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ORIGINAL PAPER

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DIRECTIVITY OF HEARING OF AUDITORY DANGER SIGNAL EMITTED BY OVERHEAD CRANE

KIERUNKOWOŚĆ SŁYSZENIA DŹWIĘKOWEGO SYGNAŁU BEZPIECZEŃSTWA EMITOWANEGO PRZEZ SUWNICĘ

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Abstract

Background: The objective of the research has been to provide an answer to the question of what the possibilities of determining the direction of approach of the auditory danger signal emitted by an overhead crane appropriately are. Cases of use and no use of earmuffs (in the passive mode and level-dependent ones) were all taken into consideration. **Material and Methods:** The auditory danger signal and ambient noise were recorded in an industrial hall. Signals were reproduced at an experimental set-up, using a large number of speakers. Eight speakers for reproduction of the auditory danger signal were placed above a subject's head. The study participants would indicate the direction from which, according to them, the auditory danger signal was being emitted. **Results:** The average percentage rate of the correct localization amounted to 75.8% when the overhead crane's signal wasn't masked. The presence of ambient noise caused a reduction of the number of correctly identified localization to 66.6%. The use of earmuffs in the passive mode resulted in the worst results (44.5%). There is some improvement when level-dependent earmuffs are used (57.3%). **Conclusions:** In situations where it is important to identify the direction from which the auditory danger signal generated by the crane's signaling device is approaching, it is beneficial to use level-dependent earmuffs rather than earmuffs in the passive mode. Correct identification of whether the auditory danger signal generated by the crane's signaling device is approaching from the left or right side is almost perfect, however correct identification of whether the signal is approaching from the front or back of a person is not always possible. Med Pr 2016;67(5):589–597

Key words: auditory danger signal, localization, directivity of hearing, hearing protectors, overhead crane, earmuffs

Streszczenie

Wstęp: Celem pracy było zbadanie kierunkowości słyszenia dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę z zastosowaniem nauszników przeciwhałasowych pasywnych i nauszników z włączonym elektronicznym układem regulowanego tłumienia oraz bez ich użycia w warunkach akustycznych odpowiadających środowisku pracy. **Materiał i metody:** Przeprowadzono pomiary parametrów i rejestrację dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę i hałasu tła w potencjalnym miejscu przebywania pracowników w hali produkcyjnej. Nagrany sygnał odtwarzano na stanowisku badawczym z użyciem dużej liczby głośników, z których 8 było umieszczonych powyżej głowy badanego. Kierunek odtwarzania sygnału wybierano losowo. Badani wskazywali kierunek, z którego według nich wyemitowano dźwiękowy sygnał bezpieczeństwa. **Wyniki:** Kiedy sygnał suwnicy nie był maskowany hałasem tła, odsetek poprawnie rozpoznanego kierunku nadejścia sygnału przez badanych wynosił 75,8%. Natomiast hałas tła obniżał odsetek poprawnych odpowiedzi do 66,6%. Przyczyną najgorszych wyników (44,5%) było stosowanie nauszników przeciwhałasowych pasywnych. Poprawa (57,3%) następuje w przypadku stosowania nauszników przeciwhałasowych z regulowanym tłumieniem. **Wnioski:** Kiedy istotne jest rozpoznawanie kierunku, z którego dochodzi dźwiękowy sygnał bezpieczeństwa wytwarzany przez sygnalizator suwnicy, korzystniejsze jest stosowanie nauszników przeciwhałasowych z regulowanym tłumieniem niż nauszników pasywnych. Badani prawie zawsze bezbłędnie lokalizowali sygnał dochodzący z lewej lub prawej strony, natomiast poprawne rozpoznanie, czy sygnał dochodzi z przodu, czy z tyłu, nie zawsze było możliwe. Med. Pr. 2016;67(5):589–597

Słowa kluczowe: dźwiękowy sygnał bezpieczeństwa, lokalizacja, kierunkowość słyszenia, ochronniki słuchu, suwnica, nauszniki przeciwhałasowe

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INTRODUCTION

The safe performance of work is conditioned by, among other things, the capability of hearing and correctly interpreting the auditory danger signal emitted by the signaling device of objects in motion. The auditory danger signal should be effectively received even in the presence of a high level of noise [1]. Moving objects in the work environment at industrial halls, where noise is generated, among others include overhead cranes used for transporting loads over small distances. Crane operation entails the hazard of detachment of the transported load from the hook or gripper, crushing persons found near the overhead crane as a consequence. Thus, reception of the auditory danger signal and appropriate reaction to the signal received, i.e., departure from the area which the crane is approaching, are both important. Such reaction can be faster when the direction from which the auditory danger signal is approaching is correctly identified.

