017	Venet et al. [61]	117 rats	Effects on hearing	Evaluation of exposure to the combination of low-frequency noise and carbon disulfide.	Low-frequency noise, ranging from 0.5 to 2 kHz at an intensity of 106 dB SPL.	Exposure to CS_2 (250 ppm or more) and noise increased the extent of the damaged frequency window, as a significant hearing deficit was measured at 9.6 kHz in these conditions; in addition, the significance at 9.6 kHz increased with solvent concentrations. Histological data showed that neither hair cells nor ganglion cells were damaged by CS_2.
2017	Alimohammadi and Ebrahimi [69]	89	Mental performance	All participants underwent the Stroop and Cognitrone tests in silent conditions, after 30 min of exposure to LFN and HFN. The Cognitrone test assesses concentration and attention, and the Stroop interference test is a sensorimotor speed test that records the performance of reading speed.	Low-frequency and high-frequency noise at 50 and 70 dBA.	Both noises emitted (LFN and HFN) not only caused precision in scaling the response but also reduced the duration of the test run. It was concluded that, disregarding the distribution of energy frequencies, noise improved the task performance of participants. The results illustrated that individuals under LFN performed the Cognitrone test more quickly than individuals under HFN.
2017	Huang, Pan, Liu, Hou and Yang [48]	-	Noise disturbance	Analysis of acoustic comfort and development of a noise analysis model for a skyscraper, through the measurement of exterior noise, mainly road traffic noise. The selection of measuring points was made on the horizontal and vertical planes and strictly follows the guidelines (Chinese standard JTG B03–206 and HJ 2.4-2009). The noise measurement instruments were an AWA6270+B noise analyser, AWA6228 frequency analyser, and TES1350A sound level meter.	-	A higher capacity to respond to high-frequency than low-frequency mining noise (LF) was observed, which probably reflects the audibility of the two frequency spectra.
2017	Mancera, Lisle, Allavena and Phillips [70]	57 rats	Effects on behaviour (stress), organ morphology, and faecal corticosterone.	Evaluation of the effects of noise from mining machines on the behaviour and physiological parameters (organ morphology and faecal corticosterone) of wild rats, when subjected to high- and low-frequency ranges, and comparison with a reference treatment without auditory stimuli.	High-frequency noise (>2 kHz); low-frequency noise (≤2 kHz).	The frequencies below and above 2 kHz had differential effects on male and female wild rats that can have important consequences for their well-being and survival.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2018	Morsing et al. [42]	12	Sleep effects	Evaluation of sleep effects, through polysomnography measurement and questionnaires, in 2 pilot studies, due to noise exposure from wind turbines. Six participants spent five consecutive nights in an ambient sound laboratory and, for three nights, were exposed to the noise of the wind turbine with the variation of some parameters.	High-frequency (>125 Hz) and low-frequency noise (125 Hz). Similar to a ventilation noise, a low background noise (18 dB LAeq) was used.	During nights with noise from the wind turbine, there were sleep disturbances compared to during control nights. Deeper sleep was negatively affected by higher rotational frequency and amplitude modulation, but light sleep increased with high rotational frequency and acoustic beat.
2018	Blair, Brindley, Dinkeloo, McKenzie and Adgate [46]	4 (residences)	Annoyance, sleep disorders, and cardiovascular effects	Determination of noise levels in a well block of oil and gas operations of several wells during construction and drilling in a residential area in Colorado and the verification of impacts on human health. A (dBA) and C (dBC) weighted noise measurements were collected at four residences located between 320 (1049.9 ft) and 550 m (1804.5 ft) from the site during development over a three-month period (February to April 2017).	A and C weighted noise levels of 60.2 dBA and 80 dBC, respectively.	Proportionally, 41.1% of continuous daytime equivalent daytime measurements and 23.6% of 1 min dBA exceeded 50 dBA, and 97.5% of daytime and 98.3% of nighttime measurements exceeded 60 dBC. Average noise levels in an oil and gas well during construction and drilling exceed levels associated with annoyances, sleep disturbances, and cardiovascular health effects (greater than 50 dBA or 60 dBC) in studies involving noise sources such as traffic, airports, wind turbines, and rail-related noise pollution.
2018	A.M. Abbasi, Motamedzade, Aliabadi, Golmohammadi andTapak [71]	35	Physiological effects and mental health (fatigue)	Participants were exposed to low-frequency noise and were ultimately asked to determine their level of mental fatigue. A cognitive test was performed to assess working memory (low, medium, or high workload). Software was used to assess mental fatigue, visual fatigue analogue scale, and psychophysiological indexes.	Low-frequency noise levels of 55, 65, 70, and 74 dBA.	The results showed that mental fatigue significantly affected heart rate, low- to high-frequency rates, and electroencephalogram rates. The results confirmed that the mental fatigue caused by low-frequency noise significantly impacted the participants' psychophysiological and working memory with exposure to noise levels of 65 to 75 dBA.
2018	Ninomiya et al. [72]	44 rats	Stress	A comparison of auditory levels and levels of expression of the Hsp70 protein in the cochlea was performed between rats exposed and not exposed to LFN.	Low-frequency noise (100 Hz to 95 dB).	The results showed that the inner ear may be one of the organs negatively affected by the stress caused by the inaudible exposure to LFN. Exposure to LFN increases the level of Hsp70 expression via Cebpb in the inner ear. The levels of Hsp70 and Cebpb may be candidates for biomarkers of responses to exposure to LFN.
2018	Rossi, Prato, Lesina and Schiavi [65]	25 (19 to 29 years)	Physiological effects (response time and heart rate)	The experiment involved 25 Italian volunteers (12 female and 13 male volunteers), aged 19–29 years. Before starting the test, each subject filled in a general questionnaire specifying age, occupation, musical experience, eyesight and hearing problems, and the presence of noise in their daily life. Measurement of changes in cognitive and physiological parameters in a sample of volunteers exposed to three types of noise in a hemi-anechoic room. Participants were involved in a cognitive task (Stroop effect) for 10 min in four different conditions: silence, multi-tonal broadband (BBN) stochastic noise, low and low-frequency stochastic noise (LFN1), and low-frequency stationary noise with regular amplitude modulation (LFN2).	Sounds reproduced with a sound pressure level equivalent to 93 dB; BBN noise based on frequencies between 315 and 2000 Hz; LFN1 with frequencies between 30 and 60 Hz; LFN2 with frequencies between 30 and 200 Hz.	In noise conditions, participants reduced their response times, that is, there was evidence of increasing stress. Dividing the participants into extroverts and introverts, it was demonstrated that LFN1 and LFN2 produced higher stress effects than BBN noise on cognitive performance and a physiological stress comparable to that produced by BBN noise.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2018	Zhou and Fu [62]	1404	Sensorineural hearing loss (SNHL); excess bilirubin (causes problems in the liver, spleen, kidneys, gallbladder).	Measurements of total serum bilirubin, tympanometry, and determination of the mean threshold of pure tones at low frequencies or high frequencies for a subset of adolescents, to assess levels of total serious bilirubin associated with different subtypes of sensorineural hearing loss.	Low-frequency noise (LPTA: 500, 1000, 2000 Hz); high-frequency noise (HPTA: 3000, 4000, 6000, and 8000 Hz).	Total serum bilirubin levels were associated with any high-frequency SNHL (HPTA > 15 dB in at least one ear) in adolescents in the USA; high-frequency SNHL with HPTA > 15 dB in both ears (bilateral) or with HPTA ≥ 25 dB in at least one ear had a stronger association with total serum bilirubin levels than HPTA > 15 dB in only one ear (unilateral) or HPTA = 15–25 dB in at least one ear.
2018	Ishitake [43]	9000 (≥20 years)	Annoyance; sleep disorders	Conducting an environmental epidemiological study and assessing the effects on sleep disturbance due to low-frequency noise generated by wind power installations, based on residents living in areas close to the source. Assessment of sleep disorders using the Athens Insomnia Scale. Assessment of environmental noise in residential areas (50 community centres) close to the noise source by measuring infrared and low-frequency sound exposure levels.	Infrared, low-frequency (20 Hz) and infrasound (<20 Hz).	As for sleep disturbances caused by infrasound (20 Hz or less), the noise level of the wind turbine measured in the ultra-low-frequency range is below the human sensory threshold. Of the participants, 63% heard the noise when the distance was less than 1000 m. However, the hearing rate decreased significantly when the distance was increased to 5000 m, when only 2% of the participants heard the noise. Based on the Athens Insomnia Scale, 40% of participants had sleep disorders when the distance was less than 1000 m. However, the frequency of sleep disorders decreased to 22% with an increase in distance. Amplitude-modulated sounds and pure tones contained in the noise generated by wind power generation facilities tend to increase annoyance.
