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MAGAZINE

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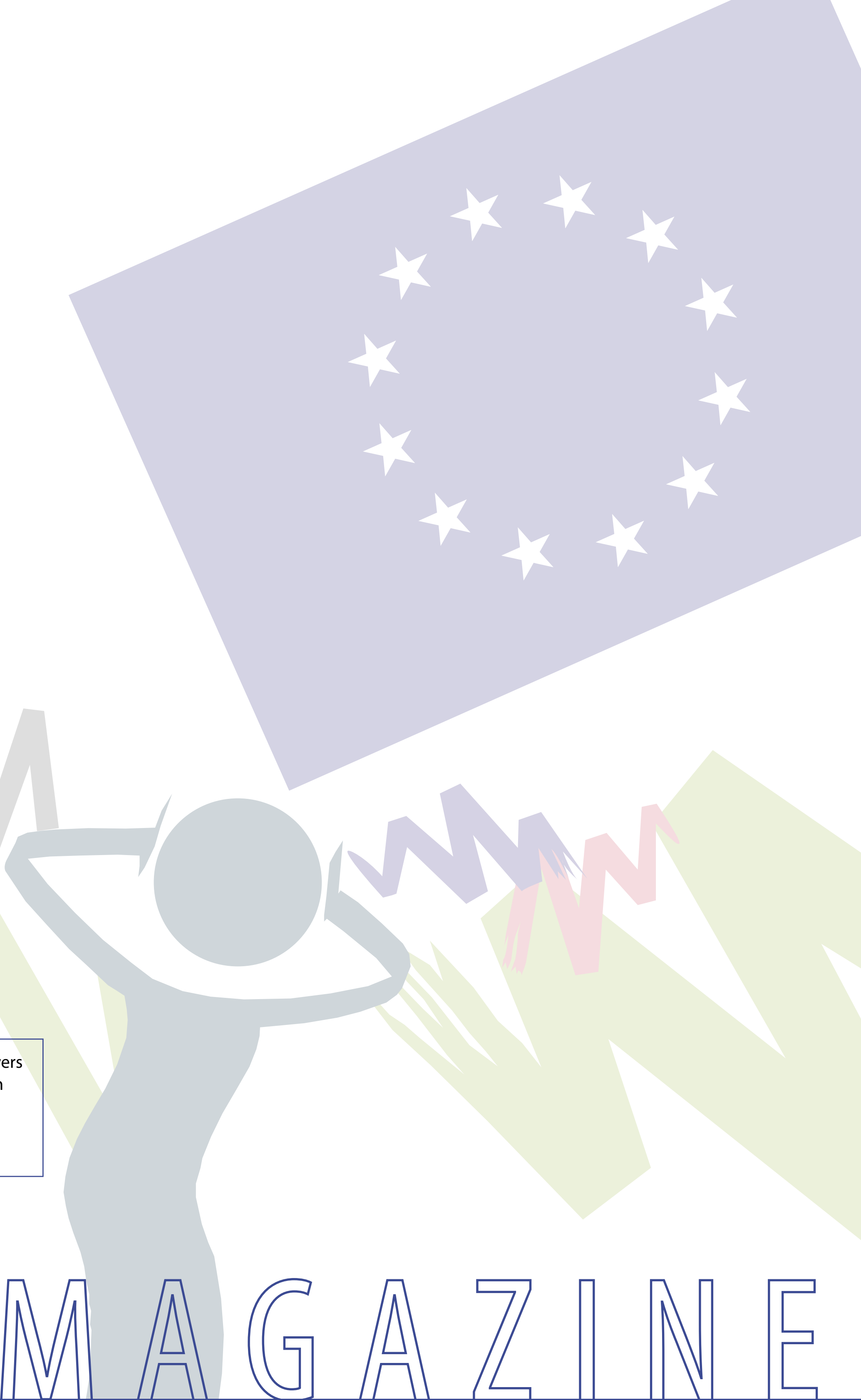
[Magazine of the European Agency for Safety and Health at Work]

ISSN 1608-4144

NOISE AT WORK

Front cover photo courtesy of SoundEar®



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Luxembourg: Office for Official Publications of the European Communities, 2005

ISSN 1608-4144

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER

Director, European Agency for Safety and Health at Work

Hans-Horst Konkolewsky

Foreword

Workplaces should 'stop that noise!'. This is the message of the European Week for Safety and Health at Work 2005 campaign, the sixth to be organised by the European Agency for Safety and Health at Work ([1]). The campaign coincides with the run-up to the final date for the introduction of the new European directive on noise at work ([2]), which must be in place in the Member States by February 2006.

The need to 'stop that noise' is evident. Millions of Europe's workers suffer from work-related hearing difficulties. Noise-induced hearing loss is amongst the most commonly reported occupational diseases in the European Union, and there are concerns other than hearing loss from noise exposure. Noise can also cause harm in other ways: it can interact with dangerous substances to cause harm to the ear; it can increase the risk of accidents by affecting communication. The range of jobs and workplaces where noise can be a problem is much broader than is commonly thought. It includes farms, building work, classrooms, drivers, clubs and bars, musicians and call-centre staff, as well as factories and shipyards.

To support the 'Stop that noise' campaign, the Agency is making available a wide range of material for all those trying to make Europe's workplaces safer and healthier, whether worker, employer, researcher or policy-maker. This information, in all the official languages of the EU, is provided free of charge by the Agency via its website at http://osha.eu.int.

This magazine is part of these resources. It gives a view across Europe of some of the work being done to protect workers. There is a description of the new directive, how it will be implemented, and new guidance that is being provided to help reduce risks. There are articles covering noise in schools, offices, and concert halls, and the work being done to ensure that effective control measures exist in the field of acoustic design and personal hearing protection.

It is hoped that these articles will provide an insight into some current noise-control issues and an update on some interesting initiatives and approaches that can be taken to tackle the problem.

([1]) http://osha.eu.int.

([2]) Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). EU safety and health legislation is online at http://europa.eu.int/eur-lex/.

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Directorate-General for Employment, Social Affairs and Equal opportunities, European

José Biosca de Sagastuy

A new directive on noise

Member States have until 15 February 2006 to bring into force the laws, regulations, and administrative provisions necessary to comply with Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise).

Loss of hearing is certainly the most well-known adverse effect of noise and probably the most serious, but it is not the only one. Other detrimental effects include tinnitus, so-called ringing in the ears, interference with speech communication, loss of sensitivity to sounds, disruption of job performance, and non-auditory effects, like psychological disturbances. The detrimental effects are not only at the origin of suffering and social exclusion but also deafness is one of the major contributors to social security compensations in all Member States.

Protection against noise effects has been one of the priorities at European level since an early stage of the development of the occupational health and safety policy. Already in 1986, the Council had adopted Directive 86/188/EEC on the protection of workers from the risks related to exposure to noise at work.

This directive had already set up exposure limit values for workers as well as the main elements of the prevention policy to be applied by employers.

On 8 February 1993, the Commission [3] presented a proposal on the minimum requirements applicable to the exposure of workers to the risks arising from physical agents. The proposal dealt with those physical agents for which there was sufficient scientific evidence for Community action — noise (risks to hearing), vibrations (risks to hand, arm and whole body), electromagnetic fields and optical radiation (risks to health from induced currents in the body, shock and burn hazards and from absorption of thermal energy).

As regards noise, the intention of the Commission proposal was to put the provisions of the noise directive into line with the prevention structure of the Framework Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work, in reply to the Council's request foreseen in Article 10 of Directive 86/188/EEC to the Commission to re-examine and submit a revised proposal on noise.

The Commission proposal was only discussed at Council level in 1999 when the German Presidency began discussions on one physical agent — vibrations. The splitting of the proposal was then decided and each physical agent has been dealt with individually, noise being the second part of the original proposal adopted by European Parliament and the Council as the 17th individual directive within the meaning of Article 16(1) of Directive 89/391/EEC: Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). This new Noise Directive 2003/10/EC will repeal Directive 86/188/EEC with effect from 15 February 2006, the deadline for the transposition of the new directive.

The main characteristic of the new noise directive is to establish a clear and coherent prevention strategy capable of protecting the health and safety of workers exposed to noise.

In order to avoid irreversible damage to workers' hearing, the directive foresees exposure limit values of 87 dB(A) and a peak sound pressure of 200 Pa, above which no worker may be exposed; the noise reaching the ear should, in fact, be kept below these exposure limit values. The directive also foresees upper and lower exposure action values of respectively 85 dB(A) (and 140 Pa) and 80 dB(A) (and 112 Pa) which determine when preventive measures are necessary to reduce the risks to workers. It is important to note that, when applying the exposure limit values, the determination of the worker's effective exposure shall take account of the attenuation provided by the individual hearing protectors worn by the worker. The exposure action values shall not take account of the effect of any such protectors.