The presence of workers in industrial halls where overhead cranes operate is usually linked to the exposure of persons to noise and, in a significant number of cases, also to the need for these persons to use hearing protectors. Such conditions may reduce the capabilities of receiving an auditory danger signal [1–5].

Hearing protectors are often used in the work environment. Level-dependent earmuffs represent one of the types of hearing protectors, besides passive protectors. Such earmuffs serve the purpose of improving the user's ability to communicate verbally. The sound reproduction function is performed by an electronic system that carries sounds at frequencies within the speech range from the environment into the earmuffs' cup [6].

In a study dedicated to the evaluation of hearing protectors in the context of audibility of signals in mining [7], it was determined, among other things, that the limitation of useful sounds along with the noise itself should be considered to be a disadvantage of passive hearing protectors. Passive protectors limit the ability to communicate with co-workers and also reduce the ability to hear the alarm and other sound warnings. Thus, reduced audibility of useful signals not only results in limitations of effective verbal communication but it may also contribute to deterioration of the safety of working conditions. In the above cited publication [7], attention was also paid to the fact that the ability to perceive useful sounds is further limited by the presence of noise (the masking effect occurs), which disrupts the ability to perceive the sounds of speech and other important sound signals. The authors of the above cited work [7] took the use of level-dependent hearing protectors into consideration. They indicate that the use of such protectors improves the audibility of certain sounds while also preserving hearing protection against hazardous noise.

However, the reported effects of using hearing protectors equipped with an electronic sound reproduction system are ambiguous and depend heavily on the conditions under which these devices are used. The results of evaluation of three different hearing protectors with the sound reproduction function in the case of users with hearing impairment have indicated that their use in the presence of industrial noise does not cause a loss of the ability to comprehend speech [8]. A comparison of verbal communication conditions in the case of use of earplugs with a filter and in the case of level-dependent earplugs was to the benefit of earplugs without electronic systems [9]. On the other hand, the use of earmuffs with electronic systems supporting the transmission of speech in a noisy environment was an improvement as compared to no use of hearing protectors [10].

When tested in the presence of signals accompanying to the work of a miner, level-dependent earmuffs did not manifest any clear advantage as compared to passive hearing protectors [7]. In turn, in the context of sound localization, it was stated that the use of hearing protectors with electronic systems by persons with normal hearing did not improve the ability to identify the direction of sound approach in comparison to passive hearing protectors, besides specific exceptions [11].

In relation to the ambiguous results of assessment of the perception of useful signals in the work environment discussed above, the objective of the studies presented in this article has been to provide an answer to the question of what the possibilities of determining the localization of the auditory danger signal emitted by an overhead crane under acoustic conditions corresponding to those of the work environment appropriately are.

MATERIAL AND METHODS

The problem presented in this article was analyzed using the example of a situation that takes place in an industrial hall where an overhead crane transporting a load is in motion. Achieving the objective of this study required registration of sound signals in an industrial hall and measurement of these signals' parameters. Next, the work environment under observation was represented in acoustic terms on an experimental set-up in laboratory conditions, with a multi-speaker system used. In this system, the crane's auditory danger signal was played back from randomly selected directions. Tests in the virtual work environment prepared in this fashion were performed with the involvement of subjects. Each of them was to indicate the direction of approach of the test signal.

In the study, cases where hearing protectors were not used and where earmuffs were used were all taken into consideration. The use of level-dependent earmuffs was considered. Studies were also conducted for the cases of using earmuffs in the passive mode, i.e., when the sound reproduction system was switched off. This mode is equivalent to the use of traditional earmuffs that are not equipped with an electronic system.

Matlab R2016a (version 9.0) with Statistics and Machine Learning Toolbox was used to perform all statistical analyses.