2018	Chalansonnet et al. [73]	133 rats	Balance effects	Study of how exposure to low-frequency noise combined with 250 ppm CS_2 affects rat balance. Vestibular function was tested based on post-rotational nystagmus recorded by a video-oculography system. These measurements were completed by behavioural tests and cerebellar analysis to measure levels of gene expression associated with neurotoxicity.	Low-frequency noise, ranging from 0.5 to 2 kHz at an intensity of 106 dB SPL.	Coexposure to CS-250 ppm and low-frequency noise reduced the number and duration of the withdrawals by 33% and 34%, respectively. It was observed that the effects of CS_2 were due to reversible neurochemical disorders of the efferent pathways that manage post-rotational nystagmus. Since the nervous structures that involve vestibular function seem particularly sensitive to CS_2, post-rotational nystagmus can be used as an early non-invasive measure to diagnose CS_2 poisoning as part of an occupational conservation programme.
2018	Min and Min [74]	466,822 (217,308 with gastric ulcer + 249,514 with duodenal ulcer)	Peptic ulcer (gastric and duodenal)	Investigation of the incidence of peptic ulcers in adults due to long-term exposure to environmental noise. The diagnosis of gastric and duodenal ulcers was made during an 8-year follow-up (2006–2013). Environmental noise data were obtained from the National Noise Information System, a national noise monitoring system.	The interquartile range (IQR) for nighttime noise exposure was 2.37 dB for gastric ulcers and 2.41 dB for duodenal ulcers.	Gastric ulcers occurred in 32.1% of individuals, and duodenal ulcers, in 10.7% of individuals. The diagnostic rate for gastric and duodenal ulcers increased with increasing cumulative mean levels of nighttime ambient noise. With increases in the IQR of nighttime noise, the risk rate increased significantly by 12% for gastric ulcers and 17% for duodenal ulcers, based on the fully adjusted model.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2018	Pohl, Gabriel and Hübner [44]	212 (1st phase) and 133 (2nd phase)	General mental indisposition; reduced performance and work capacity; lack of concentration; fatigue; voltage; nervousness; dizziness; irritability; indisposition; reduced sleep quality; annoyance	A total of 212 persons participated in the first survey; nearly two-thirds (133 persons) remained in the second. Accordingly, a third dropped out ("dropouts"; 79 participants). Indeed, dropouts differed statistically from the other participants only in terms of education level and household size. The remaining participants had higher education levels and slightly larger households compared to the dropouts (small effect size for each). These socio-demographic variables had no significant influence on the central stress and attitude indicators; significant differences in the central attitude and annoyance assessments were not apparent. Longitudinal study, based on the methodology of stress psychology with noise measurements, in which residents of a wind farm in Lower Saxony were interviewed on two occasions (2012, 2014), using audio equipment to record irritating noises. Several residents complained of physical and psychological symptoms due to traffic noise (16%) and wind turbine noise (10%; two years later, 7%), which allowed the assessment of some symptoms caused by noise exposure.	Noise from low-frequency wind turbines (<100 Hz).	Participants reported more symptoms in 2012 than in 2014. From 2012 to 2014, sleep disorders decreased and symptoms of impaired performance were not repeated. Only a few participants showed evidence of low-frequency (<100 Hz) wind turbine (WT) noise effects: in 2012, 8.5% reported feelings of pressure related to wind farms and 6.1% experienced vibrations in the body. The annoyance experienced induced by feelings of pressure or vibrations was slightly greater in 2012. Symptoms of dizziness were not observed. The participants had more symptoms and greater irritation due to traffic noise than to wind noise.
2018	X. Wang, Lai, Zhang and Zhao [75]	6 (3 exposed, 3 unexposed) Bama pigs	Effects on the blood–brain barrier (BBB)	Investigation of the effect of noise exposure on the blood–brain barrier (BBB). Healthy male Bama pigs were randomly divided into a noise exposure group and a control group (no noise) for 30 min. After exposure, brain imaging was performed using computed tomography and fluorescent images.	Low-frequency noise (50, 70, 100, and 120 Hz at 140 dB).	The BBB permeability test showed that 50, 70, and 100 Hz noise exposure at 140 dB increased the BBB permeability, and the BBB opening at 70 Hz was more severe and reversible. Tomographic images demonstrated that noise-induced opening of the BBB did not cause intracerebral haemorrhage.
2018	Suzuki, Suzuki, Onishi and Penido [49]	110	Tinnitus and LFN discomfort	Classification of persistent tinnitus and its comparison with pure tone or noise, high or low pitch, presented to the patient by the sounds of the audiometer. Participants were subject to inclusion and exclusion criteria. The following evaluations were performed on patients: otorhinolaryngological, audiological, Pitch Matching and Loudness, Visual Analogue Scale, Tinnitus Handicap Inventory, and Minimum Masking Level.	Three types of noise: white noise (WN), narrow band low frequency (LFNB) at 500 Hz, and narrow band high frequency (HFNB) at 6000 Hz.	A total of 181 tinnitus complaints were identified, in which the presence of pure tone type tinnitus was observed in 93 (51%) of the responses (4 from low pitch and 89 from high pitch) and from noise in 88 (49%) of the responses (15 low frequency and 73 high). For tinnitus with low-frequency sensation, 19 responses were determined, while for high-frequency sensation, 162 responses were determined. Visual Analogue Scale average of 5.47 for tinnitus similar to pure tone, and 6.66 for that similar to noise. Average Loudness for tinnitus similar to the pure tone of 12.31 dBNS, and for that similar to the noise of 10.54 dBNS.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2018	Paunović, Jakovljević and Stojanov [76]	112 (82 women and 30 men, aged 19 to 32).	Blood pressure; haemodynamic events	Study divided into three 10-min phases: resting in quiet conditions before noise, exposure to traffic noise, and resting in quiet conditions after noise. Measurement of blood pressure, heart rate, and haemodynamic parameters (cardiac index and total peripheral resistance) with a chest bioimpedance device. Use of four statistical models to answer the study questions.	Exposure to noise: resting in quiet conditions before noise (Leq = 40 dBA); exposure to noise registered in traffic (Leq = 89 dBA); resting in quiet conditions after noise (Leq = 40 dBA).	Blood pressure decreased during the quiet phase before noise, increased in the first minute of exposure to noise, then gradually decreased at the end of exposure to noise, and continued to decrease to baseline values after exposure to noise. The cardiac index showed a gradual decrease throughout the experiment, while the total vascular resistance increased steadily during and after exposure to noise.
2019	Negishi-Oshino et al. [77]	Rats	Irreversible imbalance with structural damage to the otoconial membrane	Assessment of rats' imbalance due to acute exposure to LFN. The exposed rats also showed decreased cervical vestibular evoked myogenic potential (cVEMP) with impaired vestibular hair cell activity.	LFN with a frequency of 100 Hz at 85, 90, or 95 dB.	The results of this study demonstrate that acute exposure to LFN at 100 Hz at 95 dB for just 1 h caused irreversible imbalance in rats with structural damage to the otoconial membrane, as the target region for the LFN-mediated imbalance, which could be rescued by Hsp70.
