



RESEARCH ARTICLE

The content of acoustic signals and biological effects of noise in conditions of high level of work intensity

IRYNA MYSHCHENKO^{1,3}, VASYL NAZARENKO², ANATOLII KOLHANOV¹, MYKHAILO IONDA¹, OLHA MALYSHEVSKA¹, LIDIYA HRECHUKH¹, MYKOLA POHORILY¹, OLEKSANDR NYKYFORUK²

¹ Ivano-Frankivsk National Medical University, Department of Hygiene and Ecology, Ukraine; ² State Institution “Kundiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine”, Laboratory for the Study and Standardization of Physical Factors, Ukraine; ³ Wroclaw University of Science Technology, Department of Geoengineering, Mining and Geology, Accredited Laboratory of Occupational Health and Safety, Poland

Keywords

Auditory perception • Occupational stress • Call centres • Health status • Workplace

Summary

Background. *The biological effects of noise depend on its physical parameters, combination with other hazards, the content of acoustic signals. This article aimed to analyze the difference in biological effects caused by the selection of nonverbal and verbal signals in conditions of a high level of work intensity.*

Methods. *Work conditions, physical characteristics of noise, levels of work intensity were studied among 75 telephone operators and 96 geophone operators. Levels of permanent hearing thresholds, evaluated by pure-tone audiometry, and results of self-estimation of operators' health were compared. The contribution of the content of acoustic signals in the shifting of hearing thresholds was evaluated by the one-way analysis of variance.*

Results. *Selection of acoustic signals in the noise background (< 65 dB), in conditions of high work intensity, causes a signifi-*

cant increase of permanent hearing thresholds in both studied groups comparing to the non-noise exposed population. A combination of the high level of work intensity and distinguishing of nonverbal acoustic messages leads to significant deterioration of health resulting in decreasing of hearing sensitivity and a number of complaints on the state of health ($p < 0.05$). The content of acoustic signals significantly contributes to the biological effects of the noise.

Conclusion. *Obtained results testify necessity to revise safe criteria of noise levels for workers, engaged in selection, recognition and distinguishing of acoustic messages in the noise background combined with a high level of work intensity. In case when the energy of the acoustic field cannot be reduced, occupational safety measures should focus on decreasing of work intensity.*

Introduction

The accepted international standards set a daily noise exposure level at 85 dBA [1, 2] for an 8-hour working day. However, when the job requires signal selection, observation, control and precise work, this threshold should be reduced to 60-65 dBA [3-5]. At the same time, the question about the safety of such levels for human health, peculiarly when work is associated with high levels of work intensity is still under discussion [6]. The conventional approach of rating sound exposure by the principle of energy equivalence can lead to a misleading assessment of their physiological costs [7]. First of all, it concerns professions connected with the selection of speech in the noise background – call centres – [8] or nonverbal acoustic messages – sonar operators of submarines [9, 10] or geophone operators in coal mines [11]. The perception, selection and distinction of speech and nonverbal acoustic signals, transmitted by abstract sound symbols, are significantly different and much more complex in the second case. It happens due to many reasons, including different neural mechanisms of signal processing, higher entropy of abstract acoustic messages compared to speech and difficulty in distinguishing of masking sounds, the need to learn an alphabet of nonverbal signals, and so

on. For example, if part of the message “I was reading a newspaper” was lost, the call centre operator could relatively easily retrieve the phrase by having the rest of it. It is virtually impossible to do the same decoding an abstract message, where signals do not have a logical sequence and hindered by noise with similar physical characteristics. Therefore, sensory loads on the auditory analyzer and higher psychological functions (memory, attention) should be higher in the case of selection and distinction of abstract acoustic messages, manifesting itself in higher hearing thresholds and worsening of physical well-being. Besides, mistakes made while decoding abstract messages can lead to health violations or even the death of other people (professional duties of sonar or geophone operators), which significantly increase job strain, affecting workers' health.

The hypothesis of our study is the following: in conditions of high work intensity, the selection of abstract acoustic signals causes more negative effects than speech distinguishing at the same level of background noise.

This work aimed to perform a comparative analysis of health effects caused by the action of the linguistic and abstract alphabets on the operators engaged in the selection of acoustic signals at the different levels of job strain to optimize their working conditions.