The preventive measures laid down by the directive are based primarily on the determination and assessment of risks that the employer has to perform using different methods for evaluation of the level of exposure to noise and the obligation to eliminate or reduce exposures primarily at the source. In this regard, in order to assess correctly the exposure of workers to noise and taking into account that it is useful to apply an objective measuring method, the directive refers to the generally recognised standard ISO 1999:1990. The assessed or

(3) http://europa.eu.int/comm/dgs/employment_social/index_en.htm.

objectively measured values should be decisive for initiating the actions envisaged at the lower and upper exposure action values.

On the basis of the risk assessment and as soon as the exposure action values are exceeded, the employer shall establish and implement a programme of technical and/or organisational measures intended to reduce the exposure to noise.

The directive also foresees detailed rules for the information and training of workers who are exposed to noise at work at or above the lower exposure action value risks arising from noise, in particular as regards the nature of the risks resulting from exposure to noise; the measures taken in order to eliminate or reduce to a minimum the risks from noise, including the circumstances in which the measures apply; the exposure limit values and the exposure action values; the results of the assessment and measurement of the noise together with an explanation of their significance and potential risks; the correct use of hearing protectors; why and how to detect and report signs of hearing damage; the circumstances in which workers are entitled to health surveillance and the purpose of health surveillance; and safe working practices to minimise exposure to noise.

Reinforced health surveillance is one of the main points of the directive — the directive confers, in particular, a right to the worker to have his/her hearing checked by a doctor or by another suitably qualified person under the responsibility of a doctor when the upper exposure action values are exceeded. Preventive audiometric testing shall also be available for workers whose exposure exceeds the lower exposure action values, where the assessment and measurement of the noise-exposure level indicate a risk to health.

The objectives of these checks are to provide early diagnosis of any loss of hearing due to noise, and to preserve the hearing function. Where, as a result of surveillance of the hearing function, a worker is found to have identifiable hearing damage, a doctor, or a specialist if the doctor considers it necessary, shall assess whether the damage is likely to be the result of exposure to noise at work.

If this is the case:

1. the worker shall be informed by the doctor or other suitably qualified person of the result which relates to him or her personally;
2. the employer shall:
   (a) review the risk assessment carried out,
   (b) review the measures provided for to eliminate or reduce risks,
   (c) take into account the advice of the occupational healthcare professional or other suitably qualified person or the competent authority in implementing any measures required to eliminate or reduce risk, including the possibility of assigning the worker to alternative work where there is no risk of further exposure, and
   (d) arrange systematic health surveillance and provide for a review of the health status of any other worker who has been similarly exposed.

The particular characteristics of the music and entertainment sectors require practical guidance to allow for an effective application of the provisions laid down by the directive. Member States are entitled to make use of a transitional period of a maximum of two years for the development of a code of conduct providing for practical guidelines that would help workers and employers in those sectors to attain the levels of protection established by the directive.

The main differences compared with the previous Noise Directive 86/188/EEC are in the reduction of the exposure limit value from 90 dB(A) to 87 dB(A) and the inclusion of all sectors of activity in the scope of the directive. Indeed, Directive 86/188/EEC excluded maritime navigation workers from its field of application. The new Noise Directive 2003/10/EC in this regard includes an optional five-year transitional period with regard to implementation of the provisions linked to compliance with the limit values for workers on board seagoing vessels, in order to take into account the specific conditions of this sector.

The new Noise Directive 2003/10/EC therefore:

- provides increased protection for workers in all sectors of the economy, including the maritime and air transport sectors (excluded from the existing Directive 86/188/EEC);
- recognises the specificity of the music and entertainment sectors by providing for a two-year transitional period during which codes of conduct shall be established for helping workers and employers in these sectors to meet their legal obligations as laid down by the directive;
- reduces the exposure limit value from 90 dB(A), as set up in the 1986 directive, to 87 dB(A), which represents clear progress.

The next step will be the transposition, by Member States, of the provisions of the new noise directive into national law, for which the deadline is fixed at 15 February 2006, and the development by Member States, in consultation with the social partners, of a code of conduct providing for practical guidelines to facilitate implementation in the music and entertainment sectors. The Commission will produce, in consultation with the Advisory Committee for Health and Safety at Work, European guidelines that could serve as a source of inspiration to Member States to develop national ones.

This new piece of legislation constitutes a major improvement in the protection of workers against noise at work, in line with the prevention philosophy of the framework directive.

However, the best legislation will not achieve its intended effects of reduction of loss of hearing due to noise exposure if it is not properly applied and enforced. It is therefore for the social partners, as the main actors in prevention of noise in the workplace, and enforcement authorities to ensure that work-related deafness will no longer be an issue in the EU.

The Commission will encourage the European Agency for Safety and Health at Work ([4]) to step up its awareness-raising activities and collection and exchange of good practices in this field to help employers and employees achieve this aim.

FURTHER INFORMATION

More information on European Union law can be found on the EUR-Lex website ([5]), the single entry point to the complete collections of EU legal texts in all the official languages.

([4]) http://europe.osha.eu.int/.
([5]) http://europa.eu.int/eur-lex/.

Hazards and Technical Policy Division, Health and Safety Executive, United Kingdom

Androulla Michael

HSE programming to cut noise at work in the United Kingdom

The new European directive on noise will soon be transposed into law in EU Member States. In this article, Androulla Michael describes how the Health and Safety Executive is working to implement the directive.

Britain's Health and Safety Commission (HSC) and the Health and Safety Executive (HSE) ([6]) are responsible for the regulation of almost all the risks to health and safety arising from work activity in the United Kingdom. Their mission is to protect people's health and safety by ensuring risks in the changing workplace are properly controlled. The HSE takes care of health and safety in most industrial workplaces including nuclear installations and mines, factories, farms, hospitals and schools, and offshore gas and oil installations. Local authorities are responsible for enforcement in offices, shops and other parts of the service sector. This article describes the HSE's future plans to tackle noise at work in the United Kingdom.

Noise at work — the scale of the problem in the United Kingdom

Occupational deafness caused by exposure to high noise levels at work is one of the most prevalent forms of ill-health in the United Kingdom. The effects of the disability are socially very far-reaching. Sufferers are committed to an increasing loss of hearing acuity which in itself may take many years to become manifest. Add the effects of the deterioration of hearing caused by natural ageing and a wide part of the hearing frequency spectrum is affected. The sufferer becomes more isolated in society and quality of life is seriously affected. And, of course, hearing loss is not reversible.

It is estimated that over 2 million people in the United Kingdom are regularly exposed to loud noise at work. About 1.1 million are exposed to levels above 85 dB(A), where there is a significant risk to health. An estimated 170 000 people suffer deafness, tinnitus, or other ear conditions as a result. Within the 35–64 age group, there are 153 000 men and 26 000 women who have severe difficulties in hearing attributable to noise at work. Severe hearing difficulty has a prevalence of 1.9 % for all occupations (5 % for construction). Occupational deafness claims on employers' liability insurance run at about 60 000 a year, or 83 % of total claims for industrial injury, while it constitutes about 10 % of claims for financial assistance from the government (under the State-run industrial injuries benefit scheme).

What is the new programme on noise at work?

The HSE is now working to transpose the latest EU directive on noise ([7]) into UK law. The introduction of the new UK regulations in 2006 is expected to encourage employers to take more appropriate action on noise. It makes sense for the HSE to try to use the momentum generated by the new regulations to good effect. It has therefore drafted a new programme of work on noise to focus resources and effort to maximum effect ([8]).

The programme consists of a series of projects which can be divided into three broad workstreams.

Workstream 1. Intelligence, targeting and fostering solutions

This workstream is fundamental to informing the other two. It will help to define a robust evidence base, quantify a baseline, identify priorities and develop and supply solutions. It is important to concentrate limited resources on industries and activities where there is the greatest scope for reduction in ill-health, i.e. where:

- ill-health is most prevalent;
- large numbers are exposed;
- exposure levels are high.

The HSE is in the process of developing a knowledge base of such industries and activities to help target resources. Other projects include:

- systems for capturing knowledge gained by inspectors;
- techniques for risk assessment;
- knowledge management: collating, dispensing and identifying and filling gaps in knowledge;
- identification and dissemination of reasonably practicable control measures;
- key messages and ways to promote them.

([6]) http://www.hse.gov.uk/.

([7]) Directive 2003/10/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise).

([8]) At the time of writing, the implementation of the programme was still subject to discussion on, and agreement of, resource allocations.

WORKSTREAM 2. REDUCING HAZARD AT SOURCE: SUPPLY OF TOOLS AND MACHINERY

Reducing noise at source by encouraging manufacturers to supply machines and tools with lower noise emissions is the optimum way to reduce exposure. Also, encouraging manufacturers to provide better information to users on emissions and proper use of machines and tools will allow the employer to choose suitable machines and tools and to assess and manage exposure to noise. Furthermore, manufacturers and suppliers are few by comparison with employers and can be readily contacted and directly influenced, for example, by convening a conference, fostering contacts between manufacturers and users, and enforcement of the legislation relating to the supply of machinery (which also stems from an EU directive).

At the same time, it is important that the HSE feeds into appropriate international/European/British standards to ensure that they represent the requirements of relevant legislation and that there is agreement on realistic emission test codes for machines and tools.

