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Journal of Sound and Vibration 277 (2004) 471–478

JOURNAL OF SOUND AND VIBRATION

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Physiological aspects of noise-induced stress and annoyance

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Accepted 25 March 2004
Available online 28 July 2004

Abstract

The relation between environmental noise exposure and physiological stress reactions is analysed, based upon the physiological characteristics of the hearing system. The potential of environmental noises to induce stress reactions is high and dependent how the noise is interpreted in the central nervous system. Occupational and environmental studies demonstrate that stress reactions occur and certain data suggest that medical effects such as increased blood pressure might result from prolonged noise exposure. As there is a relation between the extent of annoyance and stress, future research should define this on a dose–response basis using clinical as well as subjective exposure outcomes.

1. Introduction

Conceptually sounds serve as a means for contact with the environment and a primary role of the hearing system is to serve as a warning system against dangers to ensure survival. This task takes place in the central nervous system (CNS) by processing the intensities and the frequencies in the sound, comparing them to previous experience and initiating a number of reactions. The meaning and the predictability of the sounds and, to a lesser extent, the sound level, are important parameters that determine the ensuing reactions. These characteristics determine if the sound will be experienced as a noise—a negative component of the environment—or a normal, acceptable component, e.g. the sound from a waterfall. As the effects discussed in the following mostly refer to sounds that are considered as pollution by the individuals, the term noise will be used although

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0022-460X/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jsv.2004.03.008

that term in reality implies an interpretation that takes place after the stimulation of the auditory system.

The goal of this presentation is to assess the relation between noise exposure and the development of physiological stress in terms of altered homeostasis of the CNS functions induced by sound exposure and by subjective annoyance.

2. Sound and central nervous system reactions

The auditory pathways of the CNS consist of direct pathways from the inner ear to the auditory cortex and indirect pathways to the reticular activating system that connects to the limbic system and other parts of the brain, to the autonomic nervous system and to the neuro-endocrine system. In addition to these direct pathways to and from the cerebral cortex, there are a variety of indirect connections from the inner ear to brain centres that control physiological, emotional and behavioural responses of the body.

From a functional point of view, noise will affect alertness, cognition and motor performance. Through the pituitary adrenal neuroendocrine system, there is a secretion of corticosteriods, which are related to the development and control of stress and through the sympathetic–adrenal system there is a secretion of catecholamine, adrenaline and noradrenaline.

Those different activities of the CNS initiate a number of physiological, emotional, and behavioural reactions, most of which are beyond the control of the individual and with very little habituation. For a more complete description of the CNS pathways, textbooks in physiology or reviews [1] may be consulted.

There is a large variation between individuals in the induction of the above reactions by noise. The reasons for these differences are largely unknown although it is clear that genetic factors, previous experience and the simultaneous presence of other environmental stimuli play a role for noise sensitivity. Recent data have demonstrated that differences in the serotonin receptors 5-HT_{1A} are related to environmental awareness and these could be important for the individual variation in the reception of sound-mediated information through the CNS [2].

3. Effects after acute exposures

The acute effects to noise exposure comprise the orienting response, the startle reflex, and the defence/flight reaction, which are all warning/alert reflexes. The orienting response causes the head and eyes to orient towards the source of the noise as a preparation for subsequent reactions. The startle reflex comprises eye blinking and a contraction of the middle ear muscles as well as the muscles in the limbs, causing a flexion and a position of protection [3]. Fig. 1 illustrates the contraction of muscles after exposure to a sudden noise—a sonic boom experimentally generated to resemble the sonic boom from an aircraft at supersonic speed [4]. It is seen that the magnitude of the contractions decreased when the number of exposures increased but there was a plateau, indicating a limitation of the adaptation. The defence/flight reaction is an extension of the two previous responses and involves a readiness for fighting against the source of noise or fleeing.

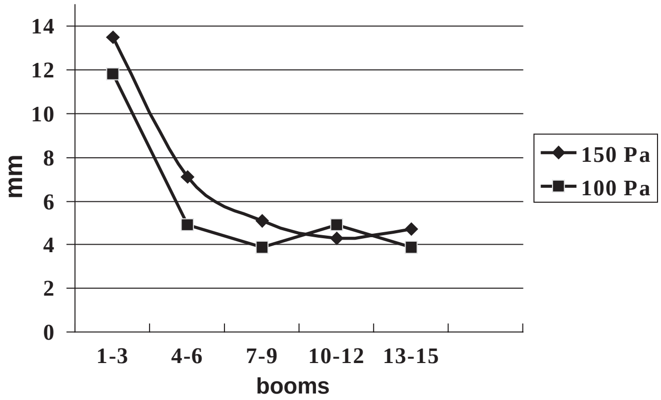

Fig. 1. Muscle contraction after exposure to sonic booms [4].