Material and methods

The study group included 75 telephone operators of JSC “Ukrtelecom” (mean age $36.5 \pm 2,3$ ranged from 20 to 59 years) selecting speech and 96 geophone operators of coal mines (mean age 33.2 ± 1.26 years ranged from 19 to 54 years) selecting non-verbal acoustic messages. All the participants were females.

Hygienic assessment of the workplace conditions aimed to measure levels of all possible occupational factors. It included the evaluation of microclimatic parameters, the levels of lighting and noise. The background noise level was measured by a sound meter ВШВ-003-М2 (Russia) according to ISO 9612:2009 [12] at the workplaces of operators. The levels of noise in the headsets of telephone operators were measured by the means of an ‘artificial ear’ (type 4152, Denmark) which has an acoustic impedance, corresponding to the physical characteristics of a human ear.

Physiological measurements consisted of the evaluation of the levels of permanent hearing thresholds (PHTs) by the method of pure-tone audiometry by the means of an audiometer MA-31 in the conventional range of test frequencies (125-8.000 Hz) using the ascending-descending technique in 5 dB step separately for the left and the right ear. Measured hearing thresholds compared to levels of non-noise exposed population of the same mean age according to ISO 7029:2017 [13].

The *level of job strain* in both studied groups was assessed by the evaluation of the Occupational Stress Index (OSI) [14] and the level of work intensity according to the Ukrainian Hygienic Classification of Work [15]. OSI is a questionnaire, adopted by SI “Kundiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine”. Arranged as a two-dimensional matrix, it represents four levels of informational transmission (input, general decision making, output/task performance, general) placed according to the vertical axis and seven stressor aspects (underload, high demand, strictness, extrinsic time pressure, exposure, symbolic aversiveness, conflict/uncertainty), composed along with the horizontal one. All the elements were equally weighted, scored from 0 (“not present”) to 2 (“strongly present”) and summed. Each participant completed the questionnaire. Being a normative document, the Hygienic classification of work comprises the following indexes of work intensity: intellectual, sensory, emotional loads, the monotony of work, labour regime. Obtained class of work conditions reflects the level of work intensity and predicts possible health deteriorations.

All the participants completed the *health-related questionnaire* “Self-assessment of health” suggested by the National Institute of Gerontology (Ukraine) [16], containing 29 questions about lifestyle and well-being. The total score was calculated for each participant according to the scale “Healthy-Unhealthy” (from 0 to 29 points).

A personalized database was statistically processed using the office suite “EXCEL 2017”. Mean values and

standard deviations were calculated for all measured parameters. Comparative analysis between studied groups was done by Student’s t-test. Correlation analysis was done between individual values of OSI and score in the test “Self-assessment of health” (Spearman’s rank correlation). The one-way analysis of variance (ANOVA) was used to identify the contribution of the independent variable (the content of acoustic signals) in the level of the PHTs. The significance level used for all the tests and the correlations was $p < 0.05$.

ETHICS APPROVAL

The research complied with the standards and recommendations for biomedical research involving human subjects adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964 and the 59th Meeting, Seoul, 2008. Informed written consent was obtained from each subject before enrollment with approval by the Ethics Committee of State Institution “Kundiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine”.

Results

GENERAL ASSESSMENT OF WORK CONDITIONS AND A LEVEL OF JOB STRAIN IN THE STUDIED GROUPS

Both telephone and geophone operators are engaged in active listening of acoustic signals in the noise background and have similar work conditions. Telephone operators use single-ear headsets for communication. 95% of studied participants prefer putting it on the left ear. Thus, one ear is listening to speech (subscriber conversation, dialling operation), whereas another one is exposed to the noise background from the office (conversations of the other operators). The headsets are connected to a volume control facility so an operator can easily adjust the loudness. The work of telephone operators includes the high number of acoustic and visual signals (175-300 per an hour) and loads on vocal apparatus (15-40% of work shift). Additional sources of electromagnetic fields are video terminal units, phones, headsets. The levels of the magnetic induction of 50 Hz at the workplaces do not exceed permissible ones.

