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Infrasound Generated by Ambulances- Sources, Levels, Consequences and Ergonomic Actions

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Introduction and Objectives

The technological progress caused that the ambulance cars are audible-noise dampened. It's very important that the emergency signal is very loud. Many publications described this exposure and health consequences both to medical staff and patients [1-3]. The elements of cars like engine and suspension of vehicles can generate also infrasonic noise near audible frequencies. This problem was not described in detail in scientific literature. The sources of infrasound in ambulance cars are very numerous: engine and other mobile elements, suspension, tires and air movement. The levels of exposure to infrasound depend among others from: vehicle speed, kind and quality of cars and roads and open or closed windows. It's possible in many cases that this exposure can be higher in rural conditions (quality of roads and longer driving times and distances).

a) The aim of the study was the presentation of sources and levels of infrasound in ambulances, potential adverse consequences of such exposure and describing of possible ergonomic actions in this area.

b) To the main causes of the arising low-frequency noise and infrasonic one - in particular, belong the following:

c) the noise coming from brake systems - in the case where used elements of the system, is a significant source of noise during braking,

d) the noise is caused by the phenomenon connected with burning the fuel mixture and the work of mechanisms. Engines are one of the dominating sources of noise. They have an impact on the noise inside the vehicle while slowing down as well as fast speeding,

e) the noise of the cooperation of a tyre and road - the noise coming from an interaction of a tyre and surface is dependent on a construction of a tyre, its characteristics, the condition of the road, and speed,

f) the noise through an exhaust and air taking systems - in most cases, the proper usage of acoustic silencers enables an omission of its influence on a driver's accidental problems at the place of work,

g) the noise of a transmission system - produced by a vehicle has an influence on systems and their usage - a clutch, type of a gear box, timing system, crankshaft with bearings

h) the noise coming from additional equipment, like: air-conditioning, ventilation and other facilities that ambulances are equipped with,

i) the aerodynamic noise is one of the most dominating sources of noise with the speeds over 100 kmph, but when over 50 kmph it already starts to influence on an accidental noise in a driver's place of work. The level and characteristics of this noise are dependent on the speed when performing and the design of the car's shape; the aerodynamic noise level significantly increases, when a vehicle's windows are open,

j) the noise of a vehicle's bodywork, including windows and the accessory elements of a vehicle, which when stimulated to vibrate by vibroacoustic energy from an engine and transmission as well as driving systems. The noise generated by a bodywork of a vehicle depends mainly on the quality of materials and their construction, joints of the elements, clearances (related to the class of the vehicle) and time exploitation,

k) The noise from a suspension system is strongly dependent on a surface roughness. The condition of the suspension of a vehicle influences the transfer of vibes arising between the surface of a road and a tyre on a bodywork. A bad technical condition of a road may cause an increase of the low-frequency noise of approximately 10 dB,

l) The external noise - coming from other vehicles passing by.

Material and Methods

Paramedics'-perceived infrasonic noise levels were examined for 91 examples departures in normal, emerging work conditions of modern (Mercedes Sprinter 316 CDI 2.4 (manufactured in 2012 and in 2014, mileage between 152 000 and 216 000 km) and old ambulances (Renault Master 2.5 Diesel manufactured in 2006, mileage about 400 000 km) in 2 localizations of Voivodship Public State Ambulance Service Stations in rural areas in Wielkopolska Region. Distances of ambulances emergency departures were in Table 1 presented. Infrasonic noise measurements were performed in 2 stations localized in 2 towns in in rural areas of Wielkopolska Region (Pobiedziska and Bolechowo). The measurements included assessment of exposure to infrasonic noise in the medical compartment and the driver's cab.

Table 1: Distances of infrasonic noise measured ambulances emergency departures.

