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# Evaluation of the Increased Accident Risk From Workplace Noise

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*Directive 2003/10/EC sets the requirement for evaluating the effect of noise on accident risk. Accident risk is elevated for workers with a hearing handicap because of their reduced speech intelligibility and reduced capability to perceive the direction of incoming sound. An audiogram is not a good method for the evaluation of these functions. To reduce accident risk, organisational and personal solutions are needed. For both methods, efficiency must be evaluated through proper risk assessment. Because practical guidelines are not available, this paper presents principles for accident risk evaluation techniques.*

accident risk   hearing   noise   hearing protectors

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## 1. INTRODUCTION

### 1.1. The Impact of Hearing Loss

To analyse the impact of hearing loss, it is important to make a distinction between impairment, disability and handicap [1]. Impairment refers to functional abnormality. In noise-induced hearing loss, impairment refers to alteration of the auditory system, such as loss of hearing sensitivity or decreased frequency resolution. Hearing disability refers to the functional limitations caused by impairment in everyday activities, primarily where communication is concerned. Handicaps are the social consequences of impairment. In noise-induced hearing loss, handicap refers to the social consequences of communication difficulties, such as social isolation and unemployment.

Hearing impairment may comprise the following symptoms [2]:

- decreased individual threshold of sound detection;

- distorted increase in loudness when the sound level increases;
- difficulties in resolving neighbouring sounds;
- reduced ability to detect gaps when there is ongoing sound;
- reduced ability to localise sound sources and
- persistent tinnitus.

Workers with hearing impairment require a signal-to-noise (S/N) ratio of up to 25 dB higher than that of normal listeners for detecting, recognising and localising the sound [2]. Due to the characteristics of the warning signals in industry and the necessity to wear hearing protection, workers with hearing impairment are more prone to accidents than workers with normal hearing. Because of a loss of frequency resolution, the S/N ratio in communication must be up to 10 dB higher among hearing-impaired listeners [3].

The correlation of an audiogram with subjective evaluation and handicap varies between .2 and .5 [4]. The subjective evaluation of disability correlates somewhat better with the audiogram than the handicap. This difference is due to the fact that the audiogram reflects only the threshold

shift, not the other symptoms that affect speech intelligibility and the capabilities that detect the direction from where the sound is coming. This is why people who need to communicate in ambient noise are more sensitive to hearing impairment than people who do not [5].

Although noise is the most common reason for hearing loss at work, ~6% of the population develops hearing loss before the age of 65 without noise exposure due to presbycusis [6].

## 1.2. The Impact of Noise Upon Accident Risk

Girard Picard, Simard, et al. [7] carried out a follow-up study of 81 346 male workers. Elevated noise level (>90 dB) seemed to create a 40% higher accident risk among workers with an elevated hearing threshold than noise level of <90 dB for workers with normal hearing. Noise increased accident risk among workers with normal hearing. Also, the grade of hearing impairment was related to accident risk even at low noise levels. In addition, there seemed to be an association with hearing loss and accident severity.

The risk of noise and hearing loss together accounted for 43% of the injuries in 1986–1987 in a shipyard in The Netherlands [8]. Exposure greater than 82 dB based on an 8-h time-weighted average exposure was found to be a safety hazard.

Hearing protectors hamper the communication and hearing of warning signals [9], especially for workers with a hearing handicap; this can lead to an increased risk of accidents. In fact, hearing protectors have a similar effect to noise-induced hearing loss. This explains why workers with a hearing handicap have an increased accident risk when using hearing protectors.

There is an elevated accident risk due to hearing loss in railways [10]. Railway Medical Services (UIMC) recommended that hearing should be better than 20 dB at frequencies of 1–3 kHz, or the worker should hear a whisper from a distance of 5 m with both ears. However, accidents still occur in rail yards, and there were cases in Finland and the United Kingdom where poor hearing contributed to lethal accidents. In

some cases the use of hearing protection devices (HPDs) was suspected to further contribute to accidents. Reduced capability to distinguish the direction from which the train was coming caused workers to take wrong actions. In Finnish accident case reports hearing protectors equipped with a radio possibly contributed to accidents [10]. These cases were related to listening to sport events. The assumed mechanism was related to loss of concentration caused by listening. In addition listening to the radio may reduce the S/N ratio, which leads to reduced speech intelligibility.