Geophone operators are involved in microseismic monitoring, serving deep coal mines prone to a sudden outburst. A workplace of an operator is a 13-15 m² office, equipped with a computer, acoustic speakers, register, telephone. These operators distinguish seismoacoustic information, consisting of nearly 40 patterns, including relevant signals (impulses of acoustic emission), masking signals (noise made by cutting machines, rock-drillers, downhole tractors). Geophone operators analyse the information in real-time due to the prediction of a sudden methane/rock/coal outburst and bear criminal responsibility for the wrong prognosis of the seismic situation in the coal mine. Using personal computers primarily for switching acoustic channels, geophone operators do not have additional visual loads, but the

Tab. I. Parameters of the working environment at the workplaces of telephone and geophone operators.

Parameters of the working environment	Average level at the workplace of		Normative value
	Telephone operators	Geophone operators	
Microclimatic conditions			
Average temperature, °C	25.7 ± 0.20	24 ± 0.6	21-23*
Relative humidity, %	24.3 ± 0.05	45	40-60*
Air velocity, m/s	0.02 ± 0.01	0.06 ± 0.1	< 0.1*
Equivalent noise level, dBA	65.1 ± 0.2	59.6 ± 0.93	65*
Equivalent sound pressure level in headsets, dBA	91.3 ± 1.3	-	85**
Characteristics of the noise	Continuous	Continuous	
Characteristics of the signals' alphabet	Linguistic	Abstract	
Density of signals per hour	175-300	> 300	

* Normative values according to the national sanitary norms: ДЧН 3.3.2.007-98; ** Upper exposure action value established by European Union Directive 2003/10/EC [1].

density of acoustic signals is extremely high (more than 300 per hour).

The characteristics of microclimatic conditions and the noise at the workplaces of telephone and geophone operators are shown in Table I.

Hygienic assessment of work conditions revealed that the average temperature exceeded the standard value at the workplaces of both studied groups, whereas the level of relative humidity was significantly lower than the permissible one at the workplaces of telephone operators. Our measurements confirmed the operators' responses because 30,9% of respondents in this study group reported microclimate to be an uncomfortable parameter of the working environment.

Noise level, listening by geophone operators and that one present in the offices of telephone operators corresponded to the national hygienic standards (< 65 dBA). Noise at the studied workplaces is continuous with an energy peak in the low-frequency range. The noise level in headsets of telephone operators exceeded the Upper Exposure Action Value, established by the European Union Directive 2003/10/EC. It ranged from 88 to 104 dB being on average 91.3 ± 1.3 dBA and forming the main acoustic load on the auditory analyzer.

LEVEL OF JOB STRAIN

The assessment, according to Ukrainian Standard "Hygienic classification of work..." [15], has revealed that the labour process of studied groups belongs to harmful work conditions by the indexes of work intensity (degree 3.1 in telephone and 3.3 in geophone

operators). In other words, degree 3.1 means that levels of harmful factors and the work process itself can cause functional changes beyond the limits of physiological fluctuations and increase the risk of health deterioration, including occupational diseases. Degree 3.3 assumes such levels of harmful factors of the production environment and work process, which increase chronic morbidity (conditionally caused and the incidence with a temporary disability), lead to the development of occupational diseases.

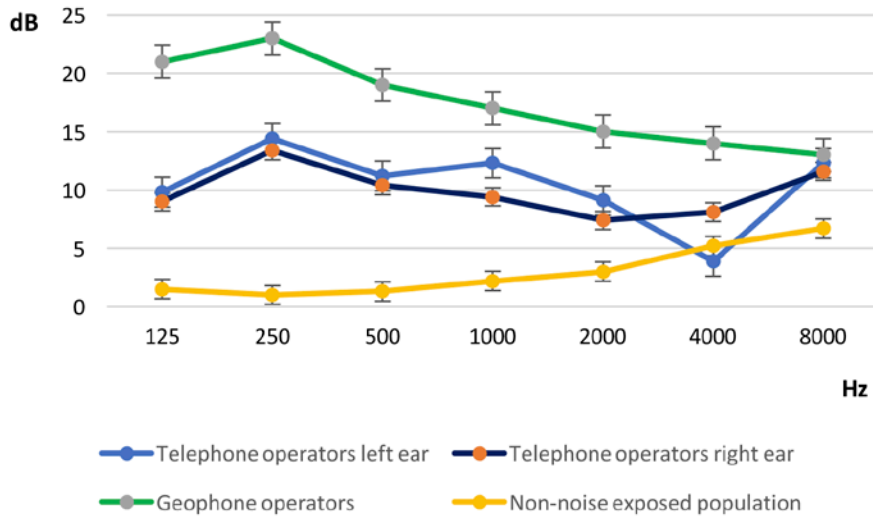
Analysis of job strain level by the OSI score has shown that the group of geophone operators had approximately twice a total OSI score compared to those of telephone operators and a significantly higher level of job strain according to the majority of dimensions aspects (Tab. II). Considering such a high level of OSI in the group of geophone operators, we conducted additional questioning which revealed the following list of work activities and tasks regarded as difficult ones (in decreasing order):