WORKSTREAM 3. ENCOURAGING COMPLIANCE THROUGH ADVICE, INVESTIGATION AND ENFORCEMENT

New noise regulations will come into force in 2006, accompanied by guidance for employers. These regulations are fundamental to the success of the programme because they set the standard of compliance. Other projects under this workstream include:

- helping to ensure compliance is achieved, by continuing to work on tools for inspectors (see Box 1) and running preventive inspections in target industries, while liaising with priority industry stakeholders on joint initiatives and developing examples of control measures;
- in accordance with the recent EU directive on work-related noise, working with social partners to produce practical guidelines for the music and entertainment sectors by February 2008 (see Box 2);
- looking at ways of disseminating simple messages to workers through discussions with trade unions and industry associations. Workers can make a major contribution to the management and control of many aspects of daily exposure, for example in the selection, use and maintenance of tools and equipment and in the proper use of hearing protection;
- exploring new ways of disseminating messages — traditional ways of providing advice and support to employers need revision to reflect the changing workforce. The HSE will also be contributing to the European Week for Safety and Health at Work which in 2005 will address noise;
- ensuring that the HSE webpages ([9]) and telephone helpline are kept up to date.

OBJECTIVE, TARGETS AND EVALUATION

Because of the robust dose–response relationship, a reduction in exposure to noise will lead directly in due course to a reduction in noise-induced hearing damage. But the chronic health effects of exposure to noise are long-latent and would normally only occur after many years of regular exposure. The overall objective of the noise programme is therefore long term: by 2030, to eliminate as an occupational disease new incidence of noise-induced hearing damage. Full compliance with the new regulations would result in the objective being achieved. Maximum compliance must therefore be sought, particularly at the higher levels of exposure. So an interim target would be 90 % compliance with the exposure limit value by 2010.

Reduction of noise at source is the optimum way of reducing exposure, but this can take time. Many employers rely on hearing protection, and this reliance is likely to increase substantially with employer action being required at lower noise-exposure levels under

Box 1: Inspecting for noise — the 'topic inspection pack' approach

The purpose of inspection is to assess the level of compliance achieved by the employer, to encourage continued improvement, and to secure compliance through enforcement where necessary. The topic inspection pack helps inspectors to target a particular hazard proactively during inspection. In the case of noise, the risks are easy to identify, there is a good dose–response relationship, there are clear legal exposure limits, noise is easy to measure, and there is well-established guidance.

Prevention of noise-induced hearing loss can be achieved by employers implementing a regime which contains the following key elements:

- senior management commitment;
- risk assessment;
- noise control at source implemented where possible;
- employees provided with information, instruction and training;
- hearing protection programme implemented where necessary;
- health surveillance provided where necessary.

Accordingly, three risk control indicators (RCIs) have been selected against which inspectors can measure employer performance.

1. Noise management system — Effective organisation and arrangements including adequate noise assessment, noise action plan, provision of information, instruction, training, supervision and a health surveillance regime. Evidence of a positive purchasing policy and strong management commitment. Arrangements for reviewing the system.
2. Control of noise at source — Reasonably practicable measures for controlling noise (other than by provision of ear protection (EP)) are in use and properly maintained.
3. Ear protection programme — Ear protection zones (EPZs) demarcated and fully observed by all personnel. EP is provided and is suitable for the individual and the task. A maintenance/replacement schedule exists including regular checks by a trained person. Evidence of full and proper use.

Following inspection, the employer is scored against the RCIs on a scale of 1 to 4. A score of 1 indicates that all relevant elements for that indicator are in place and further improvement is not possible. A score of 4 indicates poor compliance and that enforcement action is appropriate. Based on the scores allocated to each of the RCIs, the employer is assigned an overall performance rating. This rating provides information for future evaluation and to monitor improvements over time.

Inspectors are also provided with reference material about noisy activities and processes for most industry sectors, an *aide-memoire* of the issues to be addressed during inspection, control measures, details of noise legal issues, and template enforcement notices.

([9]) http://www.hse.gov.uk/noise.

the new regulations. However, hearing protection is far less effective than reducing noise levels. Hence, another interim target would be an overall reduction by 2010 in the reliance on hearing protection.

A formal evaluation of the impact of the regulations will be undertaken in approximately five years, and this will also be used to evaluate the success of the programme at that stage. In the meantime, evidence of success of the programme workstreams will be derived from peer review, enforcement activity information and interim surveys.

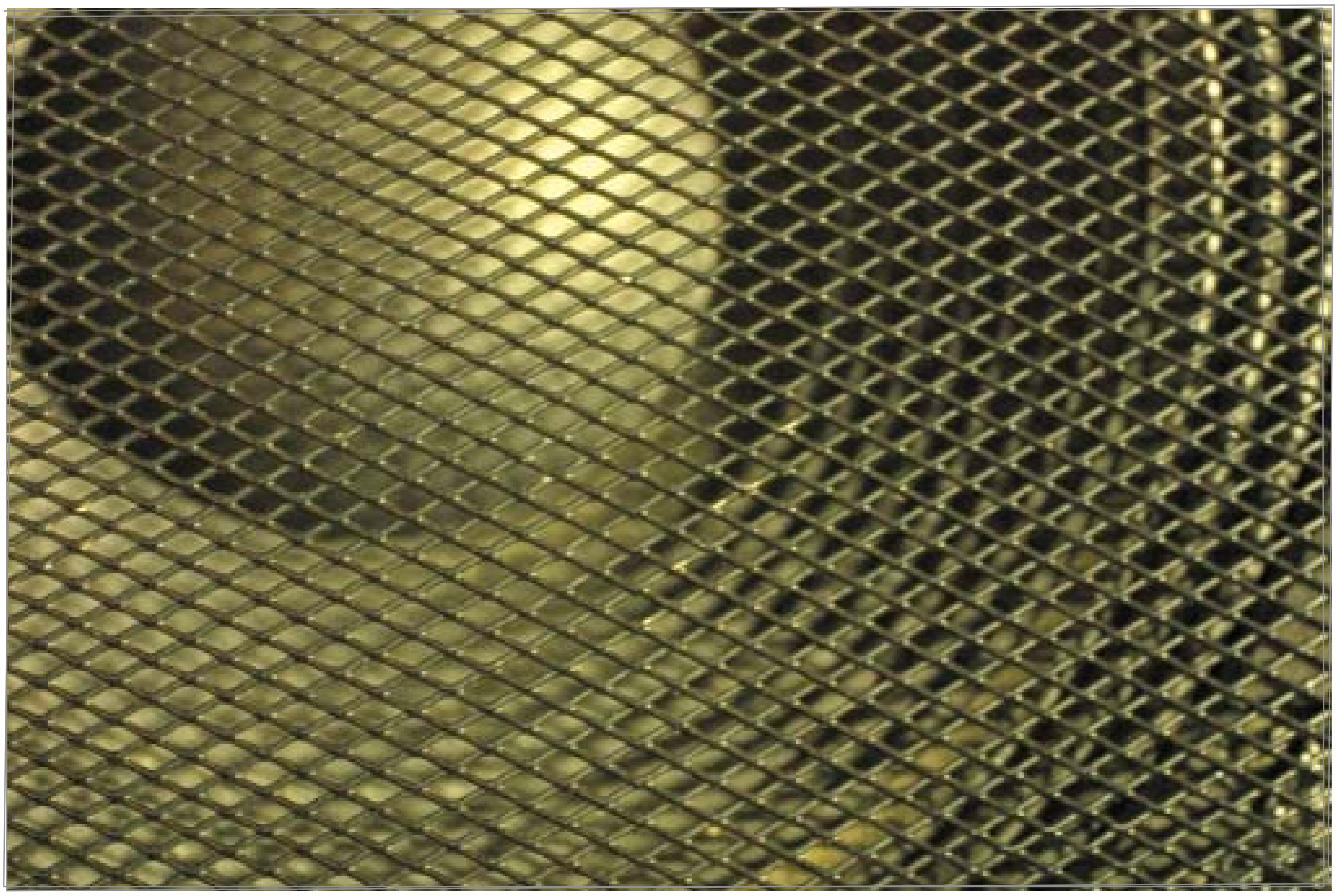
Box 2: Music and entertainment sectors

The recent EU directive on work-related noise requires Member States to work with social partners to produce practical guidance for the music and entertainment sectors, however they may be defined within different Member States. Moreover, the directive allows a transitional period of two years for these sectors whilst the guidance is being formulated. In the UK, the HSE has created two working groups (for live and recorded music) on which relevant social partners are represented to collaborate on producing practical guidance. The HSE would welcome collaboration with other Member States on this issue. Since many leisure premises and orchestras operate throughout the EU, there is a need to ensure some consistency in approach — notwithstanding the different legal systems within different Member States — across the EU.

WORKING WITH OTHERS

The noise programme will inevitably involve working with key partners (employee safety representatives, trade associations, insurers, etc.) to seek continued improvement with the limited resources available. On some issues, sharing experiences and expertise between Member States would also be helpful.