Standard No. ISO 7731:2003 gives recommendations for warning signals [11]. The sound level should exceed the background noise in at least one third-octave band by 13 dB. This S/N ratio may not be enough; for people with hearing loss it should be 10 dB higher than for people with normal hearing. This is not taken into account in the standard [12]. In addition, there can be a masking effect if the frequency difference between the noise and the warning signal is small. The standard does not take into account the effect of hearing protectors [13, 14].

Standard No. EN 458:2004 recommends hearing protectors with flat attenuation when hearing warning signals is important [15]. However, the standard does not define flat. Recommendation No. BGI 673:2003 defines a maximum allowable change as 3.6 dB/octave [16]. This requirement is necessary but not enough [14]. Hearing must also be tested in practice.

Accident risk caused by hearing loss may be attributed to three factors: (a) reduced capability to hear warning signals and moving vehicles, (b) reduced capability to localise the source of sound and (c) reduced speech intelligibility. Workers with a hearing handicap seem to have an elevated accident risk, because they use hearing protectors. According to Directive 2003/10/EC

in exceptional situations where, because of the nature of the work, the full and proper use of individual hearing protectors would be likely to cause greater risk to health or safety than not using such protectors, Member States

may grant derogations from the provisions of Articles 6(1)(a) and (b) and 7 (p. 42) [17].

This leads to a controversial situation: those who need to protect their hearing most should avoid using hearing protectors. In addition, accident risk is related to the characteristics of ambient noise. Directive 2003/10/EC sets, among others, the requirement to evaluate the effect of noise upon accident risk [17]. Although there are some practical recommendations, there are no clear guidelines regarding how to proceed with this issue. The best approach is to try to identify those work tasks where hearing impairment may lead to accidents. If there is an accident risk, workers with a hearing handicap that can increase the risk must be identified and special actions must be taken to protect them. This paper gives background information and a proposal for these guidelines.

## 2. IDENTIFICATION OF THE ACCIDENT RISK

To reduce accident risk, two tasks need to be undertaken: identification of work tasks where the worker with a hearing handicap may experience additional risk, and identification of workers with a hearing handicap. Therefore, occupational safety has to identify locations where (a) poor speech intelligibility may cause accidents, (b) a warning signal must be heard and (c) a collision with a moving vehicle is possible.

Typically, case (a) may be an issue when two or more workers work together and control their work by communicating with each other. If a misunderstanding can cause an accident, speech intelligibility must be evaluated. For this purpose, Standard No. ANSI S3.5:1997 provides four methods of estimating personal speech intelligibility for each worker [18]. Those methods require spectra of ambient noise, spectra of speech/warning signals, attenuation of HPDs and, finally, workers' audiograms. Basically, these methods evaluate in how many bands a signal exceeds the background noise. Each band has its own weight based on its effect upon speech intelligibility. If speech intelligibility is

poor, changing the HPD model to one with lower attenuation may be a solution.

Regarding case (b), warning signals may not be heard either because of the hearing handicap or because of the use of HPDs. This is especially true for workers with a hearing handicap. Because Standard No. ISO 7731:2003 [11] does not take these two phenomena into account, the audibility of the warning signal should be evaluated for each worker using Standard No. ANSI S3.5:1997 [18].

Case (c), involving the localisation of sound sources, becomes an issue when there are moving vehicles or machines in the working zone. In this case, light signs and an increased visibility of workers and machines may reduce risk. Again, hearing protectors, especially combined with hearing impairment, may cause increased risk. The first solution is to apply the Railway Medical Services (UIMC) criteria for these working conditions [10]. In terms of the capability to localise these sound sources safe evaluations are available. The use of level-dependent hearing protectors may restore the localisation of sound sources.

For evaluation purposes, the contribution of occupational healthcare is necessary in the form of providing audiograms. If an evaluation shows an increased accident risk due to ambient noise, the conclusions must be checked by occupational healthcare personnel. Speech intelligibility can be evaluated with a speech audiogram. However, this method has not gained significant popularity. An alternative technique is to use questionnaires to evaluate hearing handicap. Several questionnaires are available, such as the hearing handicap inventory and the hearing handicap scale [19, 20]. By selecting a large questionnaire [21] with questions about speech intelligibility and sound localisation it is possible to evaluate workers' speech intelligibility amid ambient noise and their capability to localise sounds.