- the necessity of constant attention;
- continual readiness to the action (explosion risk);
- criminal responsibility for the lives of other people;
- long work hours;
- absence of breaks;
- night work shifts;
- distinguishing of acoustic signals in the noise background;
- classification of acoustic signals;
- sedentary work;
- monotony of work.

Tab. II. Mean OSI score and stress dimensions aspects of the OSI for the studied groups.

Occupational Stress Index determinants	Geophone operators (mean +/- SD)	Telephone operators (mean +/- SD)	Level of significance, p <
Underload	13.8 ± 1.3	10.6 ± 0.9	-
High demands	21.2 ± 1.2	16.4 ± 1.3	0.007
Strictness	13.1 ± 1.2	6.7 ± 0.6	0.000004
Extrinsic time pressure	6.9 ± 0.4	2.3 ± 0.3	0.000001
Exposures	2.0 ± 0.7	3.0 ± 0.8	-
Symbolic aversiveness	10.4 ± 1.5	2.6 ± 0.3	0.000001
Conflict/uncertainty	9.6 ± 1.6	3.4 ± 0.8	0.00067
Total OSI score	77.3 ± 2.2	35.4 ± 3.5	0.000001

Fig. 1. Levels of PHT in telephone and geophone operators compared to a non-noise exposed population.



PERMANENT HEARING THRESHOLDS

Comparative analysis of PHTs conducted in the conventional range of frequencies (Fig. 1) evidenced that there was no significant difference between the levels of PHTs of right and left ear in geophone operators whereas hearing sensitivity in telephone operators depended on the ear and in most of the cases was worse in the left ear as they preferred putting a headset on it.

Considering Figure 1, at least three specific characteristics, contradicting the energy concept of noise, mentioned:

1. although background noise levels at the workplaces of both study groups corresponded to permissible levels, the PHTs were quite high, exceeding levels of non-noise exposed population of the same mean age according to ISO 7029:2017 [13];
2. PHTs of geophone operators were significantly higher even though the noise level in headsets of telephone operators was greater;
3. in both study groups hearing sensitivity was worse in the range of low frequencies, which contradicts the theory that hearing loss starts in the high-frequency range.

SELF-ESTIMATION OF HEALTH (SEH)

The questionnaire revealed that the mean score in the group of telephone operators was 10.5 ± 0.8 and 13.4 ± 1.18 out of 29 in the group of geophone operators ($p < 0.05$). Data analysis showed that the number of subjective complaints on the state of health increased with length of employment. For instance, 81.2% of geophone operators employed up to 1 year felt rested after a night sleep, whereas the number of workers employed more than 5 years affirming the same was only 33.3%. The distribution of complaints of the state of health in both groups has shown in Table III.

A strong positive correlation between total OSI score and score in the “Self-estimation of health” questionnaire

at the level 0.74 ($p < 0.01$) in the group of coal mine operators and 0.66 ($p < 0.01$) in the group of telephone operators confirms the point of view about the negative influence of job strain on health.

Tab. III. Subjective complaints of operators according to the “Self-estimation of health” questionnaire.