Sound signals used in tests

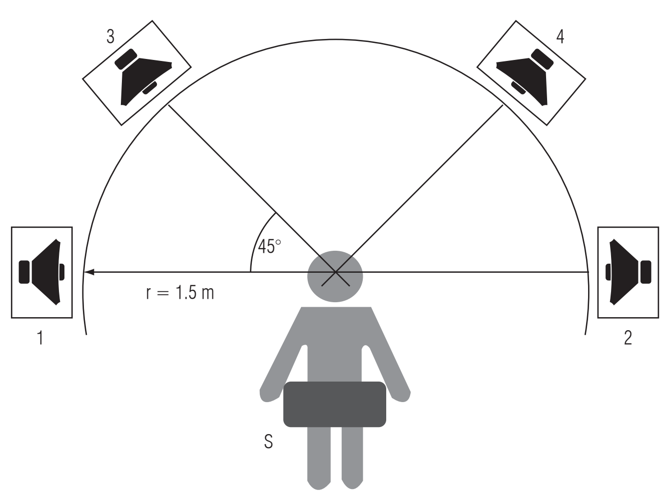
Assessment of the localization of the auditory danger signal was conducted for the sound signal emitted by the signaling device of an overhead crane transporting a load in an industrial hall. For the purpose of reproducing the acoustic conditions present in the work environment subject to analysis on an experimental set-up under laboratory conditions, the auditory danger signal and ambient noise were registered at a location potentially occupied by workers in the industrial hall. It was assumed that the most unfavorable situation would be accounted for in studies, i.e., the noise registered in the area where the A-weighted equivalent sound pressure level of this noise was greatest, amounting to 89.8 dB, would be selected. At the same time, the sound pressure level in octave bands of signals registered in the production hall was measured. The results of measurements were later used to adjust the sound pressure level of test signals on the experimental set-up. Registrations and measurements of sound signal parameters were performed using a Brüel & Kjær 4190 (1/2″) microphone along with a Brüel & Kjær 2669 microphone preamplifier and a Brüel & Kjær PULSE measurement unit (Brüel & Kjær, Denmark).

Experimental set-up

In the past, studies in which the localization of the auditory danger signal was assessed were mostly carried out in reference to a vehicle backup alarm [11]. These studies would be conducted in a measuring system in which the subject was surrounded by multiple speakers. A system consisting of a large number of speaker sets was also used in this study, however the 8 speaker sets serving the purpose of reproducing the auditory danger signal were placed above the person's head. Such a location of the speaker sets was chosen for the purpose of representing the situation where the sound generated by the crane's signaling device approaches a worker from above.

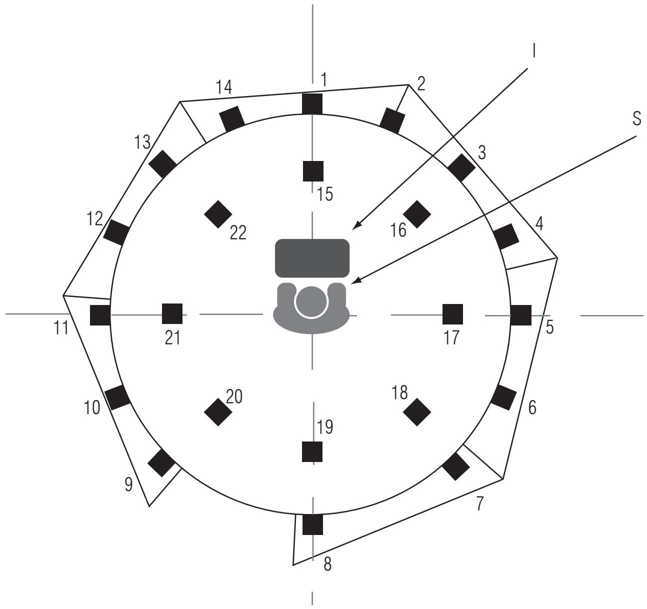
The sound signal reproduction channel consists of the following elements:
- a computer with a MOTU PCI-424 card (MOTU, USA),
- a MOTU 24 I/O audio interface (MOTU, USA),
- 14 speaker sets (M-Audio, USA) used for reproducing ambient noise, placed around the listener's seat, on a circle with 1.5 m radius, at head level (Figure 1 and 2),
- 8 speaker sets (M-Audio, USA) used for reproducing auditory danger signals, placed above the head of the study participant, so that the distance from the head to the speaker was 1.5 m (Figure 1 and 2).

The experimental set-up developed for conducting the study of the localization of the auditory danger signal emitted by an overhead crane also includes



S – the subject / badany, r – distance from the subject to the speaker set / odległość od badanego do zestawu głośnikowego.
1, 2 – speaker sets situated at the subject's head level / zestawy głośnikowe umieszczone na poziomie głowy badanego, 3, 4 – speaker sets situated above the subject's head / zestawy głośnikowe umieszczone powyżej głowy badanego.