	(59 departures)				(32 departures)			
Distance [km]	Mean	Min	Max	Standard Deviation	Mean	min	Max	Standard Deviation
	25,8	4,1	61,0	19,4	22,1	2,1	58,2	18,1

The study involved measuring during the entire duration of the team's intervention including travel to the patient and patient transport to the hospital and then returning to the waiting area of the rescue team.Measurements of infrasonic noise were taken with the use of class 1 instruments by SONOPAN, a DSA-50 digital sound analyzer and a KA-50 acoustic calibrator. All measuring instruments had calibration certificates. The parameters set in the DSA-50 sound level meter was as follows: basic error up to 0.7 dB, influence of temperature up to 0.5 dB, influence of humidity up to 0.1 dB, influence of atmospheric pressure -0.01dB kPa, influence of electrostatic/electromagnetic fields, consistent with EN 61672-1 [4]. Noise level measurements were performed in accordance with PN-Z-01338:2010, PN-EN ISO 9612:2011 and ISO 9612:2009 [5,6]. These standards determine the 5-step procedure for the analysis of occupational exposure to noise:

a) Analysis of working conditions,

b) Selection of measurements strategy,

c) Analysis of uncertainty and errors

d) Calculation and

e) Presentation of the results, including the uncertainty of measurement.

All measurements were taken using a G filter (the most popular filter for infrasound exposure analysis) and a LIN filter (e.g. in Polish conditions, this filter is used by legal requirement (Figure 1) [6,7]. Frequency characteristics of the G filter corresponds to subjective evaluation of infrasound nuisance. The measurement results included equal infrasound G-weighted levels (LG,eq,Te) - the basis of assessment of exposure to infrasonic noise measurements (PN-01338:2010) - and additionally, maximum acoustic pressure levels in the infrasonic band (LLINmax) (required by some legal regulations concerning women and young workers) [8, 10]. Measurement uncertainty was assessed according to Annex C of PN-EN ISO 9612:2011 (ISO 9612:2009) (recommended by paragraph 4.5. of PN-Z-01338:2010), assuming that exposure to infrasound during a particular task was identical during an 8-hour working day to the exposure during the time of measurement (Te), which is LGeq8h = LGeq,Te. Measurements were performed on accordance with EN ISO/IEC 17025:2005 and in cooperation with a laboratory for noise accredited by Polish Centre for Accreditation, which is a signatory of the European Cooperation for Accreditation (EA MLA) and International Laboratory Accreditation Cooperation (ILAC MRA) [11].

Results and Discussion

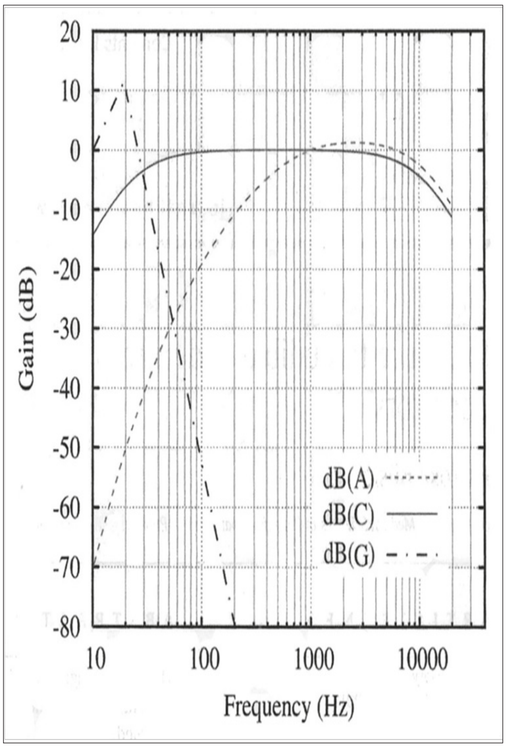

Figure 1: Frequency characteristics of G filter applied in infrasonic noise measurement applied in working environments [11-15].

The results of infrasonic noise measurements are shown in Figure 1. At the first station (town Pobiedziska) were cars Mercedes Sprinter (59 departures- measurements in driver's cabin: 1,3,5,7, 9,11,13,15,17,19,21,22,23,24,26,28,30,32,34,36,37,39,41,43,45,47, 49,50,52,54,56,58; remaining- in medical cabin) and at the second (Bolechowo) Renault Master and Mercedes Sprinter (32- departures: last 10 measurements- measurement's in driver cabin: 1,4, 5,7,8,11,12,13,16,17,19,21,23,27,29; remaining- in medical cabin) available. Unfortunately, in the presented study, the G-weighted and unweighted (LIN)- infrasound levels were significant and at many workplaces stayed within or exceeded the occupational exposure limits. This is a very important problem from the practical (technical, medical and ergonomic) point of view concerning staff and patient's exposure for infrasound.