2019	Lee, Park, Jeong, Choung and Kim [50]	400	Discomfort and sensitivity to noise; blood pressure; annoyance due to noise	The study recruited healthy residents aged between 20 and 60 years. Effects of exposure to transport noise on blood pressure in adult residents of multi-storey residential buildings, modification of the effects of discomfort from and sensitivity to internal noise, and self-assessed associations between transport noise and blood pressure. Measurement of noise levels at the top of buildings for 24 h, forecasting the levels of each unit in the house for different sources and periods using noise maps. Conducting adjusted linear regression analyses to estimate associations between noise exposure levels and systolic blood pressure (SBP) and diastolic blood pressure (DBP). Conducting a questionnaire with questions about annoyance from and sensitivity to noise and sociodemographic variables.	Exposure to noise (Lden, LDay, and LNight).	General noise (road traffic and rail noise) and road traffic showed stronger associations with SBP than with DBP, while rail noise had similar associations with SBP and DBP. Stronger associations were estimated for participants who reported higher ratings of annoyance by internal noise. The results support the hypothesis that long-term exposure to transport noise is associated with higher blood pressure in adults living in multi-storey residential buildings.
2019	Scherer and Formby [78]	151	Tinnitus retraining therapy (TRT); sound therapy (ST); tinnitus-specific educational counselling (TC)	Comparison of the effectiveness of TRT and its components, ST and CT, with the standards of care (SoC) in reducing the negative effect of tinnitus on quality of life. Study carried out in 6 military hospitals, in the office and in a data coordination centre, among active, retired, and dependent military personnel with functionally adequate hearing sensitivity and moderate to severe subjective tinnitus, with the objective of treating the military.	LFN (tinnitus).	There were few differences between treatment groups. About half of the participants showed clinically significant reductions in the effect of tinnitus.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2019	Poulsen et al. [45]	Residences between 20 and 40 inhabitants	Annoyance; sleep disorders; depression	Evaluation of the evolution of medical prescriptions related to anxiolytics and antidepressants ingested by the populations that lived near the wind turbines, in an analysis that lasted two years (2012 to 2014). A total of 7256 wind turnines (WT) was considered in noise modelling. The authors collected information on model, type, height, and operational settings. Each WT was classified into to one of 99 noise spectra classes, with detailed information on the noise spectrum from 10–10,000 Hz in thirds of octaves for wind speeds of 4–25 m/s.	Exposure to outdoor wind turbine noise (WTN) at night (<24, 24 to <30, 30 to <36, 36 to <42, and ≥42 dB) and nighttime low frequency indoor WTN (<5, 5 to <10.10 and <15, and ≥15 dB).	High levels of outdoors WTN associated with use of anxiolytics and antidepressants among the elderly, suggesting that WTN may be potentially associated with sleep and mental health.
2019	Tao, Wang, Zou, Li and Luo [51]	100	Irritation and sensitivity to noise	Assessment of noise irritation in the metro deposit and the influence of noise in adjacent residential buildings. Conducting a questionnaire with people who worked at the metro station and made field measurements, both at the metro station and in the adjacent residential buildings.	LFN and HFN (31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz)	Of respondents, 96% are disturbed by the noise and 31% of them feel that the impact of the noise is serious. They found that there is a problem of annoyance due to low-frequency noise. The authors evaluated that the noise level caused by the fans decreases with the height of the floors and that the shorter the distance between the building's fans and ventilation, the more severe the impact of the noise. They concluded that, with the increase in the distance to the noise source, the noise attenuation rate increases.
2019	Poulsen et al. [64]	717.453	Myocardial infarction (MI), stroke	The authors used the Danish Civil Registration System to identify the study cohort, defined as all adults (aged 25–84 years) who lived in one of these inclusion dwellings any time between five years before the erection of the first neighbouring WT and the end of 2013. Assessment of the impact of MI and stroke risk when there is long-term exposure to noise from wind turbines. Based on hospital and mortality records, an analysis was made of the number of cases of myocardial infarction and stroke that existed in homes located around wind turbines.	Exposure to wind turbine noise (WTN) at night outdoors (≥24 dB) and nighttime low frequency indoor WTN (≥5 dB; 10–160 Hz)	High long-term exposure to noise from wind turbines is associated with an increase in myocardial infarction and strokes.
2019	Hansen, Nguyen, Zajamšek, Catcheside and Hansen [55]	9 (residences) A total of 8716 and 8972 10 min samples of outdoor and indoor data	Annoyance	The outdoor measurements carried out at 9 different residences located between 1 and 9 km from the nearest wind turbine of a South Australian wind farm (37 operational turbines), each with a rated power of 3 MW. The wind farm is positioned along the top of a ridge, and the wind turbine hub height relative to the residences varies between 85 and 240 m. At all residences, the indoor measurements were taken in a room that faced as closely as possible towards the wind farm and the windows were closed. The presence of amplitude modulation in the noise of wind farms results in increased annoyance and possible interruptions in sleep. The study investigated the prevalence of this characteristic present in homes close to the wind farm.	-	During the night, audible amplitude modulation occurred in homes located 3.5 km from the wind farm up to 22% of the time. This had important implications for possible sleep disruptions and annoyance due to the wind farm by audible amplitude modelling, particularly as ambient noise levels in rural South Australia can be as low as 15 and 5 dBA, outdoors and in closed areas, respectively.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2019	Phadke, Abo-Hasseba, Švec and Geneid [79]	140 (between 21 and 56 years)	Voice disorders: dysphonia; neck pain; vocal effort	This study aimed to identify possible correlations between the vocal symptoms of teachers and their perception of noise, the locations of schools, as well as the locations and conditions of their classrooms. They carried out a questionnaire, whose answers were analysed statistically, with questions about the severity and frequency of their voice symptoms, noise perception, and the locations and conditions of their schools and classrooms.	-	Teachers experienced severe dysphonia, neck pain, and increased vocal effort with weekly or daily recurrence. Among the teachers who participated in the study, 24.2% felt that they were always in a noisy environment, with 51.4% of the total participants reporting having to raise their voices. The most common sources of noise were student activities and conversations in the teachers' own classrooms (61.4%), noise from adjacent classrooms (52.9%), and road traffic (40.7%).
2019	Smith, Ögren, Ageborg Morsing and Persson Waye [47]	23	Disorders in physiological sleep; heart rate	The study volunteers slept for five nights in a sound environment laboratory, which was furnished like a typical apartment. The participants were instructed to start trying to fall asleep at 23:00 each evening and were woken with an alarm call at 07:00 each morning. Sleeping at times outside of this 8 h period was not permitted. Participants could follow their normal daytime routine but arrived at the laboratory by 20:00 each evening to allow time for relaxation and the setup of the sleep-measuring equipment. Caffeine was prohibited after 15:00 each day, and alcohol was prohibited at all times. Evaluation of the effects on physiological sleep resulting from the exposure of participants to railway noise for five consecutive nights, using polysomnography and questionnaires. Heart rate was measured by electrocardiography.	Frequencies of 35, 40, and 45 dB.	No significant differences were found in the overall structure of sleep disorders between the reference tests and the 35 dB night tests. Regarding cardiovascular diseases, they observed that the noise spectrum with amplitude frequencies greater than 100 Hz led to increases in heart rate for noise levels equal to or greater than 35 dB.
2019	Zare et al. [80]	75	Serum cortisol concentration	The study aimed to examine the effect of sound pressure level (SPL) on the serum concentration of cortisol at three different times during the night shift, in an industrial and mining company. Participants were divided into three groups (one control and two groups of cases, with 25 each). Dosimetry was adopted to evaluate SPL equivalents using a TES-1345 dosimeter. The serum cortisol concentration was measured using a radioimmunoassay (RIA) test in the laboratory.	Exposure levels of 67, 80, and 92 dB.	The results indicated a downward trend in the serum cortisol concentration of the three groups during the night shift. SPL and exposure time significantly affected cortisol concentration. Age and body mass index had no significant influence on the concentration of cortisol. It was concluded that an increase in SPL leads to an increase in serum cortisol concentration.