Self-reported health disturbances	Number of complaints		Difference between the study groups, p<
	Telephone operators N (%)	Geophone operators N (%)	
Mental health/ Nervous system			
Sleep loss due to nervousness	53 (70.6)	88 (91.6)	0.0001
Frequent headaches	45 (60)	72 (75)	0.00183
Sudden awake due to unessential noise	36 (48)	72 (75)	0.0001
Dizziness	42 (56)	60 (62.5)	-
Musculoskeletal system			
Spine pain	45 (60)	71 (73.9)	0.0264
Pain in the joints	36 (48)	48 (50)	-
Sensory organs			
Visual deterioration	55 (64)	40 (41.6)	0.01
Impairment of hearing	27 (36)	32 (33.3)	-
Tinnitus	24 (32)	32 (33.3)	-
General complaints			
Walking dyspnea	43 (57)	49 (51)	-
Edemas on the legs	49 (65.3)	66 (68.8)	-
Weather sensitivity	51 (68)	72 (75)	-
Intestinal obstruction	35 (46.6)	40 (41.6)	-
Heart pain	34 (45.3)	48 (50)	-
Bad aftertaste in the mouth	17 (22.6)	32 (33.3)	-
Liver pains	21 (28)	29 (30.2)	-

As can be seen from the obtained results, negative biological effects increase at the combined influence of low-intensity noise and a high level of work intensity. It is possible to suggest the following: the more intensive work is, and the highest entropy (uncertainty) of the acoustic field takes place, the more negative physiological response will be. One-way analysis of the variance allowed us to conclude that the independent variable (the content of acoustic signals) significantly contributes to the levels of PHTs ($p < 0.001$) at the frequencies 125, 250, 500 and 1,000 Hz and $p < 0.01$ at 4,000 Hz.

Discussion

The primary aim of this article was to answer the question if the content of acoustic signals contributes to the biological effects of noise in conditions of a high level of job strain. At first glance, the work conditions of both studied groups characterizing by the combination of a high level of job strain and selection of relevant acoustic signals in the noise background are unique. But low-intensity noise itself is a widely spread factor in modern offices [17]. It is interesting to note that according to Cohen S, the uncontrollability of sound rather than its intensity causes stress in workers [18]. Glass D. and Singer J. mentioned that reducing noise intensity from 108 to 56 dB, did not cause any ameliorative effects [19]. Moreover, the unpredictability and uncontrollability of sound (noise entropy) influenced the most on work efficiency. The authors emphasized that the magnitude of adverse aftereffects was greater following unpredictable noise. Our previous study concerning the contribution of noise dose and entropy in nonspecific physiological response among rolling-mill operators revealed that adverse health effects increased when both noise dose and entropy were at the upper level of variation [20]. Entropy or uncertainty of the acoustic field had a significant impact on indexes of the cardiovascular system, attention, information perception.

In the mentioned above studies acoustic field is considered an unwished component of work rather than the essential source of information. In the case of acoustic operators, distinguishing linguistic or abstract signals in the noise background might cause additional changes in an auditory analyzer. This suggestion is affirmed by the levels of PHT in studied groups which significantly exceeded population standard (Fig. 1).

Obtained results concerning PHT of telephone operators confirm recent studies [21-24]. Many participants underlined the necessity to increase loudness in their headsets due to the high level of noise background in the office or too quiet speech of callers. However, 95% of telephone operators had normal hearing (PHTs in the range $0.25\text{-}8\text{ kHz} \leq 20\text{ dB}$ for both ears).

Instead, the highest levels of PHT in geophone operators selecting abstract acoustic signals in the noise background less than 65 dB align with the theory, that the biological effect of noise is not only in its energy but in

the content of listened information. For instance, Strasser H. and others showed that listening to the different kinds of music (house music, European and Chinese classical music) with the mean level 94 dBA within an hour, causes different physiological responses [25]. They found house music characterizing by rhythm, percussion, and a medley to cause significantly longer restitution period and higher accumulated hearing thresholds shifts. Moreover, the simple arithmetic averaging of decibels used in the energy concept of noise tends to underestimation of the physiological impact of noise, especially in terms of continuous noise [26]. It is necessary to underline that the energy of acoustic oscillations listened to by the geophone operators distributes unevenly on the frequency band. It happens because coal and rock layers extinguish the high-frequency waves so that operators listen to the noise with a peak in the low-frequency range from 20 to 1,500 Hz where PTHs were maximum. Another reason seems to be in the signal to noise ratio (SNR), defined as the target stimulus power compared to the noise background power measured in dB. Being one of the most effective physical characteristics of speech perception in the noise, SNR is applicable for the distinguishing of abstract acoustic signals in the noise background. The alphabet of relevant signals, listening by geophone operators, comprises around 40 items. Following the normative document for coal-mines seismoacoustic services, the coefficient of information load depends on the number of acoustic signatures and on the difficulty of their distinguishing from the impulse of acoustic emission. The last one has the lowest score while rock sloughing the highest, masking the impulse of acoustic emission, making distinguishing more difficult and contributing to the auditory fatigue.