The following occupational exposure limits for infrasonic noise are obligatory in Poland, according to PN-Z-01338:2010:

a) Maximum equivalent acoustic pressure level corrected by a specific G frequency filter with reference to an 8-hour-long daily exposure, total working time, or a typical working week (if the exposure varies on specific week-days: LGeq,8h or LGeq, week) = 102 dB;

b) The G-weighted maximum equivalent acoustic pressure level (LG eq,Te) = 86 dB at workplaces where the workers are required to maintain a high level of concentration.

The ranges of exposures were quite large in individual departures. The minimal values of equivalent acoustic pressure level corrected by a specific G frequency filter (LGeqTe) from all vehicles were near value 102 dB-G. These values were determined based on the criteria for health (especially hearing protection). However, they do not correspond to the threshold of auditory perception infrasound, which is related to frequency characteristics G, which correlates well with the subjective assessment of the nuisance value and perception of infrasound. The accompanying whole-body vibration can result especially in damage to the vestibule-cochlear organ. The high concentration of a worker is needed at many workplaces, as presented in this study, and is connected with opportunities for accidents. Similarly, there are special restrictions concerning infrasound exposure which apply to pregnant women and young workers. For example, in Poland, for pregnant women and young workers the limits for an 8-hour working day or work week, the values (LGeq,8h or LGeq, week) are following: 86 dB and LLIN 135 dB are applied [10,12]. The early Polish law regulation required additionally the value 145 dB as the level of maximum acoustic pressure (LLIN) [15].

All measured machines ambulances generated infrasonic noise exceeded the value LGeq,Te= 86 dB (workplaces which required maintaining mental concentration, according to PN-Z-01338:2010), and for pregnant women and young workers (when the duration of exposure is at the 8-hour level (LGeq,Te = LGeq,8h). The ambulances In first station generated infrasound exceeded maximum equivalent acoustic pressure level corrected by specific G frequency filter when time of exposure to noise will be longer than 125-480 min. (mean: 192 min.)- Levels of infrasound between 101, 1-123,3 dB-G (mean: 109.9 dB-G). The ambulances In second station generated infrasound exceeded maximum equivalent acoustic pressure level corrected by specific G frequency filter when time of exposure to noise will be longer than 166-480 min. (mean: 217 min.)- levels of infrasound between 101,9-113,9 dB-G (mean: 107,1 dB). This is important that paramedics working in 12 hours shifts in Poland and therefore the exposure limits can be easily exceeded. Average exposure to infrasonic noise in many causes was higher in drivers cabins than in medical part of ambulance cars.

Possible Adverse Consequences

A significant problem is the coincidence of vibration and infrasonic noise at many of the analyzed workplaces. This is very important in future researches to estimate frequency spectrum of vibrations and infrasound for analysis of most exposed organs in human body during emergency transport especially among pregnant women and young persons. An important factor that can influence infrasound levels inside vehicles or cabins is the position of windows which, depending on their position and the resonance frequency, can amplify the infrasound and vibration levels. Technological progress is needed to reduce exposure to infrasound in vehicles such as ambulances.Some studies have alarming indicated that prolonged exposure to infrasonic noise at levels of about 90-135 dB-G may cause a lot of negative psychological and mental reactions: drowsiness, headaches, sluggishness excessive fatigue, slowing of reaction time, irritation, hearing loss, increase in psychological tension and decrease of psychomotor efficiency. Drivers can have disrupted attention, disrupted perception, diminished sharpness, prolonged reaction time in psychomotor efficiency tests.

Vehicle drivers exposed to infrasound at levels of 100-135 dB for 15 minutes reported apathy, fatigue, depression, loss of concentration, pressure in the ears and vibrations of internal organs [12-19]. There are possible adverse consequences of exposure to infrasound and other work factors at the workplaces of paramedics and drivers of ambulance cars connected with:functions of neurons in different parts of the central and autonomic nervous systems, limbic reticular complex, hypothalamus, and other subcortical structures and fatigue, shift work and stress [20-25], adverse influence on the functions of the gastrointestinal organs, spleen and liver and shift work, fatigue and unregularly nutrition [26-28], visual impairment and specific work conditions and requirements [29], hormonal equilibrium and shift work and stress [20,30,31] cardiovascular system regulation, impairment and blood pressure and shift work, stress, overwork, patient lifting, dynamic and static loads and long standing sitting position [32-39].

