Vera B. Pankova[1,2,3], Mikhail F. Vilk[1], Evgeny V. Zibarev[4], Irina N. Fedina[4]

On the issue of taking into account new factors in the pathogenesis of occupational hearing loss (on the example of transport workers)

[1]All-Russian Research Institute of Transport Hygiene of Rospotrebnadzor, 1, Pakgauznoye highway, Moscow, 125438;
[2]Russian Scientific and Clinical Center of Audiology and Hearing Replacement of FMBA of Russia, 123, Leninsky Ave., Moscow, 117513;
[3]Russian Medical Academy of Continuing Postgraduate Education of the Ministry of Health of the Russian Federation, 1, Barrikadnaya St., Moscow, 125993;
[4]Izmerov Research Institute of Occupational Health, 31, Budyonnogo Ave., Moscow, 105275

Introduction. In the period from 2013 to 2021, industrial enterprises saw a reduction in jobs that did not meet sanitary and hygienic requirements for the level of exposure to noise, vibration, illumination, microclimate parameters and electromagnetic fields on the workers' bodies. However, the proportion of unfavorable workplaces that do not meet the standards for noise levels remains the largest, which determines the peculiarities of the structure of the occupational pathology of workers in the Russian Federation: professional pathology of the hearing organ — professional sensorineural hearing loss — remains in the first place. The transport industry is among the sectors of the economy with the most significant indicators of occupational diseases exceeding the average Russian indicator.

The study aims to analyze additional causes of pathogenetic significance in the development of professional hearing loss using the example of employees of the driving professions of railway transport and flight professions of civil aviation aircraft. Materials and methods. We have analyzed the state of the auditory function in members of locomotive crews of JSC Russian Railways for 2017–2021 according to the Territorial Administration of Rospotrebnadzor for Railway Transport and persons of flight professions of civil aviation aircraft of the Russian Federation for 2010–2020 according to the data of the Federal Center for Hygiene and Epidemiology.

Results. Professional sensorineural hearing loss prevails in the structure of occupational morbidity of railway and aviation transport workers. Despite the absence of excess in-cabin noise levels, the leading professional group for hearing loss in railway transport are locomotive drivers and assistants, in civil aviation — aircraft commanders and co-pilots. The complexity of the professional activities of persons of these professions, a high degree of responsibility for the safety of transportation of passengers and cargo, readiness to act in non-standard conditions, loads on visual and auditory analyzers, create a high degree of labor intensity that causes chronic stress. The factor of chronic stress causes a violation of adaptive mechanisms and causes a number of complex neuro-reflex and neurohumoral shifts in the body, as a result of which labor intensity need to consider as a pathogenetically significant factor in the development of professional sensorineural hearing loss.

Conclusions. *Chronic sensorineural hearing loss is a priority occupational disease in persons of driving and flying professions, it is registered even in persons working in conditions of regulatory levels of industrial noise and a high degree of labor intensity. It is necessary to discuss the possibility of including labor intensity indicators as an additional etiological, pathogenetically significant factor in the expert criteria for establishing the connection of hearing loss with professional activity.*

Keywords: transport workers; labor intensity; professional hearing loss

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For correspondence: *Vera B. Pankova,* the Head of Department in Clinical Research and Occupational Pathology of "All-Russian Research Institute of Transport Hygiene", Rospotrebnadzor; the Head of the Occupational Pathology Group, "Russian Scientific and Clinical Center for Audiology and Hearing Prosthetics", FMBA of Russia; professor of the Department of Occupational Pathology and Industrial Medicine in State Educational Institution "Russian Medical Academy of Continuing Postgraduate Education", Ministry of Health of the Russian Federation, Dr. of Sci. (Med.), Prof. E-mail: pankova@vniijg.ru

Information about the authors:
Pankova V.B. https://orcid.org/0000-0002-3035-4710
Vilk M.F. https://orcid.org/0000-0001-7103-2905
Zibarev E.V. https://orcid.org/0000-0002-5983-3547
Fedina I.N. https://orcid.org/0000-0001-6394-2220

Contribution:

Pankova V.B. — formulation of the purpose of the study, analysis of the material on railway transport, writing the text of the article, editing;
Vilk M.F. — analysis of material on railway transport, editing;
Zibarev E.V. — analysis of the material on civil aviation, participation in writing the text of the article; editing;
Fedina I.N. — review of publications on the topic of the article, design of the text of the article, figures, tables, references.