A more complex issue is the risk created by HPDs equipped with a radio. This risk seems to be related to a loss of concentration. This happens especially when workers listen to exciting events like sports games. Therefore, the risk assessment for HPDs equipped with a radio

must be considered actively by work phases and tasks where the loss of concentration can be fatal, such as the operation of presses, cutting tools, etc. An alternative solution is to restrict listening to background music.

Directive 2003/10/EC implies that in risk assessment the effect of alternative methods must be taken into account [17]. Thus, if communication is a safety factor, several possibilities must be considered. First, the possibility of visual communication must be evaluated. For example, the use of light signs may replace oral communication. Also, modern HPD systems allow two-way (wireless) communication, which means that speech is not disturbed by ambient noise.

### 3. DISCUSSION

Directive 2003/10/EC sets many new requirements for risk assessment such as (a) evaluation of combined exposure to noise and ototoxic chemicals, (b) evaluation of combined exposure to noise and vibration and (c) risk assessment of particularly sensitive risk groups and indirect

effects on workers' health and safety resulting from interactions between noise and warning signals or other sounds that need to be observed to reduce the risk of accidents [17].

These new requirements set risk assessment at a much higher level. This article focuses on accident risk in point (c). To fulfil this requirement risk assessment must be based on personal properties like the hearing threshold shift and capability to localise sounds. According to Directive 2003/10/EC, article 4.6, the employer shall pay particular attention when carrying out risk assessment to any effects concerning workers' health and safety and workers belonging to particularly sensitive risk groups, and any indirect effects on workers' health and safety resulting from interactions between noise and warning signals or other sounds that need to be observed to reduce the risk of accidents [17]. Workers with hearing impairment are at a higher risk, and special attention must be paid to protect them from accident risk. In practice this means that risk assessment must be based on personal properties like the threshold shift of hearing and the capability to localise sounds.

**TABLE 1. Exposure Evaluation When There is Risk of an Accident**

Noise Level	Additional Parameters	Action
>80 dB	Communication needed for work	Evaluate possible hazards due to reduced communication
	Effect of hearing protectors	Check the combined effect of hearing loss and ambient noise
		Evaluate the effect of HPDs on sound intelligibility
		Use level dependent HPDs when possible
	Sound localisation important	Check the results with a questionnaire
		Use railway hearing requirements
	Warning signals need to be heard	Check the workers' capability to localise sounds
Check the levels with ISO 7731:2003 [11]		
Check the hearing with ANSI S3.5:1997 [18]		
>80 dB and hearing protectors with radio are used	Accident risk caused by loss of concentration or the presence of significant cognitive requirements in the workplace should be evaluated	Do not use radio-equipped hearing protectors

Notes. HPD—hearing protection device.

For occupational safety this concept also requires changes. In the risk assessment of noise, the measurement of noise levels is insufficient. The evaluation requires a deeper analysis of the working conditions, and the individual properties of workers have to be included in the risk assessment. Table 1 presents a simple checklist for occupational safety.

Under extreme conditions, passive HPDs will increase the risk. The use of electronic HPDs with sound restoration capabilities may restore the limited functionality of hearing to an acceptable level. The use of sound-restoring HPDs was adopted at the Finnish Railroad company in railway yard work [22]. The company recognised the fact that HPDs could not restore hearing to normal, and an upper limit to the threshold shift was needed. However, there was no good method of evaluating the effect of the sound restoration system; therefore, personal information about the nature of the risk had to be given to workers with a hearing handicap. On the basis of that information, workers could evaluate the risk themselves.

Fulfilling the requirements of Directive 2003/10/EC regarding the effect of noise on accident risk requires close co-operation with occupational safety employees [17]. Occupational safety requires the localisation of tasks in which good hearing is an issue. Occupational safety employees can also evaluate the effect of HPDs on the risk and, if necessary, recommend an appropriate solution. It is worth noting that the risk assessment has become individual because it is based on the hearing function. For this purpose, audiograms are required. The safety evaluation then needs to be reviewed by an occupational safety expert, which requires a more profound understanding of the impairment than a simple audiogram can provide. For this purpose a suitable questionnaire is a useful tool.