For further information on any of the issues mentioned in this article, contact Androulla (Andie) Michael at androulla.michael@hse.gsi.gov.uk.



Department of Occupational Hygiene, Istituto superiore per la prevenzione e la sicurezza del lavoro (ISPESL), Italy

Pietro Nataletti

The new Italian good practice manual for noise control in the workplace

Employers and workers need to know how to implement noise prevention and reduction measures in the workplace in order to comply with legislation and reduce the risk to workers. This article describes a good practice manual, being published in 2005, on the control and reduction of noise in the workplace.

Introduction

Italy's Istituto superiore per la prevenzione e la sicurezza del lavoro (National Institute of Occupational Safety and Prevention), which is the technical body of the Health Ministry, released in 2001 the first national guidelines concerning risk assessment and noise management in workplaces (10). The guidelines have stimulated the great interest of all those involved in occupational safety and health.

The ISPESL's Department of Occupational Hygiene, working closely with the Technical Committee for Occupational Safety and Health of the Regions and the Autonomous Provinces, has created a good practice manual for noise control and the reduction of noise in workplaces.

The manual includes the following information:

- the elements of physical acoustics necessary to comprehend the acoustic phenomena in all their aspects (generation, propagation, absorption and isolation);
- the classification of the most common acoustic sources within the industry and the acoustic materials;
- the currently available methods for reduction of exposure to noise at work; and
- a database concerning the technical measures for noise reduction carried out on the territory and the results obtained in terms of acoustic effectiveness and costs.

The ISPESL has promoted a national working group comprising the main public and private experts on noise whose primary aim is to elaborate the guidelines. In such a way, information and methodologies normally diffused within the limited context of the acoustics experts will be made accessible to the wider public.

This manual will be addressed, in particular, to the technicians and to the structures of the National Health Service — in view of their activity of prevention and vigilance in this field — and, more generally, to employers, advisers, workers and occupational safety workers.

The dissemination of the manual will be ensured through publication in the specialist press and on the ISPESL's website (11), by CD-ROM and through national workshops to ensure that all users receive detailed information.

Good practice manual articulation

The manual is structured on three levels. The first level, which represents the essential core of the document, is divided into nine chapters for simplicity and ease of reading:

1. Objectives and recipients of the guidelines
2. From the risk assessment to the strategy for risk reduction
3. Acoustic requirements for the design and noise-reduction programmes of industrial workplaces
4. Acoustic requirements for the design and noise-reduction programmes of specific workplaces
5. Acoustic criteria for the purchase of machinery, equipment and systems
6. Methods for reducing noise emitted by machinery, equipment and systems
7. Acoustic test of measures for reducing noise
8. Bibliography
9. Glossary

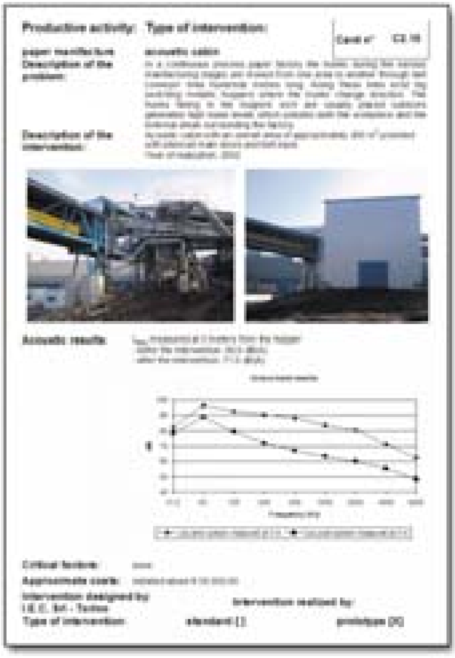
In addition to the traditional industrial sites, particular attention has been paid in the first level to other specific working environments such as schools, hospitals, offices, trading, and leisure activities. In the text, the reader can find links to the second level comprising more than 25 technical cards which analyse in greater depth technical concepts and practical aspects related to the criteria and the methodologies currently used for noise reduction.

The third level concerns the databases providing information on:

- legislation (national and European);
- technical standards (national and international); and
- materials and technologies related to noise reduction (noise absorption, noise insulation and vibration damping).

(10) ISPESL, *Linee guida per la valutazione del rischio rumore negli ambienti di lavoro (Guidelines for noise risk assessment in workplaces),* Rome, 2001 (http://www.ispesl.it/linee_guida/fattore_di_rischio/rumore.htm). English version available.

(11) http://www.ispesl.it.



Good practice example from the manual

A list of more than 50 interventions realised in various working environments is also given. Due to space limitation, only a paragraph from the first level and one example of field intervention included in a third-level database are given here.

EXAMPLE OF A 'TYPICAL' PARAGRAPH

The following text represents a synthesis of a 'typical' paragraph related to the first level of the manual, specifically the paragraph 'Noise control at source'.

Despite the reduction of machinery, work equipment, and system noise at source being primarily seen as a design issue, and therefore mainly associated with the creation of new machinery, it is nevertheless an important part of noise-reduction programmes regarding existing noise sources.

Key terms

Primary noise sources are mechanical or fluid elements that, associated with physical phenomena, generate noise (such as vibrating elements, liquids or gases with irregular flow, etc.).

Secondary noise sources are mechanical elements that do not constitute noise sources, but due to the transmission of noise waves and vibrations produced by the air, or by a mechanical structure, can irradiate acoustic energy (e.g. pipelines).

Classification of the primary noise sources

Mechanical sources

- Impulses — can be associated with specific working material movements (e.g. when using presses or hammers) or pieces falling, and represent one of the main causes of noise in manufacturing activities
- Micro impulses — associated with gears' rotation, rolling of bearings, interaction of tools with pieces in working, and transport systems
- Unbalancing of rotating and translating masses
- Friction
- Phenomena associated with magnetic fields, existing in electrical rotating machines (unevenness of magnetic field) or fixed machines (magnetostriction)

Sources due to liquids or gases in motion

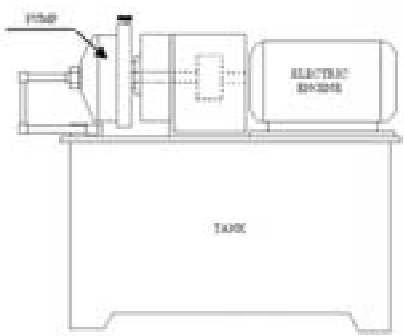
- Turbulence — an interaction of a liquid or gaseous flux with an obstacle (e.g. grid at the end of a pipe) or as an abrupt variation of the flow conditions (e.g. elbow in a pipe, exhaust jet of compressed air) or a flow interaction with a cavity or slots
- Pulsations — machines containing rotating elements often generate periodic volume and pressure variations of the fluid (gaseous or liquid) associated with emission of noise having tonal components
- Impulses — these usually occur when a fluid under pressure is abruptly put into the atmosphere (e.g. opening of valves) and can be generated with a frequency equal to or a multiple of the number of revolutions of some machines (e.g. high-pressure pumps)
- Cavitation — this occurs in a liquid when the gas pressure drops under the surface tension of the liquid, with the production of bubbles that implode when compressed

General rules

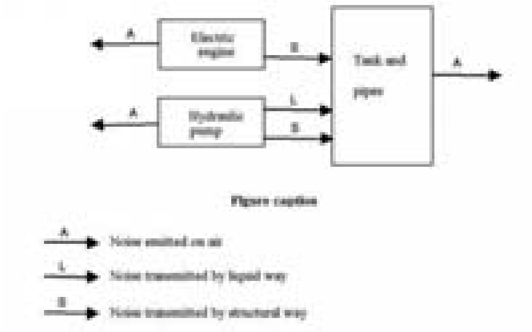
- Discriminate primary sources from secondary sources and the transmission paths of noise
- Identify, through measurements, calculations or experiments, the contribution of the various sources
- Control the sources that make the loudest noises first

Identification of priority criteria for noise control

Examination of a case



Noise sources of a hydraulic power supply



Transmission ways of noise

(approximately 1 000 events in 1999 against 7 000 in 1989). Nevertheless, it remains the main occupational disease in Italy, contributing more than 50 % to the total of reimbursed occupational diseases. During the last two statistically significant years (2000 and 2001), there were approximately 9 000 new reports of occupational hypoacuses.

In Italy, approximately 134 000 workers have permanent incapacity caused by hypoacuses and deafness due to noise, equivalent to 56 % of the total unearned income distributed by INAIL. The average degree of gravity of these hypoacuses is 24.2 % and the average age of the unearned income recipients is approximately 64 years ([14]).

One of the reasons for this situation is the difficulty of employers to avoid or reduce the risks arising from noise exposure at work by means of the technical and/or organisational measures defined by Article 41 of Legislative Decree No 277/91.