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Introduction. Decree of the Government of the Russian Federation No. 833-r dated 26.04.2019 "A set of measures to stimulate employers and employees toë improve working conditions and preserve the health of employees, as well as to motivate citizens to lead a healthy lifestyle" [1], among others, stimulates scientific and practical developments to study the multifaceted issues of etiology and pathogenesis of occupational diseases employees of the Russian Federation in order to ensure professional health and prolong working longevity.

The state of working conditions is the main reason that has the most significant impact on the state of professional health of employees, which, in turn, is an important social indicator of the state of the country's labor potential.

In the period from 2013 to 2021, industrial enterprises saw a reduction in jobs that did not meet sanitary and hygienic requirements for the level of exposure to noise, vibration, illumination, microclimate parameters and electromagnetic fields on the workers' bodies, however, despite this, the proportion of unfavorable jobs for such a physical factor as

noise remains the greatest [2]. This situation determines the peculiarities of the structure of occupational pathology in the Russian Federation, depending on the harmful production factor affecting it: it is still in the first place in 2021. there remains a professional pathology of the hearing organ — professional sensorineural hearing loss. Among the sectors of the economy with the most significant indicators of occupational diseases exceeding the average Russian indicator is the transport industry [2–4] ***(Fig. 1, Fig. 2)***.

The study aims to analyze additional causes of pathogenetic significance in the development of professional hearing loss using the example of employees of the driving professions of railway transport and flight professions of civil aviation aircraft.

Materials and methods. Scientists have analyzed the state of the auditory function in the members of locomotive crews of JSC Russian Railways for 2017–2021 according to the Territorial Administration of Rospotrebnadzor for Railway Transport and persons of flight professions of civil aviation aircraft of the Russian Federation for 2010–2020 according to the data of the All-Russian Research Institute of Transport Hygiene of Rospotrebnadzor, Russian Federation.

Results and discussion. According to literary sources [3–9], in the structure of occupational morbidity of railway and aviation transport workers, the predominant occupational pathology is also hearing loss — chronic sensorineural hearing loss, directly related to the state of the function of ensuring the safety of vehicles ***(Tables 1, 2)***.

The predominant occupational group for the incidence of occupational hearing loss from year to year remains employees of locomotive crews — machinists and assistant machinists: 72.4% in 2018; 55.4% in 2019; 46.6% in 2020; 41.6% in 2021.

In accordance with the letter No. 77-21-07FC-4189-2021 of the All-Russian Research Institute of Transport Hygiene of Rospotrebnadzor dated 06.15.2021, the flight personnel of aircraft commanders and co-pilots (from 58 to 69% for 2015–2020) have the highest rates of occupational morbidity in civil aviation.

Sensorineural hearing loss is the only occupational disease in flight personnel [10, 11].

According to early studies, there are violations not only when exposed to elevated noise levels, but also when working in conditions of regulatory levels of industrial noise.

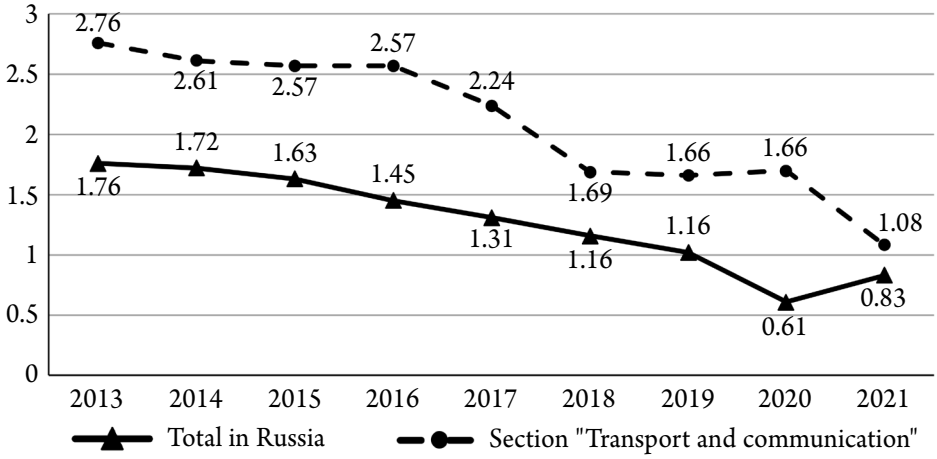

Fig. 1. Indicators of occupational morbidity in the Russian Federation per 10,000 employees for 2013–2019