Table 1. *Cont.*

Year	Studies	Studies Evaluated				
		Number of Participants/Sample	Main Human Health Effects	Methodology	Exposure	Outcomes
2019	Moradi et al. [52]	28 (14 females and 14 males)	Stress; noise sensitivity; annoyance	The study was conducted on students at different levels of educational programmes in an acoustic room in the School of Public Health, Iran University of Medical Sciences, in 2016. The study subjects were comprised of 14 female and 14 male university students who met the following entrance criteria: normal sense of hearing (hearing loss less than 20 dB) and no sensitivity to noise. Study of the effects of noise on selective attention of university students. They carried out questionnaires to determine students' personality traits (extroverted or introverted) and analyse their stability or instability. Evaluation of the level of sensitivity to noise, using the Weinstein sensitivity scale, and the level of selective attention, using the DUAF test.	80 dBA noise at 4000 Hz frequency	Introverted participants are more sensitive to noise than extroverts. The most noise-sensitive participants showed greater stimulation during exposure to noise, which led to increases in incorrect responses and a decrease in mental performance. The participants' personal traits are related to their annoyance due to noise. Stress due to noise improves selective attention in outgoing individuals.
2019	Alves, Silva and Remoaldo [53]	200 questionnaires + 62 measurements of noise levels + 14 adapted audiometric tests	Annoyance from LFN; audibility threshold	Analysis of the effects of exposure to low-frequency noise pollution, emitted by poles and power lines, on the well-being of the population, based on a study of "exposed" and "unexposed" individuals in two areas. Conducting audiometric tests adapted to complement the analysis and determine the audibility threshold of the volunteers. Sound level measurement and sound recording (at a distance of 5 m from the source), as well as the adapted audiometric performance test.	Frequency range between 10 and 160 Hz	The "exposed" area has higher sound levels and, consequently, more welfare and health problems than the "unexposed" population. Audiometric tests also revealed that the "exposed" population appears to be less sensitive to low frequencies than the "unexposed" population.

Van Kamp et al. [40] explored the determinants of annoyance due to tinnitus, that is, low-frequency noise. This article explored the relationship between contextual, situational, and personal characteristics with the level of annoyance due to low-frequency noise, based on secondary analysis of existing data. The results obtained showed significant differences between cities and neighbourhoods, a significant association between background noise levels during the day, and an inverse effect at night. The level of background noise, sensitivity to noise, and dissatisfaction with the residential situation were strongly associated with higher levels of annoyance. Based on the association with nighttime background levels, it was found that the lower the levels, the greater the annoyance due to tinnitus [40].

The main results of the studies by Blair et al. [46] and Pohl, Gabriel, and Hübner [44] have already been described in Section 3.2. Blair et al. (2018) found that the average noise levels during the construction and drilling of an oil and gas well exceeded the levels associated with health annoyance; that is, they were above 50 dBA or 60 dBC [46]. Pohl, Gabriel, and Hübner [44] found that the annoyance experienced was very low and that symptoms of dizziness were not observed in this study.

Ishitake [43] carried out a study regarding annoyance due to wind energy, with a questionnaire carried out for the analysis. In this survey, it was observed that 81% answered that they did not feel annoyed due to the generation of wind energy, while 8% answered that they felt very or a little annoyed [43].

The results related to noise annoyance determined by Moradi et al. [52] and Lee et al. [50] have already been covered in Section 3.3. However, in addition to what was mentioned earlier, Lee et al. [50] concluded that the closest associations between noise exposure and blood pressure were estimated for participants who reported higher classifications of annoyance, irritation, and sensitivity to noise. This indicates that the annoyance from internal noise and sensitivity to noise develop regardless of the level of exposure to external noise. The authors also found that people who were sensitive to noise and participants most irritated due to internal noise had significantly higher SBP and DBP than others [50].

Finally, Hansen et al. [55] determined an audible internal low-frequency tone modulated in amplitude in the frequency of the passage of the blade for 20% of the time up to a distance of 2.4 km. The audible amplitude modelling took place for a similar percentage of time between the wind farm's percentage power capacities of 40% and 85%. The modelling of the audible amplitude in the interior still occurred for 16% of the time at a distance of 3.5 km. At distances of 7.6 and 8.8 km, audible amplitude modelling was only detected on one occasion. During the night, audible amplitude modulation occurred in homes located 3.5 km from the wind farm up to 22% of the time. This had important implications for possible sleep disruptions and annoyance due to the wind farm by audible amplitude modelling, particularly as ambient noise levels in rural South Australia can be as low as 15 and 5 dBA, outdoors and in closed environments, respectively [55]. Although the geometric dimension of the room was not considered in the study by Hansen et al. [55], it is an important variable for this type of study.

3.5. Hearing Loss

Although hearing loss is reported as an effect on human health due to exposure to noise, the studies analysed were not totally conclusive regarding hearing loss due to low-frequency noise.

Selander et al. [58] assessed the impairment of children's hearing when occupational noise exposure occurred during pregnancy. They carried out a prospective cut study and determined cases of hearing impairment in children based on medical records and interviews conducted with prenatal unit teams, in a sample of births between 1986 and 2008 [58]. With the information collected, they established risk models to estimate data related to the impairment of children's hearing when exposed to noise with a strong low-frequency component during pregnancy [58].

Wang et al. [59] evaluated the exposure to noise from traffic and established a comparison regarding the potential risk of hearing loss for residents.

Ohgami, Oshino, Ninomiya, Li, and Kato [60] and Venet et al. [61] addressed experimental studies in rats and the assessment of hearing loss when they are exposed to low-frequency noise.

Ohgami et al. [60] carried out a survey of experimental studies carried out on rats when exposed to low-frequency noise and made an assessment of associated hearing loss. In this review, the imbalance in rats when exposed to noise was also assessed [60]. However, Venet et al. [61] effectively performed experimental tests on rats, testing the hearing of the rats with equipment (cubic DPOAEs – Distortion product otoacoustic emissions) when the animals were exposed to low-frequency noise combined with carbon disulfide (CS_2). The rats' hearing was tested before, during, and after exposure to noise, and blood samples were taken to assess the exposure to CS_2 [61].