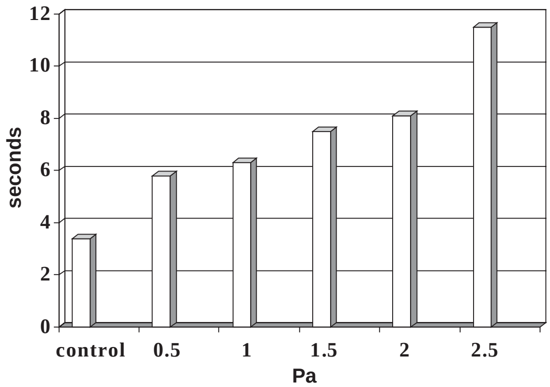

Fig. 2. Interruption in visual task [5].

There are increases in skeletal muscle tension and pulse rate and slower breathing, preparing the organism for physical action.

The acute reactions described above are accompanied by an increase in blood pressure and heart rate with an instantaneous secretion of corticosteriods. The defence response is also accompanied by a reduction in salivary and gastric secretion. Acute reactions to noise can thus cause a CNS-mediated stress reaction in the body by upsetting the normal equilibrium of several physiological functions. The reactions are short lived—in the order of a few seconds—and for some of them there is habituation, depending on exposure frequency and intensity. An important issue is whether a chronic exposures to such acute events and a repeated activation of the reflexes involved will develop into a state with lasting effects and an increased risk for medical effects.

The different reactions caused by an acute exposure to noise may be followed by an interruption of ongoing activities. Fig. 2 demonstrates the interruption of a visual task after exposure to sonic booms at varying intensities [5]. The duration of the interruption was related to the intensity of the noise stimulus.

4. Effects after chronic exposure

4.1. Annoyance

Repeated exposures to noise over longer time periods may be experienced as an uncomfortable disturbance of the way of living or interference with ongoing activities. This effect is traditionally referred to as annoyance. This has been defined as a feeling of displeasure associated with any agent or condition realized or believed by an individual or a group to be adversely affecting them [6]. It comprises a subjective evaluation of the individual's condition and well-being, based upon the experience after being exposed to noise such as interference with sleep, rest and recreation, ability to talk in the telephone, watch TV or perform work, particularly such that requires concentration and high performance. It is a reaction summarizing experience over longer time periods and is different from the subjective judgement of acute noise exposures, particularly in laboratory conditions [7]. The underlying mechanisms for annoyance are outlined in Fig. 3.

To assess the possibility that annoyance is related to physiological stress, we need to consider the CNS-mediated reactions after repeated or chronic exposures. From a physiological point of view, repeated exposure to noises that cause negative effects in terms of physiological stress reactions with little habituation, may lead to a stage where the acute effects such as blood pressure, become permanently elevated.

In this context it is equally important to consider the defeat reaction [8]. This reaction is characterized by a decreased motor function, an increased vagus-related effect, decreased secretion of cortisol, adrenaline and hormones and possibly a depression of the immune system. The ensuing clinical consequences are manifold, ranging from an increased risk for infections to a depression of the mood, social attitudes and behaviour. In humans this reaction is precipitated by intense sorrow, deep frustration or defeat. It is likely that the defeat reaction can be caused by environmental noise, particularly in situations where there is no possibility to escape the exposure such as when living in a dwelling where all the rooms face a noisy street [9]. As we shall see, there is evidence for both the continued stimulation and the defeat reaction after exposure to environmental noise.

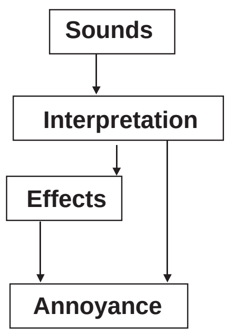

Fig. 3. Mechanisms for the development of annoyance.

4.2. Blood pressure

Based upon early studies where an elevation of blood pressure was found after acute exposures to noise, particularly those of a sudden appearance, it has been postulated that persons exposed to environmental noise for prolonged periods, might develop increased blood pressure and thus an increased risk for cardiovascular disease. Over the years a number of epidemiological studies has been performed to assess this hypothesis. Many of them are plagued by severe methodological problems. Blood pressure is a multifactorial disease and the relative contribution by noise is probably relatively small compared to other factors such as smoking, alcohol consumption and age that have often not been controlled for. Furthermore, the determination of the exposure dose in a population sample is very difficult. Area exposures are used in most studies but when the individual exposure has been determined in the same area, important differences were found [10].