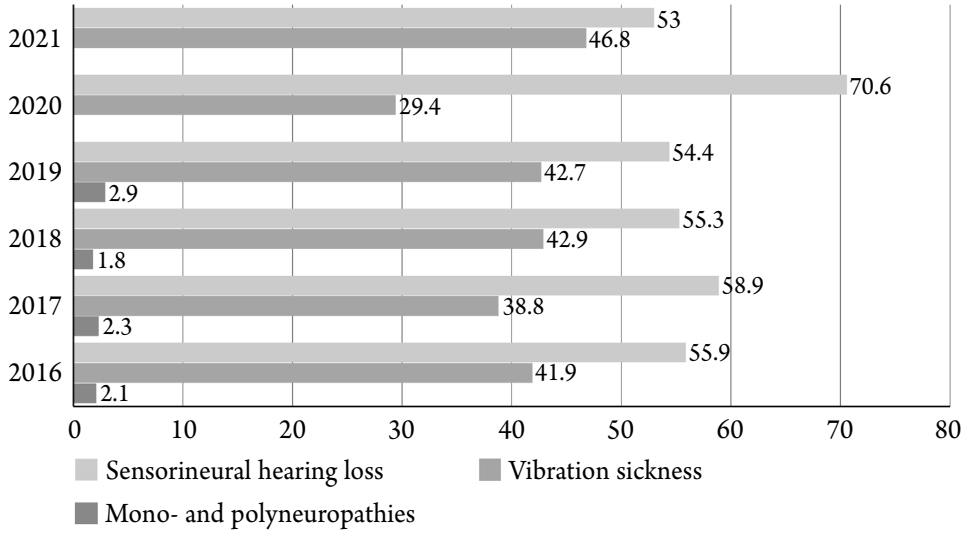

Fig. 2. The structure of the main forms of occupational pathology from the effects of physical factors in 2016–2021 (%)

Table 1

Structure of occupational diseases on the Russian railway network in 2017–2021 (%)

Nosological form	2017	2018	2019	2020	2021
Professional hearing loss	75.0	79.0	54.4	61.0	62.5
Chronic dust bronchitis	8.3	4.0	7.8	19.6	17.2
Vibration sickness	5.6	5.7	15.6	9.4	10.5
Diseases of the peripheral nervous system and musculoskeletal system	6.5	8.9	14.4	6.5	7.2
Other	4.7	2.4	7.8	3.5	2.6

Table 2

Occupational morbidity of various flight professions in the Russian Federation in 2010–2020

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total occupational diseases according to the Foreign Economic Activity "Air transport activity", including:	799	714	750	674	644	570	431	376	273	281	159
Pilot, %	26.53	27.17	26.00	28.04	29.97	29.82	33.64	33.78	23.81	19.22	21.38
Commander (pilot) of the aircraft, instructor, %	10.89	12.46	13.60	10.09	12.89	15.26	15.78	12.23	11.36	22.78	8.18
Commander of the aircraft, %	7.26	6.72	10.40	9.79	9.16	17.72	14.85	16.22	21.98	18.86	21.38
Instructor pilot, %	0.88	1.26	2.53	0.00	3.73	5.79	5.10	5.59	4.03	3.56	6.92

For drivers and assistant drivers of modern locomotives, noise levels in the cabins do not exceed the maximum permissible level (MPL), ***(Table 3)***. However, in 15% of cases, researchers identified hearing loss by the type of sensorineural hearing loss. With 10 years or more of professional experience, hearing loss develops in more than a third of employees (33%) [13].

It is important that professional hearing loss is also largely common among pilots of civil aviation aircraft, where in recent years pilots have been flying on foreign-made aircraft for the most part. These aircraft have reduced noise levels compared to aircraft of domestic production.