Zhou and Fu [62] performed measurements to assess levels of total serum bilirubin, performed tympanometry, and examined pure tone thresholds at low or high frequencies associated with adolescents with different subtypes of sensorineural hearing loss (SNHL), using binary or multinomial logistic regression models.

Regarding the results, Selander et al. [58] divided the sample into three parts: (i) mothers who worked full time, (ii) mothers who worked part-time, and (iii) mothers absent from work during pregnancy. They observed an increased risk of hearing impairment in children after exposure to occupational noise during pregnancy. In the sample considered in the study, they determined adjusted risk rates for 75–84 dBA and ≥85 dBA, compared to <75 dBA, of 1.05 and 1.27, respectively. They observed 60, 42, and 14 highly exposed cases for all hearing disorders, sensorineural hearing loss, and tinnitus, respectively. They also determined that the adjusted risk rate for exposure to occupational noise ≥ 85 dBA compared to <75 dBA was 1.82, based on 14 exposed cases and 2222 cases with low exposure. However, the corresponding relative risks (HR) were 1.25 for high exposure among mothers classified as part-time and 0.74 for women who had more than 153 days of absence from work during pregnancy or who were not working at the time of the interview. Finally, [58] found that, among mothers working full-time, high exposure to occupational noise was associated with an increased risk of hearing impairment. The authors also observed an increase in the risk of hearing impairment of the foetus for the case of mothers who worked part-time. On the other hand, [58] did not find an increased risk of hearing impairment in children whose mothers reported exposure to occupational noise in early pregnancy but were absent from work during pregnancy. Thus, the fact that the mother's risk increases with presence at work proves that occupational noise during pregnancy is associated with an increased risk of hearing impairment in children [58].

Wang et al. [59] observed that the mean annual Leq over 24 h in the flow and commercial channel areas was 71.2 ± 1.0 and 70.0 ± 2.6 dBA, respectively, revealing a potential risk of hearing loss among residents [59].

Ohgami et al. [60] determined that a sound stimulus of 375 Hz, a frequency below the audible range of rats, causes a hearing reduction in wild type rats, while in rats with an abnormal otolytic morphology, no hearing loss was observed.

Venet et al. [61] observed that, after the period of contact with noise, exposure due to noise alone caused a hearing reduction in an area of frequency that varied between 3.6 and 6 kHz. The damaged area was approximately one octave (6 kHz) above the highest frequency of the exposure noise (2.8 kHz). Since the maximum auditory sensitivity is located at around 8 kHz in rats, exposure to low-frequency noise can affect the cochlear regions that detect mid-range frequencies. Exposure to CS_2 (250 ppm or more) and noise increased the extent of the damaged frequency window, as a significant reduction in hearing was measured at 9.6 kHz in these conditions, with an increase in CS_2 concentrations [61].

Finally, Zhou and Fu [62] determined that total serum bilirubin levels were associated with any subtype of high-frequency sensorineural hearing loss (SNHL). However, they observed that total serum bilirubin levels were not significantly associated with any low-frequency SNHL (bilateral or unilateral; LPTA greater or lesser) [62].

3.6. Cardiovascular Disease/Heart Rate

Cardiovascular diseases (variations in heart rate) are another effect on human health due to exposure to low-frequency noise.

Walker et al. [63] and Smith et al. [47] used electrocardiograms to measure participants' heart rates when they were exposed to low-frequency noise. In the case of [63], participants were also subjected to blood pressure measurements and saliva samples were collected before, during, and after exposure to noise. Based on linear regression models, the differences between the results obtained before, during, and after the noise were examined [63]. In the case studied by Smith et al. [47], the authors measured participants' heart rates when they were exposed to railway noise.

Poulsen et al. [64] assessed the impact of the risk of myocardial infarction and stroke when there is long-term exposure to noise from wind turbines. Based on hospital and mortality records, they analysed the number of cases of myocardial infarction and stroke in homes located around wind turbines [64].

Wang et al. [59] evaluated the exposure to noise from traffic and established a comparison in relation to the prevention threshold established for cardiovascular diseases.

The methodology adopted by Blair et al. [46] has already been referenced in Section 3.2 According to [46], noise levels above 50 or 60 dBA can cause cardiovascular effects.

Rossi et al. [65] measured the changes in cognitive and physiological parameters—in particular, the response time and heart rate—of participants when exposed to tonal noise (silence or multi-band stochastic noise), low-frequency and low-frequency stochastic noise, and low-frequency stationary noise with regular amplitude modulation.

As for the results, Walker et al. [63] concluded that during exposure to noise, the reductions in heart rate variation (HRV) were 19% with low-frequency power and 9.1% according to the mean square difference between the intervals of adjacent normal heartbeats (RMSSD). On the other hand, during exposure to low-frequency noise, the reductions in HRV were 32% with high-frequency power, 34% with low-frequency power, and 16% according to the standard deviation of the adjacent normal heartbeat intervals (SDNN). Finally, during exposure to low-frequency noise, the reductions in HRV were 21% with low-frequency power, compared to that with exposure to noise. As a general conclusion, [63] determined that exposure to noise—and, in particular, low-frequency noise—negatively affects heart rate variation, which affects health in terms of cardiovascular diseases [63].

Part of the results observed by [47] and [46] have already been described in Section 3.2. Regarding cardiovascular diseases, [47] also observed that the noise spectrum with amplitude frequencies greater than 100 Hz led to increases in heart rate for noise levels equal to or greater than 35 dB and increasing the probability of excitation at a noise level of 45 dB. Meanwhile, [46] concluded that continuous weighted noise above the 50 dBA threshold can cause health effects, such as an increased risk of cardiovascular disease and hypertension [46].

Wang et al. [59] concluded that the average annual equivalent noise levels (Leq, 24 h) were 66.4 ± 4.7 dBA, which exceeded the threshold established for the prevention of cardiovascular diseases.

Rossi et al. [65] concluded that, on average, participants decreased their response times in noise conditions compared to silence conditions; that is, there was evidence of increasing stress, according to the excitation theory. In this study, they observed that participant exposure to low-frequency noise 1 and 2 (LFN1 and LFN2, respectively) produced cognitive stress comparable to stochastic multi-tonal broadband noise (BBN). Subdividing the participants into extroverts and introverts, they demonstrated that LFN1 and LFN2 produced higher stress effects in introverted participants than BBN noise on cognitive performance, but had no effect on extroverts. In addition, heart rates increased significantly in the introverts during the tests, compared to those in a condition of silence before the start of the Stroop effect, while the extroverts showed no changes [65].

Finally, [64] concluded that, for external nighttime noise from long-term-operated wind turbines greater than 42 dBA and low-frequency noise from internal wind turbines greater than 15 dBA, the risks were slightly higher for myocardial infarction than those from exposures less than 24 and 5 dBA, respectively, but the number of cases was low in the groups with the highest exposure. As for strokes, all low-frequency noise levels from internal wind turbines were associated with adjusted incidence rates close to 1.0, while for noise from external wind turbines, the adjusted incidence rates were greater than 1.0 for the groups of intermediate exposure, and lower than the unit for the groups with greater exposure. High long-term exposure to wind turbine noise was associated with slightly elevated point estimates for myocardial infarction, for both exposure to outdoor wind turbine noise and exposure to potentially more biologically relevant indoor wind turbine noise [64].