Particular efforts in this direction will be necessary in the near future due to the publication of the new EU Directive 2003/10/EC ([15]) regarding exposure to noise at work, which has to be transposed by the Member States by 15 February 2006. This directive contains several relevant innovations, for example the lowering of the daily exposure limit value by 3 dB from 90 dB(A), established by the former directive ([16]), to the present 87 dB(A).

Actions to reduce noise power levels

	Action performed	L_{WA} dB(A)	Remarks
	Machine in early state	90	
Action A	Engine and pump mechanically insulated from the tank	86	The structural transmission between the primary sources and the tank is predominant
Action B	Action A + tank moved away from primary sources	86	The tank is not a relevant source as the solid transmission has been eliminated
Action C	Action B + replacement of motor fan coil with a water cooling system	85	The fan contribution to the overall noise is lower than other remaining sources
Action D	Action C + acoustic shielding of the motor	80	The motor noise emission in air is very important

In order to identify the contribution of the single sources, several techniques can be used. In this example, some tests have been performed, and the noise power level L_{WA} has been measured step by step, as reported in the following table.

Final considerations

- The tank (a passive element) is the main noise source because of the structural transmission of the vibrations induced by the pump and the motor; therefore, it is necessary to reduce such transmission
- The motor and, at a lower level, the fan constitute important noise sources that need currently available measures for effective noise reduction

CONCLUSIONS

In Italy, 14 years after the regulation provided by Legislative Decree No 277/91 ([12]), noise exposure at work is still the most dangerous risk agent as regards its effects on workers' health.

At present, there are no reliable statistical data regarding the actual population of workers exposed to noise. Based on the notifications transmitted by many companies to the ISPESL, it can be assumed that the population that is exposed to a daily noise level ($L_{EX,8h}$) higher than 90 dB(A) is at least 100 000. The Istituto nazionale assicurazione

([12]) Legislative Decree No 277/91 of 15 August 1991 (Official Journal of the Italian Republic No 53 of 27 August 2001).

([13]) http://www.inail.it/.

ACKNOWLEDGEMENTS

The author wishes to thank all the members and collaborators of the national working group promoted by the ISPESL and the Technical Committee of Regions dealing with the elaboration of the good practice manual presented here. Special thanks, for their helpful and original contributions, go to Omar Nicolini (local health service, Modena), Iole Pinto (local health service, Siena), Marco Pirozzi and Aldo Pieroni (ISPESL), Giuseppe Elia (Modulo Uno, Turin), Angelo Chiattella (Electrotechnical Institute 'G. Ferraris', Turin), Alessandro Peretti (Italian Acoustical Association, Padua), Marco Vigone and Francesco Furnari (IEC, Turin) and Luigi Maffei (University of Naples).

([14]) Ministero della Salute (Italian Health Ministry), *Relazione sullo stato sanitario del Paese 2001–2002 (Report on national health status 2001–2002)*, Rome, 2003 (http://www.ministerosalute.it/; http://www.ministerosalute.it/imgs/C_17_bacheca_32_listaelencodocumenti_elen).

([15]) Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (17th individual directive within the meaning of Article 16(1) of Directive 89/391/EEC) (OJ L 42, 15.2.2003).

([16]) Council Directive 86/188/EEC of 12 May 1986 on the protection of workers from the risks related to exposure to noise at work (OJ L 137, 24.5.1986, pp. 28–34).

Project Manager, European Agency for Safety and Health at Work

Tim Tregenza

A stepwise approach to noise at work

Protecting workers from harm arising from noise at work can be approached step by step, this article argues.

European Agency for Safety and Health at Work

Noise is unwanted or harmful sound. Every day, millions of employees in Europe are exposed to noise at work and the risks that this can entail. One in five of Europe's workers have to raise their voices to be heard for at least half of the time that they are at work and 7 % suffer from work-related hearing difficulties ([17]). Noise-induced hearing loss is one of the most commonly reported occupational diseases in the EU ([18]). While noise is mostly recognised as a problem in industries such as manufacturing and construction, it can also be an issue in a wide range of other working environments, from call centres to schools, orchestra pits to bars.

A number of factors influence the potential risks from noise at work. The most obvious is perhaps its intensity ('loudness'), measured in decibels (dB), but the duration of exposure is also important, along with factors such as the impulsiveness of the noise, its frequency, measured in hertz, and the time distribution of its occurrence (i.e. when the sound occurs and how often).

What problems can noise cause?

Exposure to noise may pose a variety of health and safety risks to workers. Excessive noise damages the hair cells in the cochlea, part of the inner ear, leading to loss of hearing. In many countries, noise-induced hearing loss is the most prevalent irreversible industrial disease ([19]). There is evidence that exposure to noise has an effect on the cardiovascular system resulting in the release of catecholamines and an increase in blood pressure. Levels of catecholamines in blood (including epinephrine (adrenalin)) are associated with stress. Work-related stress rarely has a single cause, and may result from a range of risk factors, including noise in the work environment. Additionally, high noise levels make it difficult for staff to hear and communicate, which can raise the probability of accidents. Work-related stress (in which noise may be a factor) can compound this problem.

Sources of noise

Sector	Activity	Noise level
Agriculture	Pig feeding	104–115 dB(A) ([20])
Construction	Likely noise exposure of labourer during scabbling	100 dB(A) LEP,d ([21])
Emergency services	Firefighters exposed to impulse noises in excess of:	115 dB(A) ([22])
Education	Average noise exposure in nurseries	80.3 dB(A) ([23])
Engineering	Riveting	100–110 dB(A) ([24])
Entertainment	Orchestra — exposure of conductor during performance of Swan Lake	88 dB(A) ([25])
Fishing	Typical noise levels recorded in engine room	100–110 dB(A), with peaks up to 115 dB(A) ([26])
Healthcare	Removing a (plaster) cast	88–95.2 dB(A) ([27])
Manufacturing	Compressed air cleaning — workers' exposure	92 dB for eight hours ([28])
Textiles	Sewing shop ('atelier de couture')	90 dB(A) ([29])
Transport	Trucks (heavy goods vehicles) — driver exposure	78–89 dB(A) ([30])

([17]) EU-15 figures. Reported in Eurostat, *Work and health in the EU — A statistical portrait*, ISBN 92-894-7006-2.

([18]) EU-15 figures. Reported in European Agency for Safety and Health at Work, *Data to describe the link between OSH and employability*, 2002, ISBN 92-95007-66-2.

([19]) World Health Organisation, *Prevention of noise-induced hearing loss*, 1997.

([20]) Jackson, A., *Noise-induced hearing loss in the piggery*, DPI&F Note, Farmsafe Queensland, Australia, 2002.

([21]) Health and Safety Executive, *Noise in construction*, 1996.

([22]) Hilton, A. D., *Occupationally acquired hearing loss among civilian and active duty firefighters*, 2002, United States.

([23]) Voss and Hanson, 'Noise exposure of staff in children's daycare centres in Denmark 1997 to 1998', paper to the ICSV, Hong Kong, 2001.

([24]) Health and Safety Executive, 'Noise in engineering', Engineering Sheet 256, 1998.

([25]) Toppila, Laitinen, Olkinuora, Kuisma and Perälä, 'Development of hearing conservation programme for the Finnish National Opera', article for the 2001 International Congress and Exhibition on Noise-control Engineering, The Hague, Netherlands, 2001.

([26]) *Seafish: Noise and fishing vessels*, 1988.

([27]) Wiggens, C. E. and Brown, K. D., 'Hearing protection and cast saw noise', *Journal of the Southern Orthopaedic Association*, 5, 1996, pp. 1–4.

([28]) World Health Organisation, 'Occupational and community noise', Factsheet 258, 2001.

([29]) INRS, *Réduire le bruit dans l'entreprise*, 2003.

([30]) Van den Heever, D. J. and Roets, F. J., 'Noise exposure of truck drivers: A comparative study', *American Industrial Hygiene Association Journal,* 57, 1996, pp. 564–566.

REDUCING RISKS TO WORKERS

Eliminating or reducing workers' exposure to noise at work is not simply a legal responsibility for employers; it is also in an organisation's commercial interests. The safer and healthier the working environment, the lower the probability of costly absenteeism, accidents and underperformance. A common approach to reduce the risks to workers from noise at work is to follow a three-step process:

- assess the risks;
- based on the assessment, take steps to prevent or control the risks;
- regularly monitor and review the effectiveness of the measures in place.

ASSESSING THE RISKS

The degree and type of assessment will depend upon the scope and extent of the problem in the workplace, but all the risks arising from noise should be considered. For example:

- a workplace where there is very loud noise, perhaps including impulse noise (e.g. from rivet guns), may require a detailed noise survey;
- a workplace where there is a lot of vehicular activity may need to be more focused on reducing the risk of accidents caused by workers failing to hear warning signals;
- some organisations (e.g. emergency services) may be concerned about the ability of workers to communicate with one another in noisy environments over which they have little control;
- in some workplaces (e.g. the education or social and healthcare sectors), occupational noise may be just one of a number of stressors to which workers are exposed and so a holistic approach to the reduction of work-related stress is required in which noise reduction is just one part.