In the last 10–15 years, the share of foreign–made aircraft in operation has increased — in 2005 — 28.7%, in 2010 — 84%, and in 2015–2019 — more than 96% [14].

The levels of in-cabin noise of modern aircraft vary from 72 to 82 dB. However, signs of professional hearing loss still appear, including in pilots with 16–20 years of experience ***(Table 4)***, which we cannot explain only by working in conditions of high noise levels in the first years of flight experience on aircraft such as AN-2, Yak-18, AN-24.

The reasons may be both the combined effect of a complex of factors (vibration, labor intensity, barometric pressure), aggravating the effect of noise, and underestimation of the calculated acoustic load.

An analysis of the sanitary and hygienic characteristics of the working conditions of pilots showed that most of them flew several types of aircraft during their service [15].

Aircraft pilots are characterized by the skills of flying on different aircraft: 75.4% of pilots flew more than 4 types of aircraft, 25.4% — on 2–3 types of aircraft and only 1.1% — on one type of aircraft. At the same time, helicopter pilots during the entire flight activity flew no more than three types

Table 3

Working conditions of employees of locomotive crews of different types of locomotives [12]

Type of locomotive		Factors working conditions					
		Noise		Vibration		Labor intensity	General assessment of working conditions
		dB	Class of working conditions	dB	Class of working conditions		
Electric locomotives	VL-82M VL-80 VL-80M VL-10 VL-11	65.0–73.0	2	76.0	2	3.2	3.1
Diesel locomotives	2T10UT 2T10M 2T10V	68.0	2	85.0	2	3.2	3.1

Table 4

Indicators of age, length of service and flight time for pilots of civil aviation aircraft when establishing a diagnosis of professional hearing loss

Pilots by aircraft types	Age, years			Experience before the appearance of signs of OD, years			Total flight time, hours			Operating time in conditions of increased noise levels, hours		
	average	min	max	average	min	max	average	min	max	average	min	max
Aircraft pilots	63.3±4.6	53.7	72.6	37.3±4.9	20.0	44.5	17,230.4±5,189.9	1,765	24,333	12,129.7±4,576.6	2,933	24,240
Helicopter pilots	58.2±5.3	48.1	71.3	32.3±6.7	16.0	48.0	12,890.9±4,043.6	2,563	20,882	11,396.4±4,522.0	1,738	20,882

of aircraft (73.6%), almost a third of pilots (31.5%) operated only one type of aircraft (Mi-8).

A small part of the pilots (4.1%) operated both airplanes and helicopters. These data show the complexity of the professional activities of the majority of pilots who, during their flight activities, had to master the management of many types of aircraft, as well as the peculiarities of working conditions in different periods, differing in different exposures of vibroacoustic, ergonomic, psychophysiological factors in the workplace.

Domestic and foreign studies have shown that the manifestation of signs of hearing loss depends on the severity of pathogenetic factors, such as the inflammatory process, impaired absorption and excretory function of tissues, hypoxia and changes in their trophic [16–19].

The morphological substrate of hearing loss from noise (impaired sound perception) is degenerative-dystrophic changes in the hair cells of the spiral organ.

The main cause of snail cell death under the influence of noise is the damaging effect on intracellular structures of reactive oxygen species (ROS) released as a result of excessive mitochondrial activity and oxidative stress.

The reaction of free radicals with plasma membranes leads to the formation of phospholipid and aldehyde peroxidant products, and, ultimately, apoptosis of the hair cells of the neuroepithelium of the inner ear [19, 20].

The currently accumulated theoretical, experimental and clinical data suggest that the main link in the pathogenesis of occupational hearing loss are vascular disorders caused by inhibition of cerebral circulation function, which are one of the main causes of early constrictor changes in the vessels of the brain, which can result in cerebral ischemia, stroke. Noise can be one of the causes of sudden death in the workplace (pilots, drivers and drivers of vehicles) [21, 22].

Scientists have found that disorders of cerebral circulation, as a rule, precede hearing loss and are detected in persons of "noise" professions, even with normal auditory function.