Some studies do, however, report more precise data. Regarding occupational noise a recent study on 374 workers in an automobile plant concluded that the use of hearing protectors was associated with a lower systolic and diastolic blood pressure [11]. In a recent study on aircraft noise, the medical history of persons living near an airport was investigated [12]. After correcting for a number of important confounding agents such as age, education and smoking, a dose–response relationship between a history of blood pressure and noise exposure was found (Fig. 4). This dose–response relationship was most marked for peak noise levels which is in agreement with the physiological reaction pattern where the auditory system reacts particularly to changes in sound levels and less to a continued sound [1]. Another study on exposure to road traffic noise and blood pressure, demonstrated a relation between the risk for high blood pressure and the exposure during the night [13]. In the latter study, a relation was also found for chronic bronchitis, which suggests the presence of residual confounding.

If a relation between noise exposure and blood pressure can be verified in future studies, it indicates that the stress reaction found after acute exposures of noise may lead to a prolonged and continued stress effect, resulting in an increased blood pressure.

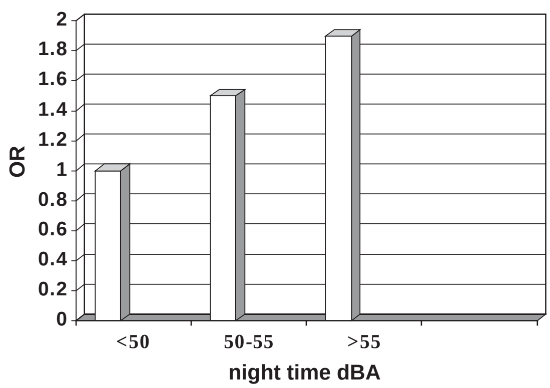

Fig. 4. Blood pressure history among persons exposed to aircraft noise [12].

4.3. General health parameters

The interpretation of one's own health may reflect the effect of an ongoing physiological stress situation. In an investigation on road traffic noise, the extent of annoyance was related to an increased risk for sleep disturbances and health worries and a reduced quality of life [14]. Similar findings were earlier reported for road traffic noise by Öhrström [15]. The general pattern in these studies suggests that a defeat reaction was present.

5. Annoyance and stress

In epidemiology dose–response relationships constitute an important support for the validity of observed relations. The above cited studies suggest that markers of chronic physiological stress exhibit such a relationship with measures of noise, particularly those of a nature that would imply particularly powerful effects such as night time noise and peak levels. Previous data have also demonstrated a dose–response relationship between environmental noise exposure and the extent of annoyance [16–18] and the importance of noise during the night and peak noises. One can thus deduct that chronic stress and annoyance are related.

Whether this is a causal relationship or not cannot be deducted from cross-sectional epidemiological studies. That would require intervention experiments studying annoyance and markers of stress on the individual level, controlling for confounders such as work stress or field studies in populations after a change in noise levels, e.g. after deviating road traffic or changing airport flight patterns.

6. Measures of physiological stress

The review on the central nervous system and its functions after exposure to sounds demonstrated a variety of parameters that could be used to assess the presence of physiological stress. Over the years several such measures such as noradrenaline and corticosteriods have been used in connection with acute exposures to noise. One of the most promising methods developed during the last years is measurement of cortisol in saliva. The levels have a diurnal variation with a peak some 30–45 min after awakening as well as a weekly variation [19,20]. The levels show a fast increase as a response to stress.

For the chronic exposure, the reaction pattern is more complicated. When the hypophyse–-pituitary–adrenal reaction chain is registering a continued stress, resulting in an increased cortisol secretion, the glucocorticoid receptors gradually lose their function, implying a neuro–degenerative condition that results in a blunted cortisol response and smaller diurnal variations [21]. In a study on nurses in emergency wards, subject to high stress levels and ward nurses, subject to lower work-related stress, saliva cortisol was measured in the morning and in the afternoon [22]. A lower morning saliva cortisol level was found among the emergency nurses and it was related to some subjective expressions of stress.

Saliva cortisol has also been used to study noise effects. Generally, increases have been found after high levels of exposure but the results at levels of around 60–70 dBA, which are levels more relevant for environmental exposures, are less conclusive. Recent studies involving exposure to low-frequency noise at low levels when performing a demanding task have indicated a decrease in saliva cortisol after several hours of work [23].

So far no data are available on the relation between annoyance and cortisol in saliva, neither in acute nor chronic exposure situations. Such studies should have a high priority, as the results will be useful to further assess the validity of annoyance as an indicator for stress and the risk of development of noise-related diseases.

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