In the occupational conditions of acoustic operators, auditory fatigue, accompanied by a significant level of job stress, intensifies adverse health effects. Venet T. concluded that normal levels of noise, combined with emotional strain, caused increasing of hearing thresholds by the end of the work shift [27] in call dispatchers. This auditory fatigue intensifies by cognitive fatigue, emotional exhaustion due to the heavy mental workloads. The total score of OSI in both groups of acoustic operators was quite high. In a group of geophone operators, it was two times more than those in telephone operators. Table II shows that the main aspect contributing to OSI in both study groups is "High demand". It includes such elements as the presence of several info sources, high frequency of upcoming signals, decisions affect the work of others, rapid decision making, etc. The mean score on every studied aspect apart from "Exposure" was significantly more in the group of geophone operators. Job strain, being the main adverse factor, is primarily formed by sensory acoustic loads. It is also necessary to point out an extremely high score of "symbolic-aversiveness" or "treat-avoidance" among geophone operators. According to the literature [14], this aspect does not belong to the sociological work-stress models. Because our nervous system focuses on threatening stimuli, it should be ready for rapid response

in conditions of possibly fatal consequences (methane outburst, death of coal miners). It causes an additional load on the nervous system of geophone operators resulting in more negative health outcomes.

Most of the acoustic operators complained about sleeping difficulty due to nervousness (91.6% of geophone and 70.6% of telephone operators) or sudden awake in the night (75 and 48% correspondingly). Similar disturbances of circadian rhythms in acoustic operators were noticed by Raja JD et al. Studying sleep quality in 375 call centre operators, he reported 77.6% of respondents having insomnia or other sleep-related problems [28]. Headache and dizziness were other frequently encountered health problems, comparable with literature data [29]. It is possible to suggest that such reactions of the nervous system are caused by specific occupational factors i.e. necessity to handle stress, long work shift, night shifts, high density of signals, time pressure ecc.

We also noticed a high amount of musculoskeletal problems such as spine pain and pain in the joints, reported in both study groups, which possibly related to sedentary work within 12 hours which contributes significantly to the physical discomfort of operators [30]. A great number of acoustic operators reporting about oedema on the legs (68.8% of geophone and 65.3% of telephone operators) confirms this point of view. Nearly every other acoustic operator reported eye-related problems which possibly caused by the necessity to work with VDUs and the high density of visual signals.

Conclusions

A combination of job strain and low-intensity noise at the workplaces of acoustic operators has different biological effects. The most adverse health consequences were found in geophone operators, distinguishing abstract acoustic signals at a significantly higher level of job strain than the telephone operators. PHTs were found to be higher comparing to the non-noise exposed population despite levels of noise that corresponded to hygienic standards. The fact, that combination of job strain and low-intensity noise can cause worsening of hearing sensitivity and general well-being of operators contradicts the energy concept of noise. It requires revision of safe levels of acoustic irritant depending on the level of job strain. Considering that levels of noise at the studied workplaces are low enough, their decreasing is not acceptable because an acoustic signal might have sufficient intensity for the distinguishing. Instead, the level of job strain requires elimination.

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Conflict of interest statement

The authors declare no conflict of interest.

Authors' contributions

IM, VN, AK were involved in the experimental design, OM, MP, LH, MI and ON performed the measuring of physical factors at the workplaces and evaluated the OSI level. IM, VN assessed PHTs in study groups and measured noise levels in headsets of telephone operators by artificial ear. IM, VN, AK, OM, LH analyzed the data. IM, VN, AK wrote and edited the paper. All authors have read and approved the final version of the manuscript.

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Correspondence: Iryna Myshchenko, Biology, 91a Fedkovicha St., Ivano-Frankivsk, 76008 Ukraine - Tel.: +380676205356 - E-mail: kolg.ira21@gmail.com

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