When carrying out the risk assessment, one should: identify the different noise-related hazards and risks in the organisation; consider who may be harmed and how, including temporary and part-time staff, as well as workers in specific risk groups such as employees who are pregnant; evaluate measures that are already in place to control noise levels, and decide what further action needs to be taken; then record all the findings and share them with workers and their representatives.

Without an adequate assessment of all the noise-related risks to which workers may be exposed, some risks may be missed, or workers overlooked (e.g. non-production workers such as cleaners can often be forgotten). For the employer, an inadequate risk assessment may lead to spending on control measures that are not targeted and may be an ineffective use of scarce resources.

Noise and pregnant workers

Exposure of pregnant workers to high noise levels at work can affect the unborn child. 'Prolonged exposure to loud noise may lead to increased blood pressure and tiredness. Experimental evidence suggests that prolonged exposure of the unborn child to loud noise during pregnancy may have an effect on later hearing and that low frequencies have a greater potential for causing harm.' (31)

Employers are required to assess the nature, degree, and duration of exposure of pregnant workers to noise (32) and, where there is a risk to the safety and health of the worker or of an effect on the pregnancy, the employer must adjust the working conditions of the pregnant woman to avoid exposure. The use of personal protective equipment (e.g. earplugs) by the mother will not protect the unborn child.

TAKE STEPS TO PREVENT OR CONTROL RISKS

There is a hierarchy of control measures that can be followed to ensure the health and safety of workers:

- elimination of noise sources;
- control of noise at source;
- collective control measures through work organisation and workplace layout;
- personal protective equipment.

Elimination of noise sources

The elimination of noise sources is the most effective way to prevent risks to workers, and should always be considered when new work equipment or workplaces are planned. A 'no-noise or low-noise' procurement policy is usually the most cost-effective way to prevent or control noise.

Control of noise at source

Should elimination of noise sources not be possible, the second objective should be to control the noise at source. This can involve looking at the noise source (often an item of work equipment) bit by bit to identify the main sources of noise (within the machine) and to see what can be done to control that noise.

The reduction of noise, either at its source or in its path, should be a major focus of noise management programmes, considering both equipment and workplace design and maintenance. A range of engineering controls can be used to achieve this, including:

- isolation of the source, via location, enclosure, or vibration damping using metal or air springs or elastomer supports;
- reduction at the source or in the path, using enclosures and barriers, mufflers or silencers on exhausts, or by reducing cutting, fan or impact speeds;
- replacement or alteration of machines, including belt drives as opposed to noisier gears, or electrical rather than pneumatic tools;
- application of quieter materials, such as rubber liners in bins, conveyors, and vibrators;
- active noise reduction ('anti-noise') which can in certain circumstances be used;
- carrying out preventive maintenance: as parts become worn, noise levels can change.

Collective control measures

Where noise cannot be adequately controlled at source, further steps should be taken to reduce the exposure of workers to noise. Collective control measures are broader than the previous measures to reduce

(31) Communication from the Commission on the guidelines on the assessment of the chemical, physical, and biological agents and industrial processes considered hazardous for the safety or health of pregnant workers and workers who have recently given birth or are breastfeeding (Council Directive 92/85/EEC).

(32) Council Directive 92/85/EEC of 19 October 1992 on the introduction of measures to encourage improvements in the safety and health at work of pregnant workers and workers who have recently given birth or are breastfeeding.

noise exposure. These involve workplace and organisation measures to reduce the number of workers exposed, the time in which they are exposed, and the routes by which they are exposed.

Measures can include changing the:

- workplace — sound absorption in a room (e.g. a sound-absorbing ceiling) can have a significant effect on reducing workers' exposure to noise, or by limiting access to particular work areas;
- work organisation (e.g. using working methods that require less exposure to noise, limiting working time in noisy environments, and access to noisy work areas); and
- work equipment — how work equipment is installed, and where it is located, can make a big difference to workers' noise exposure.

The ergonomics of any noise-control measure should be considered. When noise-control measures create difficulties for workers to carry out their jobs, the measures may be modified or removed, rendering them ineffective.

Personal protective equipment (PPE)

Only when all other noise-reduction and noise-control measures have been implemented should personal protective equipment (earmuffs, earplugs, etc.) be considered. Personal hearing protection can be very effective, but in the real workplace it can be difficult to select the right type of personal hearing protection, wear properly for long periods of time, and maintain so that it works effectively. In addition, wearing personal protective equipment, including hearing protection, can be very uncomfortable.

Issues to take into account when using PPE:

- ensure that the PPE chosen is appropriate for the type and duration of the noise. It should also be compatible with other protective equipment;
- employees should have a choice of suitable hearing protection so that they can select the most comfortable solution;
- many workers, such as drivers, police officers, pilots, and camera operators, need communication earmuffs or headsets, often with active noise cancellation (ANC), to ensure clear communication and to minimise risks of accident;
- the PPE should be correctly stored and maintained;
- training should be given on why the PPE is necessary, how it should be used, and how to store and maintain it.

INFORMATION AND TRAINING

Workers should receive information and training to help them understand and deal with the noise-related risks. This should cover:

- the risks faced, as well as the measures taken to eliminate or reduce them;
- the results of the risk assessment and any noise measurements, including an explanation of their significance;
- noise-control and hearing protection measures, including PPE;
- why and how to detect and report signs of hearing damage;
- when workers are entitled to health surveillance and the purpose of the surveillance.

EMPLOYEE INVOLVEMENT

Consulting the workforce is a legal requirement, and helps to ensure that the workers are committed to safety and health procedures and improvements. Using their knowledge helps to ensure hazards are correctly spotted and workable solutions implemented. Worker representatives have an important role in this process. Employees must be consulted on health and safety measures before the introduction of new technology or products.

REGULARLY MONITOR THE RISKS AND CONTROL MEASURES

Employers should check regularly that the measures in place to prevent or control noise are working effectively. Depending on their noise exposures, workers have a right to appropriate health surveillance. Where this occurs, individual health records must be kept and information provided to the employees. The knowledge gained from the surveillance should be used to review the noise risks and noise-control measures.

Finally, it is necessary to impose external checks to determine that the measures implemented to control noise in the workplace are actually working. The type and frequency of this monitoring and review will depend on the workplace and the exact nature of the risks faced, and national legislation may have specific requirements regarding health surveillance.

Austrian Social Insurance Agency for Occupational Risks (AUVA) —
Department for Accident Prevention and Occupational Disease Control (HUB), Austria

Ahmed Gaafar

Acoustics in indoor workplaces

This article describes how the examination of the acoustics of a workplace can lead to a real reduction in the exposure of workers to loud noise.

THE TRANSMISSION OF SOUND

Before dealing with acoustics in buildings, it is best to examine briefly the transmission of sound in the open air.

If, for example, sound is emitted from a machine operated outdoors, consideration must be given to the fact that part of the power supplied to the machine creates noise, which is known as the acoustic output of the machine. Because the operation takes place outdoors, this noise is transmitted in all directions without obstruction. Accordingly, the further people move away from the machine, the greater the area over which the sound is diffused by the time it reaches them. If a live microphone were to be moved away from the source of sound, the fact that its membrane is of a fixed size and that the sound input becomes increasingly 'thinly spread' causes it to receive an increasingly weak signal. If we use our ears as the receiver, we perceive that the sound becomes quieter and quieter as we move away from the source.

Another characteristic of sound diffusion in the open air is that, if an area is screened off, the audible sound in that area is restricted to those parts of the emitted acoustic output which are carried round the edges of the screen and to those which — if the screen lives up to its name — are filtered through at a far fainter sound level and are negligible in their effect. The sound behind the screen is ultimately restricted to the sound waves that either hit or brush past the screen. Waves diffused in other directions have no impact on the screened area.

In the case of the human voice, for example, where the sound source has a definite directional focus, a very marked difference in volume is registered if the speaker turns his or her head away from or towards the listener.

If the sound source is then moved indoors, however, the transmitted sound output is no longer freely diffused. Every part of it, in whatever direction it travels, very soon hits an enclosure boundary. How quickly it does so can easily be calculated by using the atmospheric speed of sound. A microphone placed inside a room therefore registers not only that part of the output which travels directly from the sound source to the microphone but also those parts that were originally carried in other directions but were deflected once, twice or several times by enclosure boundaries before finally arriving, in weakened form, at the microphone. The measured value is therefore higher than the number of decibels that would be registered at the same distance out of doors, all other things being equal. If an indoor microphone is moved away from the sound source, the sound level drops far more slowly than in the open air.

If we once again take our ears as the receiver in place of the microphone, it will be noticeable that the sound level is also higher indoors than outdoors at the same distance. There is a perceptible reverberation, and the acoustic signal sounds less sharp. If there are many sound sources in an indoor area and the various noises are unfamiliar, our ears find it difficult to locate sound sources and identify individual sounds. Holding a conversation is a strain, and tannoy messages are often barely comprehensible.