Earing impairment coincides with a decrease in pulse blood filling in the vertebrobasilar system, an increase in the tone of small and medium-sized arteries, an increase in the frequency of angiospasm, and difficulty in venous outflow. Hemodynamic disorders are the leading pathogenetic link in the violation of sound perception of any etiology, which are based on anatomical features of the blood supply to the ear labyrinth and the high sensitivity of the cochlea receptors to hypoxia due to the terminal position with the absence of *a.labyrinthi* collaterals, and direct dependence on the state of central and cerebral hemodynamics [23].

We consider the effect of noise on the body from the standpoint of chronic stress, which leads to a violation of adaptive mechanisms, and causes a number of complex neuro-reflex and neurohumoral shifts, causing neurotic, depressive states, which in turn cause the development of psychosomatic diseases, forming a "closed" circle of pathological reactions [24, 25].

There is no getting used to noise in the physiological sense. The response to noise exposure manifests itself in the form of specific (aural) and non-specific (extra-aural) effects. During the first period of work in noise conditions, there is a predominance of extra-aural effects (headaches, memory loss, fatigue, drowsiness, sleep disorders, emotional instability), which increase at a faster rate than the aural effects. Therefore, jobs characterized by increased levels of labor intensity (especially with high emotional and sensory loads) can increase the negative effect of noise and have an aggravating effect on the development of professional hearing loss [26, 27].

Thus, the labor intensity factor is undoubtedly significant in the pathogenesis of occupational hearing loss. Noise and work intensity are inextricably linked and can potentiate each other's action, causing fatigue and stress in the short term, and in the long term — the development of chronic diseases, including the loss of the possibility of continuing professional activity. Taking this into account, on the basis of the revealed dose-effect dependence of the increase in the degree of fatigue and other extra-aural effects, with an increase in noise exposure, researchers have previously developed the principles of its differentiated rationing taking into account labor intensity. [28, 29].

The noise with levels from 50 to 80 dB has not only a tedious, but also a direct interfering, irritating effect, with the development of a complex of extra-aural effects [12]. Based on the above, taking into account labor intensity and noise in the development of professional sensorineural hearing loss deserves special attention, especially for a profession with a high degree of nervous and emotional stress and, above all, for people working in the transport sector.

People exposed to noise, even with levels of 57–73 dB, have changes in the functional state of the nervous system in the form of asthenic reactions, autonomic dysfunction syndrome with subjective symptoms characteristic of them — absent-mindedness, irritability, attenuation and memory, apathy, depressed mood, fatigue, sleep disorder (drowsiness or insomnia).

The functional state of the vestibular apparatus changes (dizziness, nystagmus appear), the pulse is reduced, blood pressure increases or decreases [24].

Important adverse effects are also a decrease in the stability of clear vision. There is an increase in the time of motor reaction to sound and light stimuli, the reaction speed slows down when solving text tasks. With an increase in the degree of intensity of work in noise conditions, according to

chronoreflexometry, the number of errors in the dynamics of the work shift increases. At the same time, the number of errors increases in direct proportion with an increase in the noise level above the standards for strenuous types of work.

These data indicate that noise, not only with levels exceeding the permissible (80 dB), but also within significantly lower permissible parameters (50–80 dB) when performing highly stressed types of work, attributes to risk factors contributing to the development of fatigue and stress, in turn, affecting the neuroepithelium of the inner ear, changing the processes of sound perception.

The emergence of new technologies, the introduction of modern machines and mechanisms, the increase in the complexity of control and life support systems in the transport industry of the Russian Federation contributes to the transformation of the levels and duration of the impact of individual factors of the production environment and the labor process, changing the overall working conditions [30].

The work of workers of various types of transport refers to rather complex types of activities in the aggregate: the duration of the working shift, the "shift" method of work, the alternation of day and night shifts of work, the complex impact on workers of various factors of the production environment and the labor process, the need to use special protective equipment and radio communications that worsen the functional state of the employee, a high degree of responsibility for the safety of cargo transportation, the life of passengers, etc. [7, 30, 31]. These features cause a different, most often high, degree of labor intensity of workers in the transport industry.

The intensity of the labor process, as a harmful production factor, is one of the most significant for employees of locomotive crews.