4. Conclusions

In the present research, 39 articles addressing exposure to low-frequency noise and its impacts on human health were analysed in depth. The articles were divided into categories according to the emitting source of the noise, and the effects on human health were addressed. Regarding the emitting source, there was a greater number of articles addressing issues related to environmental noise and wind turbine sources.

As for the effects generated on human health, there was a greater number of articles referring to effects on sleep disorders, discomfort, sensitivity to and irritability from noise, annoyance, hearing loss, and cardiovascular diseases, and these effects were analysed in more detail in this article.

In the case of impacts on sleep disturbance, a dependence on the distance to the source of noise was observed; that is, the greater the proximity to the source, the greater the effects on sleep, as established by [41,43]. With long-term noise exposure, noise sensitivity is lower, which reduces the effects on sleep disturbance, as determined by [44]. Exposure to noise at night disturbs sleep and causes more frequent awakenings, less deep and non-continuous sleep, and morning tiredness in the participants, as discussed by [42,47].

With increasing age, especially for people over the age of 65, exposure to noise causes sleep disturbances, which adds to the demand for sleeping pills and antidepressants, as determined by [45].

According to [46], the average noise levels exceeded the levels for sleep disturbances established for human health.

Discomfort, irritability, and sensitivity to noise were among the effects analysed. Discomfort due to noise depends on the proximity of people to the emitting source, making their sensitivity to noise different. Tao et al. [51] proved that with increased distance from the noise source, the noise attenuation rate increases, due to the fact that they feel uncomfortable and disturbed by the low-frequency noise. **Alves et al. [53] observed that constant exposure to noise makes people less sensitive to the perception of noise compared to people who are more distant from the emitting source, necessitating greater sound intensity for the perception of low-frequency noise. This sensitivity of people to noise leads to a decrease** in their mental performance, as ascertained by [52], and an increase in blood pressure, especially when people are more irritated, as noted by [50]. Huang et al. [48] observed that the convenience of sound does not increase with distance from the ground for buildings of great height, such as skyscrapers, and that exposure to this noise has an impact on the annoyance and discomfort of its residents. However, Suzuki et al. [49] noted that there was a low percentage of people who were uncomfortable with the presence of low-frequency noise compared to the presence of high-frequency noise.

Background noise levels and sensitivity to noise are associated with higher levels of annoyance; that is, they exceed the thresholds established for this health effect, as indicated by [40,46,54]. Moradi et al. [52] also confirms that the level of annoyance when exposed to noise varies with people's personal traits, with greater sensitivity and annoyance in introverts than in extroverts. Exposure to noise from rail transport is associated with the blood pressure of exposed people, which indicates that people with greater sensitivity to noise, greater annoyance, and more irritability have higher blood pressure values than those who do not have these symptoms, as studied by Lee et al. [50]. Thus, the annoyance increases with exposure to noise, especially when people experience unconventional noise. As described by [81], a greater disturbance is observed due to railway noise in people who are not normally exposed to this noise source. Hansen et al. [55] noted that noise levels had implications for annoyance due to exposure to the wind farm. However, both Pohl et al. [44] and Ishitake [43] determined that people do not feel annoyed due to exposure to wind energy noise. New methodologies for the evaluation of noise emitted by wind turbines could be used to provide new findings in this field [82].

Exposure to noise causes a potential risk of hearing loss in people subjected to it, as studied by Wang et al. [59] and Venet et al. [61]. Venet et al. [61] also determined that exposure to carbon disulfide (CS_2) and noise caused a reduction in the auditory level when an increase in CS_2 concentrations was observed. Exposure to occupational noise during pregnancy was also a topic studied by Selander et al. [58] who proved that exposure to this type of noise is associated with the risk of increased hearing impairment in children, with greater relevance in mothers who worked full-time and part-time during pregnancy. Through experiments on rats, Ohgami et al. [60] observed a hearing reduction in wild type rats, in contrast to in rats with an abnormal autolytic morphology in which this hearing loss was not observed. However, studies were observed in which no effects associated with hearing loss were found with exposure to low-frequency noise, as ascertained by Zhou and Fu [62]. All studies analysed in this domain regarded low and high frequencies, revealing hearing loss in the samples exposed to high frequencies. Hearing loss due to low-frequency noise was not totally observed.

Finally, it was observed that exposure to noise—in particular, low-frequency noise—negatively affects the variation in heart rate, which harms health in terms of cardiovascular diseases, as it exceeds the levels established for the prevention of these diseases, as discussed by Walker et al. [63], Wang et al. [59], and Blair et al. [46]. According to Rossi et al. [65], heart rate increases significantly in introverts compared to in a situation of silence, while extroverts show no change in their heart rate. Smith et al. [47] realized that the heart rate in people increased with greater exposure to noise. High long-term exposure to noise from wind turbines is associated with an increase in myocardial infarction and stroke, as studied by Poulsen et al. [64].

The literature review carried out constitutes a novelty in Portugal, whether in the social sciences or the more exact ones, such as environmental acoustics. It is expected that in future studies, this type of evaluation can be explored for a longer period and more sources of low-frequency noise emission. This may provide important data on low-frequency exposure and its effects on human health, as well as important information on the definition of limits for installing wind farms and other sources of low-frequency noise. While some type of impacts on health have not yet been analysed and continue to be an understudied field, the impacts studied can provide good advice for the planning field. Thus, these studies can point out good ways of minimising the influence on human beings and can constitute a good tool for the preventive dimension of planning.

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Infrasonic Music

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Abstract

Low frequency sound on the cusp of the audible offers the possibility to redefine the way we think about listening to music. As the perception of pitch is lost in very low frequency sound emissions, an opportunity arises for a different kind of music, and a different way of listening. Low frequencies can be engaged to activate responses other than the aural or be used as a kind of 'silent activator', enabling or affecting other sounds. This paper explores the possibilities for what may be called an 'infrasonic music'.

Hearing and listening to music

Sound is a minimal condition of the music fact [1].

What constitutes a sound – the vibrations that create it, our ability to hear it, or our understanding of it? Sound itself has a rather slippery definition in regards to our way of perceiving it. Whilst vibrations are the core of sound itself, to consider them as art or music, they need to be organised, contemplated, created and/or controlled to some extent. And we need to be able to listen to them.

So, is it possible to hear and subsequently listen to music in more ways than with the ear? Hearing is of course our first step in listening but we may also sense sounds in other ways - such as through anticipation or physical response, such as feeling the movement of air (like standing in front of a loud sub woofer speaker at a rock concert, for example) or feeling vibrating objects. We hear sounds around us every day, but we don't always listen to them. For hearing to be processed by the brain into a more refined sensibility, we must consider how hearing becomes listening. When do sounds demand to be listened to, rather than just heard? The study of semiotics has some useful ideas here. French postmodern theorist Roland Barthes, for example, suggested that hearing is a physiological condition, whereas listening is actually a psychological act [2]. That is, listening requires a certain type of additional engagement from the brain that hearing does not. Music requires a process of listening that requires understanding or appreciation, and of course hearing facilitates this psychological state. If a way of listening is what helps us form music from sounds, and the body provides ways to experience the sound without the ear, listening can then involve sounds that are beyond the normal human hearing range.