Fig. 1. Arrangement of speaker sets (vertical section) during the examination of directivity of hearing of the auditory danger signal emitted by an overhead crane reproduced at the experimental set-up
Ryc. 1. Rozmieszczenie zestawów głośnikowych (przekrój pionowy) podczas badania kierunkowości słyszenia dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę, odtwarzanego na stanowisku badawczym



I – the interface for acquisition of responses of the subject / interfejs do udzielania odpowiedzi przez badanego.
S – the subject / badany.
1–14 – speaker sets situated at the subject's head level / zestawy głośnikowe umieszczone na poziomie głowy badanego, 15–22 – speaker sets situated above the subject's head / zestawy głośnikowe umieszczone powyżej głowy badanego.

Fig. 2. Arrangement of speaker sets (view from the top) during the examination of directivity of hearing of the auditory danger signal emitted by an overhead crane, reproduced at the experimental set-up
Ryc. 2. Rozmieszczenie zestawów głośnikowych (widok z góry) podczas badania kierunkowości słyszenia dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę, odtwarzanego na stanowisku badawczym

the interface enabling acquisition of responses given by the subject along with a multi-channel speaker system for reproducing sound signals. This interface consists of a panel with buttons, the geometric arrangement of which represents the positions of speaker sets reproducing auditory danger signals. The location of the interface on the experimental set-up is presented in the Figure 2.

Signal amplification in the channels for auditory danger signal and ambient noise reproduction was corrected so as to obtain values of sound pressure level in octave bands and A-weighted equivalent sound pressure level equal to the values measured at the industrial hall at head level of subjects. This was for the purpose of achieving test conditions that would most faithfully represent actual conditions. The sound pressure level in octave bands of the ambient noise and auditory danger signal reproduced at the experimental set-up are presented in the Figure 3. The values presented in the Figure 3 indicate that in the octave bands in which the auditory danger signal produced by the overhead crane has the dominant character, the sound pressure level of this signal exceeds the level of ambient noise 1.3 dB and 2.7 dB, respectively for 1 kHz and 2 kHz. The A-weighted equivalent sound pressure level of ambient noise was 89.8 dB. In the case of the auditory danger signal it was 90.7 dB. Measurements of sound pressure level at the experimental set-up were conducted using a SVAN 945 sound meter (Svantek, Poland).

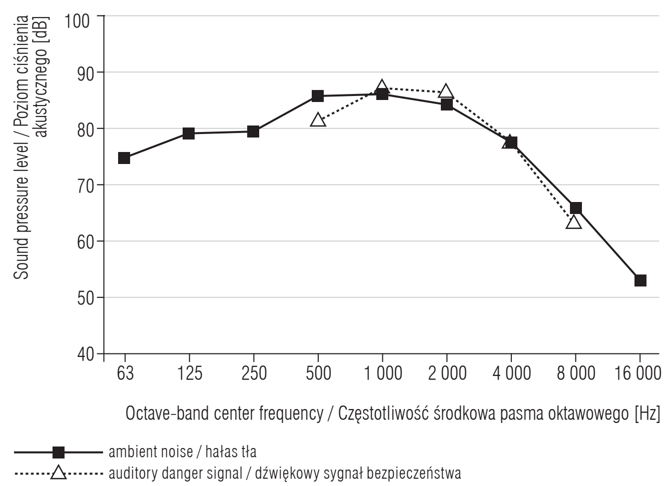


Fig. 3. Octave-band sound pressure level of the ambient noise and auditory danger signal emitted by an overhead crane reproduced at the experimental set-up
Ryc. 3. Poziom ciśnienia akustycznego w pasmach oktawowych w przypadku hałasu tła i dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę, odtwarzanego na stanowisku badawczym

Measurements conditions

Four cases of measurement were accounted for in tests. In 3 cases, the localization of the auditory danger signal of the overhead crane was tested when ambient noise was simultaneously reproduced. The difference between these 3 cases was that the subjects either did not use hearing protectors or used level-dependent earmuffs (i.e., with an active electronic system) or used those in the passive mode. Level-dependent earmuffs transmit ambient sounds at frequencies within the speech band to the ears of the hearing protectors' user. In this way, auditory danger signal, the dominant components of which are within the speech band, is also transmitted under the cups. In consequence, the sound pressure level connected to the auditory danger signal has a relatively higher value when a person wearing level-dependent earmuffs is compared to the situation in which passive earmuffs are worn. The fourth measurement situation covered the assessment of the localization without background noise and without the use of hearing protectors.