An attempt to protect oneself from noise in an indoor area by screening oneself off from the source will very often have disappointing results. Not only do sound waves penetrate or circumvent the screen, as in the open air, but much of the remaining sound is reflected by the enclosure boundaries into the screened area. The sound, we might say, spills over the barrier.

The degree of difference between values measured indoors and those measured outdoors depends very much on the extent to which the acoustic output bounces back from enclosure boundaries. Concrete, plastered masonry, glass, sheet metal and wood reflect more than 90 % of the sound that hits them. In conventional workplaces, noise levels are greatly increased by the acoustic properties of the surrounding surfaces.

REDUCING NOISE BY IMPROVING ACOUSTICS

For several decades, the Austrian Social Insurance Agency for Occupational Risks ([34]) has been offering free advice to businesses on noise-reduction measures in workplaces. In the course of this activity, it has become apparent that there are few working situations where no additional sound absorption is needed. Sometimes soundproofing is needed to keep noise levels below the critical value, a daily noise-exposure limit of 85 dB(A), but in far more frequent cases action is required to improve an unsatisfactory acoustic situation where noise levels are relatively low.

Recently, when AUVA needed data on workplace acoustics for its activity within a national standards authority, it was able to use the

([34]) http://www.auva.at/.

findings gathered by three employees in the course of their consultancy work over the past three to four years, during which time they measured sound reverberation in more than 250 enclosures. The bulk of the enclosures that were examined had a volume of between 50 and 10 000 m^3, while some individual enclosures were even larger, the greatest being more than 150 000 m^3 in volume. The median size was around 1 500 m^3, and half of the enclosures had a volume of between 400 and 5 000 m^3. See Figure 1.

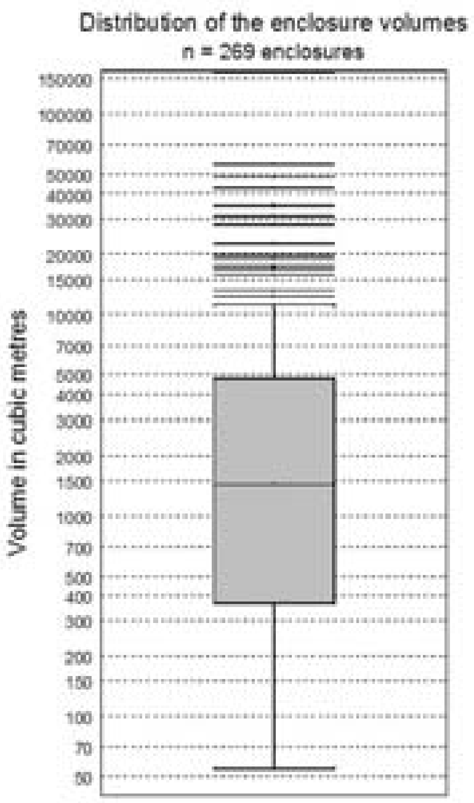


Figure 1: Distribution of the volume (m^3) of the 269 enclosures

When assessing the acoustics of an enclosed space, the reverberation time needs to be measured against the volume of the enclosure in question.

Measuring reverberation

The reverberation time is the time it takes for the noise level to fall by 60 dB from the initial level recorded when the noise was emitted. In practice, the time taken for a reduction of 30 or 20 dB is measured, and the reverberation time is extrapolated from this measurement. The main reason for using this method is that it is not easy to find a suitable source to produce an initial noise level that exceeds the normal ambient level by 60 dB.

AUVA normally uses shots from a signal pistol as excitation and records the process on a DAT. The equipment is easily portable and the duration of the measurement is so short that it can mostly be accomplished during a break in working time. The adequate quality of the results can be assured by applying the backward integration (BI) process on the impulse response (ISO 3382). This can be done either by using available software or an instrument with an installed BI option.

For areas in which good audibility is essential, such as lecture theatres or concert halls, an optimum volume-linked reverberation time is actually a quality criterion. 'Optimum' in this case means that the acoustic output must not be too 'live', i.e. insufficiently absorbed, in such auditoriums, but it must not be excessively deadened either. In shops, offices and factories, however, only a very small fraction of the acoustic output produced by the numerous sound sources performs a useful function as an 'information carrier'. The great bulk of the sound may be regarded as superfluous acoustic waste. Accordingly, it is scarcely possible to overdeaden the sound in such premises.

The assessment of the acoustics of an enclosed workplace on the basis of reverberation measurement must therefore answer the question whether the accumulated sound energy is being adequately reduced. One of the assessment criteria must be a minimum standard of sound absorption. To this end, the measured reverberation time, denoted by the letter T, is used to calculate the equivalent absorption area of the enclosure.

Let us imagine a room in which the entire sound-absorption capacity is concentrated in one surface, from which no sound at all is reflected. If the room is seen as a container into which acoustic output is fed, the equivalent absorption area is the only opening in the otherwise entirely sound-reflecting container through which sound can escape.

The equivalent absorption area A, expressed in square metres, is calculated by means of the following formula:

$$\mathbf{A = 0.16(V/T)}$$

where V is the volume of the space in cubic metres, and T is the reverberation time in seconds.

Like the reverberation time, however, the equivalent absorption area of an enclosure, taken on its own, is not a sufficient basis for assessing the adequacy of sound absorption. Larger enclosures, as well as having longer reverberation times, are more likely to have larger equivalent absorption areas than smaller ones. If the equivalent absorption area is divided by the total surface area of the enclosure in question, the result is a ratio that indicates the sound absorption of the enclosure. This means that the sum of the surface areas of the enclosure boundaries, i.e. the ceiling, walls and floor, is the reference value by which the equivalent absorption area is divided to produce the mean sound-absorption coefficient for the enclosure, which represents the average deadening of acoustic energy by the boundary surfaces. The mean sound-absorption coefficient (α_m) of an enclosure is calculated by means of the following equation:

$$\boldsymbol{\alpha_m = A/\Sigma S_i}$$

where S_i is the surface area of the i-th part of the total area of the enclosure boundaries in square metres.

Irrespective of the size of the enclosure, the mean sound-absorption coefficient provides information on the extent of its sound absorption. Since the acoustic characteristics of all objects are dependent on sound frequency, the reverberation time and the values derived from it are calculated accordingly. The six octave bands with centre frequencies of 125 to 4 000 Hz are taken into consideration.

The mean sound-absorption coefficients obtained from the aforementioned reverberation tests in the enclosures under examination are shown in Figures 2 and 3 below.

If all enclosures are taken into account (Figure 2), the most important octave bands in the range of 500 to 2 000 Hz produce a mean sound-absorption coefficient (α_m) of about 0.16 to 0.17. For 75 % of the enclosures, the coefficient is less than about 0.23.

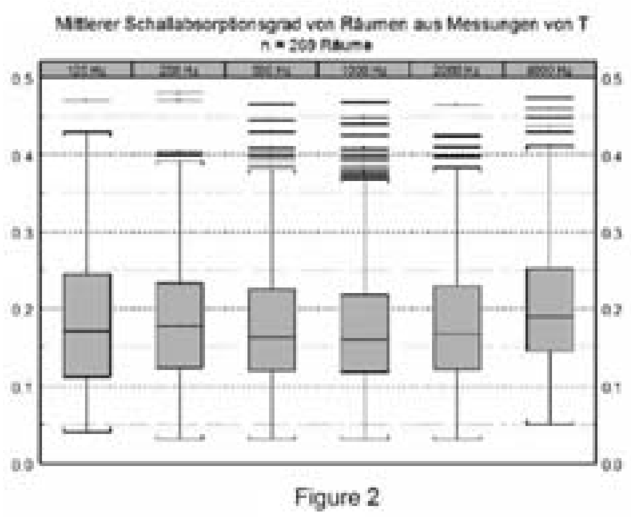


Figure 2: Mean sound-absorption coefficient of enclosures resulting from measurements of T (measured reverberation time) for 269 enclosures

Figure 3 shows the findings after elimination of the test results for those enclosures where it was clearly demonstrable that acoustic improvements had already been made.

The median value of the mean sound-absorption coefficient in the 500 to 2 000 Hz octave bands in this case is around 0.15 and is below about 0.18 in 75 % of the enclosures. Experience has shown, however, that the value of α_m needs to be at least in the region of 0.35 before sound absorption is adequate for noise-control purposes.

In order to attain this value, the enclosure boundaries, which generally means most of the ceiling and possibly parts of the wall surfaces, need to be fitted with sound-absorbing cladding. The disproportionately high cost often proves to be a deterrent to the upgrading of an indoor workplace, particularly when such a project is considered in terms of its impact on the current operational situation. Had due consideration been given to sound absorption at a sufficiently early stage of the planning process, however, provision could have been made for adequate sound absorption at little extra cost when the enclosure was first constructed. For this reason, it is advisable to formulate minimum standards of sound absorption in indoor working areas which planners can apply at the outset.