Infrasound is generally considered to be a sound below the audible range for human beings (the 'hearing threshold'), the lower range usually cited as being between 15 and 20 Hz. Your age, genetic make up or general hearing history can effect your ability to hear low frequencies, and our hearing ability fades gradually rather than suddenly cutting off at these limits. However, studies have shown that sounds below 16 Hz can be audible if there is sufficient volume, but the ear does lose its ability to define pitch or even a tone [3]. A listener is more likely to become aware of other objects vibrating, a change to more traditionally audible tones, feel the air from the speaker, experience physical responses, or hear a pulsing, chugging sound that defies tonal definition [4]. Other responses include psycho-physiological effects, such as 'chills'. Often, the sound we hear when very low frequencies are produced is the sound of the mechanism engaged to reproduce it. Where music engages sounds that move below tonal recognition and can encourage the listener to seek other sensations as a way to experience that sound is what I propose as *infrasonic music.* This is a music that enables a type of listening defined by factors other than pure aural recognition, engaging other sensations such as a listener's physical experience of the work.

How does our body experience low frequency sound then? The brain becomes increasingly sensitive to messages about sound from organs other than the ear, such as skin, through the Merkel Cell, the Meissners and Pancinian corpuscles when sufficient volume is present [5]. Low frequencies may also be perceived inside resonating cavities of the body, such as the ribcage or the inside of the head [6]. These different ways to experience sound offer the possibility to create music where the entire body, rather than any particular organ, can be active in the listening experience. This way, thee whole body may become a kind of vessel for the instantiation of musical works [7]. The conscious attempt to achieve a bodily response of patterns and formations in music compositions is a realisation that the medium of sound is in fact a very visceral, physical phenomenon.

Infrasonic music need not be a loud, intrusive music in any conventional sense. Whilst high amplitude is required to sound the low frequency range, it does not emit a 'loud' volume as you may expect with similar amplitude in other ranges. Suitable equipment is required to produce and support such amplitude, often engaging very powerful amplifiers and loudspeakers of unconventional design and materials. It is rarely possible to hear such frequencies on consumer home stereos or as a result of the Compact Disc reproduction process, let alone after the compression employed for internet distribution of music. However, some effects may be experienced with mastering techniques, dedicated bass range amplifiers, large speakers such as those used by bass guitarists and dedicated sub woofers. The intention is to create a range of sounds where different physical reactions are enabled. These may include internal vibrations of the body, objects and structures vibrating, or the sensation of air pressure on the skin or through the body.

The Sound that's not THE sound

Sound in compositional contexts can take on many forms – as playback, input, artifact, interactive signal or even as a three dimensional aspect. It can be employed as a conceptual framework, as was preferred by Fluxus artists such as Yoko Ono and Dick Higgins among others. This often means that the audience is left to 'imagine' a sound or be challenged about the very idea of sound and its creation. This kind of conceptual music offers a useful analogy for the experience of sounds on the cusp of the human hearing range. Could the absence of conventionally audible sound that very low frequency offers be considered a silence in music, an art form generally perceived to be constructed from tones? Where Douglas Kahn (and Alvin Lucier before him) discusses the idea of an 'impossible inaudible' in music and claims; "there is no doubt that silence exists. On the contrary, there is an acknowledgement of a multitude of silences" [8] he provides an opportunity to incorporate silence as a key to understanding listening. Where an inaudible sound is used to generate other sounds or objects (through vibration, for example), it could be thought of as a kind of silent stimulus, not unlike the spaces between notes of a more traditional music score, which shapes and directs the listening experience. It is an integral part of the music composition, constructing and enriching it– as do the frequencies required to build harmonics required to hear specific notes and chords on certain low instruments, as in those of the string family and the lower ranges of bass wind instruments [9]. Infrasonic music provides an interesting conceptual framework in which to create music compositions from material that could be thought of as hidden, ignored, difficult to hear or access.

Pierre Schaeffer's acousmatic ideas, which shaped new phenomenological approaches to music and listening, provide another way to think of infrasonic music. A sound can have its own musical existence and identity quite distinct from its source – in this case, coming into existence in bodies or other objects. Inaudible sound activity is then incorporated and reinterpreted in a music composition where sounds may be measured according to their relationship to hearing thresholds and resonant frequencies. A similar idea has been explored in works such as Alvin Lucier's *Music for Solo performer* (1965) where low tones are used to vibrate a variety of percussion instruments into action, being generated by the amplified alpha waves of the seated 'performers' brain. Often, it was the speaker's movements, not any resultant tone, that would activate the instruments. The idea that something hidden in the relaxed, stationary performer could be the source of the sound is what is fascinating here and in a concept for infrasonic music.

The proposition of an infrasonic music then pushes the dimensions of silence, acousmatics, and sound art even further, by offering a music that combines new ideas of listening with the physiological possibilities of the listeners themselves.

Methodologies for composing infrasonic music

Immersive and ephemeral art experiences are enhanced by the opportunities offered when working with low frequency sound – creating a music that moves between innovative and traditional ways of listening. Low frequency sound can be used in three general approaches – creating music that activates physiological or psychological experiences in the listener, the activation of objects to become music generators themselves, and the translation of inaudible sonic data into other dimensions. A fourth approach is the lacing of music with very low frequency tones, effecting the way we experience other sounds and achieving some of the outcomes of the other methods. Perhaps the most relevant examples of this approach are in the cinema sound effects, from the Sensurround technology used to vibrate entire cinema audiences, first used in *Earthquake*, (Mark Robson, USA, 1974) to the use of a 24Hz tone in the first half of the harrowing film *Irreversible* (Gaspar Noé, France, 2002). In both these examples, the low frequency seeks an effect – a simulation of an earthquake, and an attempt to psychologically disturb the cinema patron. In my own practice I have created a variety of works that explore the possibilities of music creation using low frequency.

Installation

Influenced by this idea of low frequency lacing, I created the *The Low Groom* (2006). This is an audio/visual/performance installation where low frequency is used to alter a participants experience of a room, where they are engaged in listening, looking at and doing different things (Fig.1). A static low frequency tone is emitted from a hidden bass amplifier into a small room, where one person may enter at a time. A stationary performer is seated slumped over the amplifier, naked from the waist up, back turned, with a projection on their back. The person listens to the performers slow sultry voice on closed headphones which instructs them to don thin latex gloves and manipulate pieces of fresh, varied offal (mostly intestines, kidney and liver) in a bowl before them. The fondled offal is filmed live and projected onto the performers back which simulates a three dimensional image of the performers internal organs being 'manipulated' by the participant. This is a direct reference to the ability of low frequency to resonate different cavities and organs of the body, as well as to the plethora of urban myth surrounding the effects of infrasound. The participant is made aware of references to infrasound in sonic weaponry, the 'brown note' and paranormal experience by being given a program note to read before entering. Here the intention of the low tone is not to offer the audience something to listen to or focus on in a conventional sense, but to offer an effect that will alter the way the listener experiences the voice in the headphones, sees the video on the performer, or feels the offal through the latex gloves. The tone creates a resonance within the body when the ears are closed off and the eyes focused elsewhere, and attempts to link these different senses. Its employment also lends from the philosophy of *Muzak* – to control the way people experience a space. Muzak claims to 'affect those who hear it but does not require a conscious listening effort' and uses psychology to understand the best types of music for certain situations [10]'. *The Low Groom* uses low frequency sound not as music in its own right (it is after all a rather tedious ongoing tone) but as part of a larger, spatial concept of composition and listening.