As follows from ***Table 3***, the work of members of locomotive crews is associated with a high nervous and emotional load. With the introduction of new technologies (driving trains at speeds over 140 km/h, driving a train driver without an assistant, etc.), the intensity of the driver's work increases. At the same time, the intensively intense activity of the driver proceeds in conditions of monotony, which, together with the need to resist it in any unexpected (extreme) situations that arise during the flight, imposes its own characteristics on the state of functional activity of all the main systems of the driver's body. Among the workers of locomotive crews, almost the main factor is the tension of the analyzer functions, primarily the visual, auditory and vestibular analyzers.

The intensity of labor of locomotive crew workers when driving heavy trains according to the "system of many units", as well as when moving trains at speeds over 140 km/h, increases compared to traditional work. In these conditions, the assistants perform additional navigational functions.

Especially stressful is the work of the drivers of mainline locomotives when driving a locomotive without an assistant.

This technological regime imposes increased requirements on the driver's attention, hearing, vision, his psycho-emotional sphere, monotonous stability. This is due to the driver performing part of the duties of an absent assistant, a long (during the flight) isolated stay in the locomotive cabine, etc.

Confirmation of the increase in the production load for representatives of this professional category are the results of comprehensive studies on the assessment of the functional state and working capacity of locomotive crews, conducted in real production conditions and showed an increase in the volume of incoming information load in conditions of relative lack of time for decision-making by a driver working without an assistant. The number of operations per hour is more than 350, the share of complex operations reaches 95%, causing the level of production load as "high" [30].

We also characterize the work of the pilots of the aircraft as work of high intensity. This is due to such unavoidable factors as the special nature of work: the presence of responsibility not only for one's own life, but also for the lives of other people; the forced pace of work; the tension of visual and auditory analyzers, the need for constant radio exchange and work in aircraft sets; the frequent occurrence of a severe time deficit decision-making; perception of signals in conditions, in terms of quantity and quality, close to the physiological limits of analyzer systems; the effect of concomitant production and external factors that interfere with the performance of basic labor operations; at times — monotony, followed by unpredictable activity), etc. [30, 32, 33].

The studies that included time-lapse measurements in accordance with the Manual for the Flight Operation of the aircraft showed that the number of incoming signals (light and sound) from pilots is more than 3,000 in one hour.

However, the use of objective methods for registering visual signals based on the assessment of oculomotor activity (eye-tracking) indicates that their number for one hour of work can actually be more than 8,600, which exceeds the values even for Class 3.2 in terms of labor intensity by up to 30 times [34].

Thus, both factors — noise and labor intensity come out on top in terms of severity among other factors of working conditions for persons of flight and driving professions. The current situation makes it necessary to determine the role of labor intensity in the development of an occupational disease — sensorineural hearing loss.

However, in the List of occupational diseases in paragraph 2.4.1. of Order No. 417n dated 27.04.2012 "On approval of the List of Occupational Diseases", the only etiological factor is indicated — noise, in the spectrum of manifestations of which there is sensorineural hearing loss bilateral H83.3; H90.6.

The presented materials indicate the need to consider the possibility of including indicators of labor intensity, along with industrial noise of varying intensity, as an additional etiological, pathogenetically significant factor in the expert criteria for establishing a link between hearing impairment and the impact of a complex of these factors in the etiology of professional hearing loss.

Conclusions:

1. Chronic sensorineural hearing loss is a priority occupational disease in persons of driving and flying professions.

2. Sensorineural hearing loss is registered in persons working in conditions of regulatory levels of industrial noise and a high degree of labor intensity.

3. It is necessary to discuss the possibility of including labor intensity indicators as an additional etiological, pathogenetically significant factor in the expert criteria for establishing the connection of hearing loss with professional activity.