The auditory danger signal was reproduced by 8 speaker sets situated above the subjects's head during each of the 4 aforementioned measurement situations. The test signal was emitted 3 times from every direction, which means that a single measurement situation covered 24 reproductions of the auditory danger signal. The sequence of the test signal's appearance in each of the 8 speaker sets was determined at random. Over the course of the experiment, the study participant indicated the direction from which, according to them, the auditory danger signal was emitted. The response was indicated by pressing the appropriate button on a panel placed directly in front of the subject.

Studies were conducted in the participation of 20 normal-hearing persons (10 women and 10 men) with hearing threshold level (as determined for each ear) no greater than 15 dB for frequencies within the range of 125 Hz – 8 kHz. The age of people participated in this study ranged 21–25 years.

A-weighted noise exposure level normalized to an 8 h working day of the signals used during tests did not exceed 75 dB. Therefore, participation in the studies was not fraught with the risk of hearing damage. Studies were conducted after obtaining the consent from the Ethics and Bioethics Committee.

Commonly available Peltor LiteCom III earmuffs (3M, USA) were used.

Ways of analysis

The analysis of the localization of the auditory danger signal generated by an overhead crane was conducted in 2 ways, allowing greater and lesser accuracy of indication of the signal's direction of approach. In the first method of analysis, the number of correct responses given by each subject was counted, under the assumption that indicating the precise direction from which the crane's signal was reproduced would be considered a correct response. For 8 directions of signal reproduction available for identification, the resolution of obtained responses amounts to 45°.

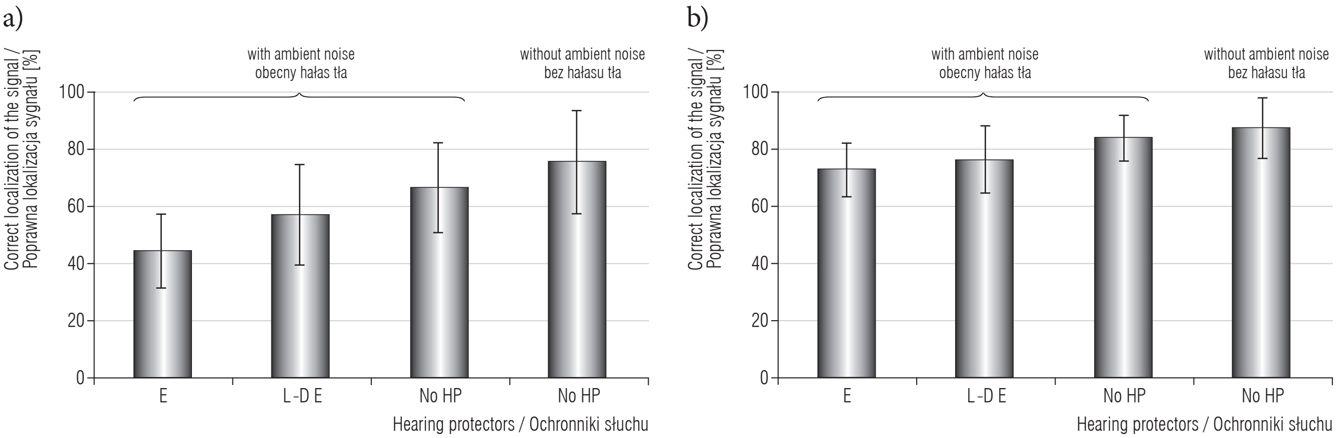
In the second method of analysis, indicating any of the 2 neighboring directions, not only indicating the exact direction from which the crane's signal was reproduced, would be considered a correct response. Such analysis seems to be of practical significance. Detection of a hazard by a worker in a specific sector, with accuracy lower than in the first method of analysis (the resolution of obtained results equals to 90°) should also allow the worker to react appropriately to the received warning.