It should be noted that there are simple methods for evaluating accident risk caused by noise. However, it should always be borne in mind that there are other causes of accidents for which there are no straightforward evaluation methods. For example, it is difficult to measure the taking of unnecessary risks, which may be an even

greater cause of accidents than noise or a hearing impairment.

#### 4. CONCLUSIONS

Ambient noise increases accident risk, especially among workers with hearing loss. This increased risk is caused by reduced speech intelligibility and a reduced capability to localise sounds. In addition, passive HPDs may decrease these functions. A careful evaluation of the effect of hearing impairment and HPDs must be carried out. Although Directive 2003/10/EC provides the possibility of not using HPDs if they cause elevated risk of another kind [17], this option should not be used in the context of accidents because hearing ability can often be restored to an acceptable level through the use of sound-restoration HPDs.

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## APPENDIX

### Example of a hearing handicap inventory [21]

(Only speech intelligibility and spatial parts are included here)

Speech spatial qualities SSQ3.1.2.

#### I. Speech hearing rating scale

1. You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow what the person you're talking to says?
2. You are talking with one other person in a quiet, carpeted lounge-room. Can you follow what the other person says?
3. You are in a group of about five people, sitting round a table. It is an otherwise quiet place. You can see everyone else in the group. Can you follow the conversation?
4. You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?
5. You are talking with one other person. There is continuous background noise, such as a fan or running water. Can you follow what the person says?
6. You are in a group of about five people in a busy restaurant. You cannot see everyone else in the group. Can you follow the conversation?
7. You are talking to someone in a place where there are a lot of echoes, such as a church or railway terminus building. Can you follow what the other person says?
8. Can you have a conversation with someone when another person is speaking whose voice is the same pitch as the person you're talking to?
9. Can you have a conversation with someone when another person is speaking whose voice is different in pitch from the person you're talking to?
10. You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?
11. You are in conversation with one person in a room where there are many other people talking. Can you follow what the person you are talking to is saying?
12. You are with a group and the conversation switches from one person to another. Can you easily follow the conversation without missing the start of what each new speaker is saying?
13. Can you easily have a conversation on the telephone? (using one, none, or both aids?)
14. You are listening to someone on the telephone and someone next to you starts talking. Can you follow what's being said by both speakers?

SSQ3.1.

#### II. Spatial rating scale

1. You are outdoors in an unfamiliar place. You hear someone using a lawnmower. You can't see where they are. Can you tell right away where the sound is coming from?
2. You are sitting around a table or at a meeting with several people. You can't see everyone. Can you tell where any person is as soon as they start speaking?
3. You are sitting in between two people. One of them starts to speak. Can you tell right away whether it is the person on your left or your right, without having to look?
4. You are in an unfamiliar house. It is quiet. You hear a door slam. Can you tell right away where that sound came from?



5. You are in the stairwell of a building with floors above and below you. You can hear sounds from another floor. Can you readily tell where the sound is coming from?
6. You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look?
7. You are standing on the footpath of a busy street. Can you hear right away which direction a bus or truck is coming from before you see it?
8. In the street, can you tell how far away someone is, from the sound of their voice or footsteps?
9. Can tell how far away a bus or a truck is, from the sound?
10. Can you tell from the sound which direction a bus or truck is moving, for example, from your left to your right or right to left?
11. Can you tell from the sound of their voice or footsteps which direction a person is moving, for example, from your left to your right or right to left?
12. Can you tell from their voice or footsteps whether the person is coming towards you or going away?
13. Can you tell from the sound whether a bus or truck is coming towards you or going away?
14. Do the sounds of things you are able to hear seem to be inside your head rather than out there in the world?
15. Do the sounds of people or things you hear, but cannot see at first, turn out to be closer than expected when you do see them?
16. Do the sounds of people or things you hear, but cannot see at first, turn out to be further away than expected when you do see them?
17. Do you have the impression of sounds being exactly where you would expect them to be?