References

1. Decree of the Government of the Russian Federation No. 833-r dated 26.04.2019 «A set of measures to encourage employers and employees to improve working conditions and preserve the health of employees, as well as to motivate citizens to lead a healthy lifestyle» (in Russian).
2. On the state of sanitary and epidemiological welfare of the population in the Russian Federation in 2021: State Report. Moscow: Federal Service for Supervision of Consumer Rights Protection and Human Well-Being; 2022 (in Russian).
3. Pankova V.B., Fedina I.N., Volgareva A.D. *Professional sensorineural hearing loss: diagnosis, prevention, examination of working capacity.* Ed. Daikhes N.A. M.: Izdatelskaya Torgovaya Korporatziya «Dashkov and K°»; 2017 (in Russian).
4. Pankova V.B., Fedina I.N. *Occupational diseases of ENT organs: manual.* Ed. Bukhtiyarov I.V., Daikhes N.A. M.: GEOTAR-Media; 2021 (in Russian). https://doi.org/10.33029/9704-6069-6-ENT-2021-1-544
5. Vilk M.F., Pankova V.B., Kaptsov V.A. Transport noise as a risk factor for professional hearing loss (by the example of aviation and railway transport). *Meditsina truda i promyshlennaya ekologiya.* 2017; (9): 36–37 (In Russian)
6. Vilk M.F., Kaskov Yu.N., Kaptsov V.A., Pankova V.B. Dynamics of industrial risk and indicators of occupational morbidity of railway transport workers. *Meditsina truda i ekologiya cheloveka.* 2020; (1): 49–59 (in Russian). https://doi.org/10.24411/2411-3794-2020-10105
7. Kaskov Yu.N., Podkorytov Yu.I. The current state and solution of issues of sanitary and sanitary conditions at railway transport facilities in Russia. *Gigiena i sanitariya.* 2012; 91(5): 37–40 (in Russian).
8. Loginova V.A. Hygienic assessment of working conditions and occupational health risk of employees at railway transport facilities. *Analiz riska zdorov'yu.* 2017; (2): 96–101 (in Russian). https://doi.org/10.21668/health.risk/2017.2.10
9. Koretskaya T.D., Pfaff V.F., Chernov O.E. Occupational morbidity in railway transport. *Meditsina truda i promyshlennaya ekologiya.* 2015; 1(1): 1–5 (in Russian).
10. Pankova V.B., Kashina O.A., Barkhatova O.A., Scriabina L.Yu. *Problems of hearing disorders in civil aviation personnel.* Tezisy dokladov X Vserossijskoj nauchno-prakticheskoj konferencii s mezhdunarodnym uchastiem, posvyashchyonnoj 75-letiyu kafedry aviacionnoj mediciny GBOU DPO RMAPO Minzdrava Rossii. M.; 2014: 141–145 (in Russian).
11. Pankova V.B., Glukhovsky V.D. *Hearing loss among members of the flight professions of civil aviation.* Ed. prof. Vilk M.F. M.: Izdatelskaya Torgovaya Korporatziya «Dashkov and K°»; 2018 (in Russian).
12. Kaskov Yu.N., Loginova V.A., Krivulya S.D. Hygienic assessment of working conditions of workers of locomotive crews. *Zdorov'e naseleniya i sreda obitaniya.* 2017; 2(287): 18–21 (in Russian). https://doi.org/10.35627/2219-5238/2017-287-2-18-21
13. Pankova V.B., Kaptsov V.A., Tavartkiladze G.A., Mukhamedova G.R., Kaskov Yu.N. *Hearing loss in railway transport workers.* Ed. Vilk M.F. Izdatelstvo «Polikart». M.; 2015 (in Russian).
14. *Transport in Russia.* 2020: Statisticheskij sbornik Rosstat. M.; 2020 (in Russian).
15. Bukhtiyarov I.V., Zibarev E.V., Kuryerov N.N., Kimmel O.V. Sanitary and hygienic assessment of working conditions of civil aviation pilots. *Gigiena i sanitariya.* 2021; 100(10): 1084–94 (in Russian). https://doi.org/10.47470/0016-9900-2021-100-10-1084-1094
16. Lopotko A.I., Tsvyleva I.D., Zhuravsky S.G., Thomson V.V. General pathological aspects of damage to hair cells of the spiral organ. *Arhiv patologii.* 2004; (1): 44–50 (in Russian).