In the assessment of the correct localization, it is also important whether a useful signal is approaching from the front or back of a person and whether this signal is approaching from the left or right side of a person. In this study, such cases were also analyzed because an error resulting in indication of a direction at the extreme opposite of the direction from which the emitted sound signal is approaching may lead to situations endangering the safety of workers. In the case of front-rear analysis, a person's response was considered to be correct if the person responded that the signal was approaching from the front in the case where the signal was actually reproduced from the direction in front of the person (the speaker set number 15 in the Figure 2) or from one of the neighboring directions (directions designated by the speaker set numbers 22, 15 and 16). The same scheme of analysis was applied in the case of crane signals reproduced from a person's rear, as well as in the case of left-right analysis.

RESULTS

The results of the first and second method of analysis, with the application of a percentage rate, are given in the Figure 4. In the case of the first method of analysis, the average percentage rate of correct responses stood at 75.8% without the ambient noise. In the presence of ambient noise the percentage rate of correct responses was within the range of 44.5–66.6%, depending on whether earmuffs were used or were not used. The second method of analysis showed higher values of the percentage rates of correct responses. Without ambient noise it was 87.2% while the presence of ambient noise resulted in values from 72.8% to 83.7%.

Results of the correct localization for the cases of auditory danger signal reproduction from the front, back, and from the left and right side of a person are presented in the Table 1. In the case where the auditory danger signal was emitted from the front of a subject, the most correct responses were given in the experiment without masking ambient noise (80%), and the least correct responses were given in the case where earmuffs were used in the passive mode (45%). Signal emission from the rear also caused the most problems when earmuffs were used in the passive mode (68.3% of correct responses) and the least – when the test was performed with ambient noise and without the use of hearing protectors (85% of correct responses). In al-



E – earmuffs in passive mode / nauszniki przeciwhałasowe pasywne, L-D E – level-dependent earmuffs / nauszniki przeciwhałasowe z regulowanym tłumieniem, no HP – without hearing protectors / bez ochronników słuchu.

Fig. 4. Directivity of hearing of the auditory danger signal emitted by an overhead crane, reproduced at the experimental set-up – a correct response is considered indicating: a) the direction from which the signal was reproduced, b) the direction from which the signal was reproduced or one of the neighboring directions
Ryc. 4. Kierunkowość słyszenia dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę, odtwarzanego na stanowisku badawczym – za poprawną odpowiedź uznaje się wskazanie: a) kierunku, z którego odtworzono sygnał, b) kierunku, z którego odtworzono sygnał, lub kierunku sąsiedniego

Table 1. Directivity of hearing (front–rear and left–right) of the auditory danger signal emitted by an overhead crane reproduced at the experimental set-up*
Tabela 1. Kierunkowość słyszenia (przód–tył i lewo–prawo) dźwiękowego sygnału bezpieczeństwa emitowanego przez suwnicę, odtwarzanego na stanowisku badawczym*

Direction of reproduction of the signal Kierunek odtworzenia sygnału	Correct localization of the signal Poprawna lokalizacja sygnału [%]			
	ambient noise present obecny hałas tła			without ambient noise and hearing protectors bez hałasu tła i ochronników słuchu
	with earmuffs in passive mode z nausznikami pasywnymi	with level-dependent earmuffs z nausznikami z regulowanym tłumieniem	without hearing protectors bez ochronników słuchu	
From the front / Z przodu	45.0	53.3	68.3	80.0
From the back / Z tyłu	68.3	70.0	85.0	82.5
From the right / Z prawej	100.0	100.0	100.0	100.0
From the left / Z lewej	100.0	96.7	100.0	100.0

* The values quoted were determined by averaging the responses of all persons / Podane wartości wyznaczono, uśredniając odpowiedzi wszystkich osób.

most all cases, persons gave 100% of correct responses when the auditory danger signal was emitted from the left or right side.

DISCUSSION

The tests performed in this study helped to achieve the objective presented in the introduction, providing data about the capabilities of correct localization of the auditory danger signal emitted by an overhead crane under acoustic conditions corresponding to those in the work environment.

When analyzing the data contained in the Figure 4, one should note that in the reference case when the test is performed without masking ambient noise, the average percentage rate of correct responses was the highest, which was expected. The presence of ambient noise reduced the number of correctly identified directions of approach of the auditory danger signal. These reductions amounted to 9.2 and 3.5 percentage points in the case of the first and second method of analysis, respectively. The statistical analysis of the obtained results (t-test) indicated that in the case of the first method of analysis that reduction was significant (p = 0.01) whereas in the case of the second method of analysis, the observed difference was no significant (p = 0.1).