The work makes use of the omni directional nature of low frequency sound and its ability to fill the space, combining it with the different, highly directed sonic experience in the headphone. The headphones provide a very intimate and personal listening experience, and the style of speaking played through them reinforces this intimacy. The voice in the headphones tells the participant what to do, when to start and stop, where to look or what to feel for, what they may expect: "is that a low tone you hear that could be making you feel…uneasy?" It is a sultry, sexy voice recorded in close proximity, coaxing, enticing. It is unlikely the participant knows it is the stationary performer is the microphone is not visible. The low tone also feels very close (it is in fact repeated through the performers microphone and so into the headphones) even through the source is not – it is not even visible, the amplifier seems a prop for the performer. It serves to unite the concept of the video performance with a multilayered aural and tactile experience, heightening the intensity of the work, and confusing the sensory to some degree.

Composing for installation

I have found the most interesting results eventuate when infrasonic effects are incorporated into the musical fabric of a work. *Lost* (2008) is a collaboration between myself and photo media artist Kate McMillan, where an image of a volcanic site is stretched and printed on a curtain which lines a room (Fig. 2). This is a piece about the possibility of landscape to hold and articulate personal memories, and that the landscape was volcanic was of great interest to me, volcano's being a major source of natural infrasound. Four sub woofers built into the walls behind the curtain playback a loop of around twenty multilayered bass parts, mixed, delayed and equalized to create more of a 'rumble' than any melodic or harmonic structure. The speakers are placed in pairs facing each other, creating a buffering effect resulting from interference between waves traveling in opposite directions. This in turn creates particular resonance in the space that results in a feeling of pressure. In a deliberate attempt to reflect the disorientation and claustrophobic nature of the images and installation appearance, the sound offers what cannot be seen, or even heard – but can be listened for – a kind of tension and suspension. Like in *The Low Groom,* low frequency sound acts as something of a conditioning device for the work, but in *Lost* it plays a key role in the musical composition as well as the constructed environment .

Installation meets Performance

A different approach again is employed in works created for my Abe Sada project (2006 to present). Abe Sada is a performance and recording project for any number of bass guitars. It creates soundscapes that are constructed almost exclusively of sounds below 100Hz (the lowest note on a bass guitar is traditionally 30 Hz), laced with bass feedback. Abe Sada aims to make the sonic experience as visceral as possible – the music fills and affects various sites in a performance – onto bodies of the audience, using different approaches to sound diffusion and by controlled vibration of objects. These effects are not meticulously controlled or measured, rather they ebb and flow with the improvisations of the rotating performers featured in each Abe Sada performance. Each Abe Sada performance has a score, sometimes graphic, other times more propository, as seen in Fig. 3. This gives performers freedom to improvise below a set pitch, and allow sounds to interact by accident, but within stated parameters.

Abe Sada usually performs distributed around a venue rather than on a stage, out of the spotlight and in the audience space, installed to make best use of the acoustic space the venue provides. Most performances are designed for specific chosen spaces, so far including multi roomed art spaces, car parks, theatres and a football field. The performers use only their bass amplifiers to ensure a tonal control and consistency of bass sound in the mix, and enabling the speakers to be much closer to the audience, intensifying the listening and performative experience. This also keeps the guitar/ amplifier pair more of a whole instrument in its own right, enabling the sound to be controlled by the performer only, personalizing it. They engage bass feedback that resonates in the room, moderating it with their own and the audience bodies, even using it as a melodic source. The music moves between different levels of frequency and volume, climactic and meandering, to create a live music experience that invites different types of listening perception. Audience members describe physical experiences such teeth chattering, pressure in the chest, chills, and note objects and structures vibrating in the room. In *Abe Sada: multiroom* (2008) each player was in a different room of an old building, amplifiers against the walls, one upstairs amp facing into the thin wooden floor, the performer jumping off it, 'playing' the ceiling for the audience below (Fig. 4).

In *Sada Abe 1936* (2006), the group performed under raked seating in a theatre, and put high volume bass amplifiers in contact with the rather light seating support structure, allowing their music to vibrate the audience through the very structure they were seated upon (Fig. 5). Here the focus was very much on the physicality of the sound for the audience; feeling it in their seats and hearing the structure create a sound of its own, different for each audience member depending on their position and hearing threshold. The music that activates these effects is not the prime focus here, and the inability of the audience to see the sound source also helps focus the audience attention on the sensations created: they were seated in front of a lit but empty stage.

A more studied approach to low frequency takes place in recordings. Whilst a detailed study on mastering and what it has to offer is out of the range of this paper, I will touch on some of my own attempts. My album *Fetish* (2002) is a recorded collection of short bass guitar solos that explore movement in and out of pitch recognition in low frequency ranges. Pitches move below the range of the bass guitar using unique tunings, octave displacement, post production tuning and loop manipulation. Distortion is used to blur the sound and create diverse textures from a limited pitch set. Likewise, *Hertz Circus* (2001) composed by bass duo Lux Mammoth (myself and sound engineer Dr Alien Smith), explores bass effects for two bass guitars and tone generators through the compact disc mastering process, whereby the manipulation of the final mix uses a variety of low frequency management and outboard effects to move sound through different volumes, pitches and timbres. Abe Sada recordings make use of other instruments to colour the low frequency of recordings. *Subzilla* (2007), for example, features chainsaws, and acknowledges the early contributions of the Italian Futurist's 'noise machines' for the possibilities for low frequency noise in music. Often, the effects in the extreme low frequency range are able to be experienced only through the best high fidelity system, so those with access to one are rewarded.

Conclusion

Lux Mammoth and Abe Sada investigate a focus on bass not common in live music performance and recording. In the works by these ensembles, bass is never used as reinforcement for the beat or to underpin chordal structures; bass *is* the whole work. Many anecdotal comments made after my concerts have proved useful in shaping the aims of this music. A common description is that the music creates a 'sensual' and 'warm' experience in the body. This is in marked contrast to the 'annoyance' or 'pressured' feelings reported by people exposed to environmental, unfocused ongoing infrasound noise [11], showing more in common with the responses of patients exposed to low frequency vibration in treatments such as Vibroacoustics, where low frequency sinusoidal pressure waves are blended with music for therapeutic use.

John Cage believed that 'the principal of form will be our only constant connection with the past' [12]. Infrasonic music offers a new approach to form, adding new dimensions not only of music composition, but also reception. Infrasonic music can offer a conceptual, sensorial and tangible approach to music composition, and further extend the possibilities for a more visceral experience of music.

Resources

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References and Notes

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Figure Captions

Fig. 1: Cat Hope, *The Low Groom*. Audio/video/performance installation, 2006. Audience member and performer. Photo © K.Ford

Fig. 2: Kate McMillan and Cat Hope, *Lost.* Installation of digital print on polysynthetic fabric 4000 x 5000 x 7100 with multichannel sound, 2008. Photo © Robert Frith

Fig. 3: Abe Sada, *Abe Sada carpark* Music performance/installation, 2007. Score © Cat Hope

Fig. 4: Abe Sada, *Abe Sada multiroom* Music performance/installation, 2008. Performer jumping from amplifer to the floor, with the audience listening downstairs, and other performers in other rooms. Photo © Tom Hall

Fig. 5: Abe Sada, *Sada Abe 1936,* Music performance/installation, 2006. Performer situated under raked seating of a theatre, audience above. Photo © K.Ford

Biography

Cat Hope is a classically trained musician who later became interested in noise music, film music, performance art and sound installation. She tours internationally as a performer and composes music from songs to graphic and notated scores. She is the founder of bass noise group Abe Sada and sound art collective Metaphonica. Cat is currently is the head of composition and music technology at the Western Australian Academy of Performing Arts at Edith Cowan University and completing a PhD at RMIT University in Melbourne, Australia.

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