17. Tavartkiladze G.A. *Guide to clinical audiology.* M.: Meditsina; 2013 (in Russian).
18. Fedina I.N., Preobrazhenskaya E.A. Features of hearing loss caused by noise in modern conditions. *Meditsina truda i promyshlennaya ekologiya.* 2017; (9): 200 (in Russian).
19. Alves-Pereira M., Castelo Branco N.A. Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signaling. *Prog. Biophys. Mol. Biol.* 2007; 93(1–3): 256–79.
20. Bottger E.C., Schacht J. The mitochondrion: a perpetrator of acquired hearing loss. *Hearing Research.* 2013; 303: 12–19.
21. Izmerov N.F. Bukhtiyarov I.V., Ermakova M.A., Shpagina L.A. Features of the hemostasis system and vascular endothelial growth factors in arterial hypertension in conditions of high occupational risk. *Meditsina truda i promyshlennaya ekologiya.* 2014; (3): 1–6 (in Russian).
22. Kozak-Voloshenko Yu.N., Ovsyanik E.V. The state of cerebral hemodynamics in patients with sensorineural hearing loss of «noise» genesis depending on the length of work in noise. *Rossijskaya otorinolaringologiya.* 2011; 1(50): 89–92 (in Russian).
23. Kunelskaya N.L., Garov E.V., Fedorova O.V., Zelikovich E.I. Degiscence of the upper semicircular canal: diagnosis and treatment. *Vestnik otorinolaringologii.* 2011; (5s): 96–7 (in Russian).
24. Kuleshova M.V., Rusanova D.V., Katamanova E.V., Pankov V.A., Lakhman O.L. Emotional and physiological features of civil aviation flight personnel with sensorineural hearing loss. *Meditsina truda i promyshlennaya ekologiya.* 2017; (1): 14–6 (in Russian).
25. Rukavishnikov V.S., Pankov V.A., Kuleshova M.V. On the theory of sensory conflict under the influence of physical factors: the main provisions and patterns of formation. *Meditsina truda i promyshlennaya ekologiya.* 2015; (4): 1–6 (in Russian).
26. *Occupational pathology: national guidelines.* Ed. Izmerov N.F. M.: GEOTAR-Media; 2011 (in Russian).
27. *Encyclopedia of occupational medicine.* Ed. Izmerov N.F. M.: Meditsina; 2005 (in Russian).
28. Suvorov G.A., Shkarinov L.N., Denisov E.I. *Hygienic regulation of industrial noise and vibrations.* M.: Medicina; 1984 (in Russian).
29. Suvorov G.A., Ermolenko A.E., Loshak A.Ya. *Problems of noise, vibration, ultra- and infrasound in occupational hygiene: scientific review.* Ed. Kovshilo V.E. M.; 1979 (in Russian).
30. Vilk M.F., Pankova V.B., Kaptsov V.A., Bazazyan A.G., Latynin E.O. New occupational risks to the health of transport workers in the conditions of its modernization. *Nauchno-prakticheskij zhurnal «Zapiski uchyonogo» Yuzhnyj universitet «Institut upravleniya, biznesa i prava» (IUBiP) Rostov-na Donu.* 2022; (1): 108–116 (in Russian).
31. *Aviation Medicine Manual.* Ed. prof. Razsolov N.A. M.: Ekon-Inform; 2006 (in Russian).
32. Zinkin V.N., Sheshegov P.M., Slivina L.P. Justification of the choice of personal noise protection equipment for civil aviation engineering specialists. *Bezopasnost truda v promyshlennosti.* 2020; (7): 54-59 (in Russian). https://doi.org/10.24000/0409-2961-2020-7-54-59
33. Sheshegov P.M., Zinkin V.N., Slivina L.P. Aviation noise as a leading factor affecting morbidity and occupational risks in engineering aviation personnel. *Aviakosmicheskaya i ekologicheskaya meditsina.* 2018; 52(3): 62–8 (in Russian). https://doi.org/10.21687/0233-528X-2018-52-3-62-68
34. Bukhtiyarov I.V., Zibarev E.V., Immel O.V. *Scientific substantiation of new criteria for assessing labor intensity among pilots of civil aviation aircraft. Professiya i zdorov'e.* Materialy 16-go Rossijskogo nacionalnogo kongressa s mezhdunarodnym uchastiem. Vladivostok; September 21–24, 2021: 87–91 (in Russian).