The use of earmuffs in the passive mode yielded the worst results among the data obtained for the 4 measurement situations. The average number of correctly identified directions was only 44.5% and 72.8% for the first and second method of analysis, respectively. There was some improvement in the case where level-dependent earmuffs were used. Signal transmission by the electronic system to under earmuffs' cups increased the number of correct responses by 12.8 percentage points (the first method of analysis) and 3.5 percentage points (the second method of analysis). It should be noted that the significant difference between earmuffs used in the passive and level-dependent mode occurred only in the case of the first method of analysis (p = 0.001). In the case of the second method of analysis the difference between mentioned earmuffs' modes was not significant (p = 0.25).

It is also essential to check how the use of earmuffs influences the localization of auditory danger signal as compared to the situation when earmuffs are not used (in the presence of ambient noise). The study showed that in the case of the first method of analysis (the greater accuracy of indication of the signal's direction of approach) the percentage rate of the correct localization in the situation of the use of level-dependent earmuffs did not significantly differ from the situation when hearing protectors were not worn in the presence of ambient noise (p = 0.11). In contrast, the use of earmuffs in the passive mode caused a significant decrease in the percentage rate of the correct localization from 66.6% to 44.5% (p = 0.0001). This means that the use of level-dependent earmuffs, in contrast to earmuffs used in the passive mode, may not affect the localization of auditory danger signal.

The front-rear and left-right analysis (the data contained in the Table 1) indicated the lack of problems with differentiating whether the auditory danger signal is approaching from the left or right side. In this case only one person gave incorrect responses. However, there are problems when a subject is to identify whether the sound is approaching from the back or front. What is more, in each of the 4 measurement situations accounted for in the studies (with or without ambient noise and with or without earmuffs), fewer incorrect responses were observed when the sound of the crane's signal approached from the back than when it approached from the front. Activation of the electronic sound reproduction system increased the number of correct responses as compared to the case where earmuffs were used in the passive mode.

It should be noted that despite the obtained results (mean values of the percentage rate of the correct localization) indicated a problem with the judgement whether the sound is coming from the front or the back of the person, significant differences between different study conditions cannot be clearly indicated. The reason for this arises from extremely varied answers (both 0% and 100% of the correct localization) provided by particular subjects in the same measurement conditions.

The tests conducted in this study differ from those published earlier, dealing with the most frequently analyzed problems in that the approach of the auditory danger signal from directions above the head of the person, not from directions at the person's head level, has been considered here. After the tests performed in this study, subjects expressed their opinions about problems with differentiating whether the crane's signal is coming from the front or rear. One person stated, for example, that it was difficult to determine where the sound was coming from in such cases (there was only the impression that the sound was coming from above) and that their response concerning the sound coming from the back was based on the sound being perceived as relatively quieter.

The opinions of subjects were confirmed by the results presented above. No problems were observed with indicating whether the sound was approaching from the right or left side of a subject, however correct indication of front-rear directions caused problems. Similar conclusions were drawn in the study on the localization of a sound while using hearing protectors in impulse noise conditions, and slight problems with the left-right localization were found [12]. In the same study, it was determined that hearing protectors exacerbate problems with the front-rear localization.

Moreover, the study cited above [12] found that the average percentage rate of correct responses amounted to 40% when earmuffs with electronic systems were used and was equal to 96% in the case when hearing protectors were not used. Such a great divergence was not observed in this study, where the auditory danger signal was emitted above the person's head and the percentage rate of 57.3% was obtained with the use of level-dependent earmuffs while 66.6% was achieved without the use of hearing protection (the first method of analysis). It should be noted, however, that despite the similarity of the general concept of the cited study [12] to the tests conducted in this study, they differed in both the type of test signals and the location of sources reproducing the useful signal. This confirms the comments made in the introduction that the results of the localization assessment depend on the conditions under which tests are performed.

It is also worth noting that different conditions of hearing protection used may sometimes lead to fundamentally different conclusions. An example of this was provided by the study in which participants were tasked with determining which out of 8 speakers distributed evenly around the participant was the source of a vehicle backup alarm, in the presence of noise with A-weighted equivalent sound pressure level amounting to 60 dB or 90 dB [11]. The average percentage rate of the correct localization without the use of hearing protectors was 82.2%. A worse result was obtained when earmuffs were used in the passive mode (70.2%), and the use of level-dependent earmuffs did not cause an improvement but actually reduced the percentage rate of correct responses even further (down to the value of 66.3%).