Possible Ergonomic Actions

Considering the great length of the low-frequency noise wave, the traditional noise abatements protection, like absorbent silencers, light protection screens, offset acoustic panels, light metal layered partitions, are no longer efficient. A number of car producers' brands are improving their vehicles to make them more and more modern and thus more popular. These include:

a) an increase of construction elements' stiffness, including vehicles' body sheets - which influences suppressing the vibroacoustic energy which while stimulating these elements to vibe is re-radiated inside the air center as acoustic energy,

b) introducing electric and hybrid cars, where there are no disturbing infrasounds emitted, to the market,

c) an application of tyres minimizing noise emitted during friction between tyres and a surface,

d) an application of acoustic reflection silencers in exhaust and air injection systems,

e) a variolations of engines, drivetrains, drivelines and driver's cabins,

f) stiffening of the construction of cabin's walls in case resonance occurs,

g) in the latest German models of cars, the side mirrors are designed in order not to emit resistance during driving, and air resistance is fragmented onto other elements of the bodywork of a vehicle,

h) an increase of acoustic absorbing of a cabin by adding several absorbing layers to silence the interior of a car,

i) an increase of acoustic isolation of a driver's cabin walls, especially the walls between the engine chamber and the interior and floor of the cabin.

Limitting the noise coming from the engine to the interior of the car may be done by improving acoustic isolation of the cabin and decreasing the noise of the engine and exhaust system (using vibroisolators and acoustic silencers). The fact that together with wasting of engine the noise emitted by it increases, should also be taken into consideration [40-43].

What Should be Taken into Consideration in Order toLimit Driver's Organism Exposure on Infrasound:

a) minimizing vibrations from the source of their occurrence (decreasing vibroactivity of sources), minimizing vibrations on the track of their propagation, automation of the technological processes and remote controlling of the vibrations' sources,

b) shortening an exposure to vibrations time during shifts, separating special rest rooms, moving to other work stations of those workers who are especially sensitive to vibrations' movement, educating workers in order to make them aware of the risk caused by exposure to vibration and safe service,

c) medical prevention which would eliminate employment on such workplaces, where exposure of the above vibrations is high, of those workers whose functional state of an organism differs from the norm, because the deviations may deepen while being influenced by vibrations. The workers already working in the above conditions should be examined periodically by doctors in order to detect any illness changes as soon as it is possible [44-46].

Next solution of the concerned subject problem includes providing ambulances with electrical engines, what would cause limiting, and in some cases, a total elimination of emitting inappropriate ultrasounds. Simple solutions are the best, nevertheless, until present there is no one who would undertake such a task. Vehicles with electric engines happen to be very unreliable and less agile which is unacceptable while saving ones' lives. Often, during interventions, ambulances must be working due to the medical equipment and appliances which must be turned on. All in all, the last example of how to cope with the infrasounds' influence is the study conducted by Łazarz and co-authors, titled: The driver's seat as an element of silencing vibration system, which showed that the driver's seat is one of the elements of limiting silencing vibrations transferred from a vehicle to a driver. The tests were conducted on a passenger car moving with various speeds on different surfaces. The research shows that the driver's seat reduces vertical vibrations even three times for the speed of 40 kmph on an asphalt road, and the bigger the speed is, the less visible the tendency is. Even less values of silencing vibes are observed on a paving. For this case, only for a vertical unit of vibrations acceleration a significant silencing of vibrations coming to four times, may be observed [47].

The biggest value of silencing the vibrations of a chair may be observed during measuring an engine while standing in a place. The vibrations of the floor layer invoked by the work of an engine were even ten times bigger than the chair's vibrations. As a result, it is clear that the most effectively chair silences the high frequency and low amplitude vibrations, which correspond to the vibrations of an engine.As one may conclude, the determining influence on the values of accelerations of local vibrations, is the surface of a road. During driving on the paving, the value of the cross-section and vertical vibrations acceleration, is increasing even four times, and for the compound vertical vibrations- even ten times in relation to driving with the same speed on an asphalt road. At the time of measuring the influence of the speed of driving on the same surface on the level of vibrations, it is visible that the greatest influence appears on the vertical and cross-section vibrations. The increase, thus, is not of a significant number [47].

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