The study finding that the effectiveness of reception of a tonal warning signal of vehicle backup alarm is the lowest and is greatest for a wide-band signal, while a signal consisting of multiple tones is received with intermediate effectiveness, also indicates that the type of sound signal may have a significant impact on the ability to receive it [13].

CONCLUSIONS

In this study, the localization of the auditory danger signal emitted by an overhead crane was tested by using sound signals registered in a real work environment. The sound signal generated by the crane's signaling device and ambient noise, registered during the operation of this crane in an industrial hall, were both used. Based on the tests conducted, the following observations may be formulated:

1. In the situation when hearing protectors are used in a workplace, in the case of an industrial hall where it is important to identify the direction from which the auditory danger signal generated by the crane's signaling device is approaching, it is beneficial to use level-dependent earmuffs rather than passive earmuffs.
2. Differentiation of whether the auditory danger signal generated by the crane's signaling device is coming from the left or right side of a person is not a problem in the case when hearing protectors are used and in the case when they are not used. Correct identification of whether the auditory danger signal generated by the crane's signaling device is approaching from the front or rear of a person is not always possible.

REFERENCES

1. ISO 7731:2003. Ergonomics – Danger signals for public and work areas – Auditory danger signals. Geneva: International Organization for Standardization; 2003.
2. Bolia RS, d'Angelo WR, Mishler PJ, Morris LJ. Effects of hearing protectors on auditory localization in azimuth and elevation. Hum Factors. 2001;43:122–8, http://dx.doi.org/10.1518/001872001775992499.
3. Tran Quoc H, Hétu R. [Acoustic planning and signaling in industrial workplaces: Design criteria of acoustic warning signals]. Can Acoust. 1996;24:3–17. French.
4. Simpson BD, Bolia RS, McKinley RL, Brungart DS. The impact of hearing protection on sound localization and orienting behavior. Hum Factors. 2005;47:188–98, http://dx.doi.org/10.1518/0018720053653866.
5. Carbonneau M-A, Lezzoum N, Voix J, Gagnon G. Detection of alarms and warning signals on an digital in-ear device. Int J Ind Ergon. 2013;43(6):503–11, http://dx.doi.org/10.1016/j.ergon.2012.07.001.
6. Kozłowski E, Młyński R, Usowski J, Jurkiewicz D. [Hearing protectors – New solutions]. Lek Wojsk. [Internet]. 2014 [cited 2015 Nov 24];4(92):466–71. Available from: http://www.lekarzwojskowy.pl/arch/04_14.htm. Polish.
7. Azman AS, Hudak RL. An evaluation of sound restoration hearing protection devices and audibility issues in mining. Noise Control Engineer J. 2011;59(6):622–30, http://dx.doi.org/10.3397/1.3654146.
8. Dolan TG, O'Loughlin D. Amplified earmuffs: Impact on speech intelligibility in industrial noise for listeners with hearing loss. Am J Audiol. 2005;14(1):80–5, http://dx.doi.org/10.1044/1059-0889(2005/007).
9. Plyler PN, Klumpp ML. Communication in noise with acoustic and electronic hearing protection devices. J Am Acad Audiol. 2003;14(5):260–8.
10. Arlinger S. Speech recognition in noise when wearing amplitude-sensitive ear-muffs. Scand Audiol. 1992;21(2):123–6, http://dx.doi.org/10.3109/01050399209045992.
11. Alali KA, Casali JG. The challenge of localizing vehicle backup alarms: Effects of passive and electronic hearing

protectors, ambient noise level, and backup alarm spectral content. Noise Health. 2011;13(51):99–112, http://dx.doi.org/10.4103/1463-1741.77202.
12. Zimpfer V, Sarafian D. Sound-localization performance with the hearing protectors. In: Proceedings of Meetings on Acoustics. Vol. 19. ICA 2013: Proceedings of the 21st International Congress on Acoustics; 2013 Jun 2–7; Montreal, Canada: Acoustical Society of America; 2013, http://dx.doi.org/10.1121/1.4799544.
13. Vaillancourt V, Nélisse H, Laroche C, Giguére C, Boutin J, Laferriére P. Comparison of sound propagation and perception of three types of backup alarms with regards to worker safety. Noise Health. 2013;15(67):420–36, http://dx.doi.org/10.4103/1463-1741.121249.

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