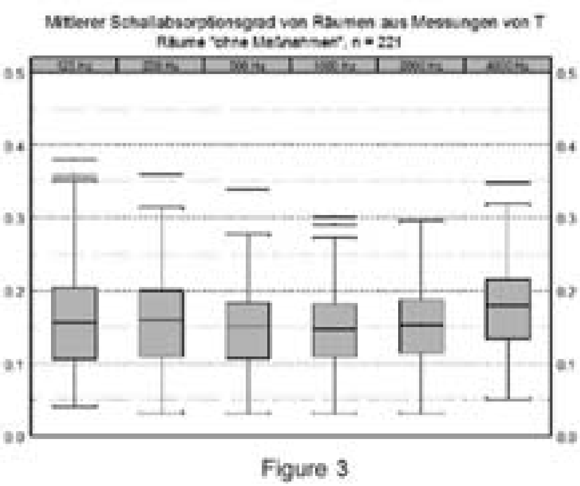


Figure 3: Mean sound-absorption coefficient of enclosures resulting from measurements of T (measured reverberation time) for 221 enclosures 'without improvement'

In standard EN ISO 11690 [34], the indicators used to describe the acoustics of an enclosure include the reduction in the noise level when the distance from the sound source is doubled and the reverberation time. These, however, would have to be supplemented by the calculation of the equivalent absorption area of the furnished enclosure in order to make a prediction and be able to compare the calculated values with the recommendations, but this means an acoustics expert performing the relevant calculations, which tend to be complex and time-consuming.

Austrian standard ÖNORM B 8115-3 [35] defines the equivalent absorption area of an enclosure as follows:

$$\mathbf{A = A_B + A_E + A_P + A_L}$$

where

$\mathbf{A_B}$ is the equivalent absorption area of the enclosure boundaries in square metres,

$\mathbf{A_E}$ is the equivalent absorption area of the furnishings in square metres,

$\mathbf{A_P}$ is the equivalent absorption area of the people within the enclosure in square metres, and

$\mathbf{A_L}$ is the equivalent absorption area of the air in square metres.

What makes it such an exacting task to forecast the value of A in respect of an enclosure is the need to insert accurate values for all four elements listed above and to predict the interaction of these elements, which might be done in accordance with EN ISO 12354-6, for example. It is far simpler to calculate only the equivalent absorption area of the enclosure boundaries (A_B), which is derived from the following equation:

$$\mathbf{A_B = \Sigma S_i \cdot \alpha_i}$$

where

S_i is the surface area of the i-th part of the total area of the enclosure boundaries in square metres, and

α_i is the sound-absorption coefficient of the i-th part of the total area of the enclosure boundaries.

The figure used for α_i is obtained from the values of the practical sound-absorption coefficient [36] for tested sound-absorbent constructions or from the typical values for concrete, windows, floor coverings, etc. [37]. Since planners can choose the properties of the enclosure boundaries, the value of A_B is calculable for them. By analogy with the calculation of the mean sound-absorption coefficient (α_m) of a whole enclosure, a mean sound-absorption coefficient can be calculated for the enclosure boundaries ($\alpha_{m,B}$) by means of the following formula:

$$\mathbf{\alpha_{m,B} = A_B / \Sigma S_i.}$$

Both experience and extensive calculations performed by Professor Judith Lang show that a value of about 0.25 is required for $\alpha_{m,B}$ in order to obtain a mean sound-absorption coefficient α_m of about 0.35 in a furnished workspace.

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(34) 'Acoustics — recommended practice for the design of low-noise workplaces containing machinery'.

(35) 'Sound insulation and architectural acoustics in building construction — architectural acoustics'.

(36) EN ISO 11654.

(37) Indicated in EN ISO 12354-6.

The 1996 version of ÖNORM B 8115-3 and, as far as can be predicted, the revised version currently being compiled both specify the frequency-dependent minimum values for both mean sound-absorption coefficients that will provide an enclosed workspace with adequate sound absorption. The mean sound-absorption coefficient of an enclosure (α_m) is especially suitable as a criterion for assessing the acoustics of existing enclosures. Nevertheless, it could also serve as a criterion to be applied in the planning process if the calculations it entails did not act as a deterrent.

The benefit of the mean sound-absorption coefficient of the enclosure boundaries ($\alpha_{m,B}$) is that its application requires planners to determine only the surface properties of parts of the enclosure boundaries and the values of their sound-absorption coefficients. The ensuing calculations are straightforward and do not require the services of an acoustics specialist.

The mean sound-absorption coefficient of the enclosure boundaries ($\alpha_{m,B}$) would also be a very suitable criterion for the specification of statutory minimum values, because it provides the requisite basis for adequate sound absorption, computational evidence of the appropriate choice of construction and dimensioning of the sound-absorbent surface areas, and the information it imparts can be verified by anyone without training in acoustics when planning documents are submitted. A check of the completed enclosure, however, which might be necessary in case of doubt, would certainly have to be conducted by an expert capable of performing the more complex and time-consuming calculations that could be required.

CASE STUDY — REDUCING REVERBERATION

A company manufacturing trailers and special superstructures had built a new production shed. It soon became apparent that it was disagreeably loud inside the shed. Although assembly work accounts for the bulk of the company's operations, they also involve the use of angle grinders, hammers, power drills and power screwdrivers.

Sound absorption in the shed was very low. The mean sound-absorption coefficients obtained from a reverberation test in the octave bands from 500 to 2 000 Hz lay between 0.14 and 0.11. Appropriate acoustic measures could certainly increase the sound absorbency of the building. While using angle grinders, hammers, power drills and power screwdrivers, workers would still have to wear ear protectors to protect their hearing. Better acoustic properties do not help workers who use such noisy tools. Improvement measures would, however, benefit all people in the shed not using noisy tools, because they would not need ear protectors whenever someone else happened to be working on a component part some distance away.

Cube-shaped sound absorbers were hung from the ceiling, and a second reverberation test was conducted. On the basis of the results of this test, some of the wall surfaces were clad with laminated sound-absorbent panels. The final reverberation test resulted, as expected, in a mean sound-absorption coefficient of 0.30. The improvement is so clearly perceptible that no further action is needed.

A more than adequate level of sound absorption can be achieved through the prudent planning and construction of production sheds. If the noise situation in very many workplaces is to be substantially improved or even made acceptable, measures designed to improve the acoustic properties of the enclosure are advisable and indeed, in some cases, imperative. An even more important message, however, is that the planners of working premises must bear in mind that human beings have ears as well as eyes.

Case study illustrations

Ergonomics and Physical Environmental Factors Division,
Berufsgenossenschaftliches Institut für Arbeitsschutz (BGIA), Germany

Eberhard Christ

Acoustic measures in sheltered workshops

When examining protection measures for workers, it is necessary to take into account any special requirements for particular groups of workers. Pregnant workers are one group who may need particular preventive actions, workers with disabilities are another.

Introduction

Since 1986, uniform minimum health and safety requirements on risks related to exposure to noise at work have applied to all Member States of the European Community by virtue of Directive 86/188/EEC ([38]). By the time of its adoption, hearing impairments caused by workplace noise were already one of the most common conditions being registered in the annual statistics for newly reported occupational diseases.

The directive required employers to assess and, where necessary, measure the noise levels to which their employees were exposed and to establish whether workers' daily personal exposure to noise exceeded fixed limit values. If the limit of 90 dB(A) is exceeded, the employer must draw up and apply a programme of technical and/or organisational measures with a view to reducing noise exposure to the lowest practicable level.

The directive lays special emphasis on the proven fact that the most effective way of reducing noise levels is to incorporate noise-prevention measures into the design of workplaces and to choose materials, procedures and working methods which produce less noise, and it identifies this reduction at source, in other words collective protection, as the priority aim. If the technology in use cannot be operated at acceptable noise levels, individual protection in the form of personal hearing protectors is to be used to reduce exposure below the limit of 85 dB(A). The principles governing protection from noise-related risks that were established back in 1986 were laid down as general guidelines in the 1989 Framework Directive 89/391/EEC ([39]).

A revision of the 1986 directive entered into force in 2003 ([40]). It is to be transposed into national law by 15 February 2006 and supersedes the provisions of the 1986 directive. There are essentially no major changes other than a reduction of the exposure limit value to 87 dB(A) and of the upper and lower action values to 85 dB(A) and 80 dB(A) respectively.

([38]) Council Directive 86/188/EEC of 12 May 1986 on the protection of workers from the risks related to exposure to noise at work (OJ L 137, 24.5.1986, pp. 28–34).

([39]) Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (OJ L 183, 29.6.1989, pp. 1–8).

([40]) Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (17th individual directive within the meaning of Article 16(1) of Directive 89/391/EEC) (OJ L 42, 15.2.2003, pp. 38–44).

In Germany, rules governing protection against workplace noise in accordance with the 1986 directive had already been put into force in 1974. The German legislation also accords priority to technical and organisational measures, preferably at source, within the bounds of the available technical solutions. It also lays down that action designed to improve the acoustic properties of indoor workplaces should be incorporated into the technical noise-reduction measures. It is common knowledge that conventional industrial buildings increase the noise emitted directly by machinery by reflecting the sound waves off walls, floors and ceilings. The indicators of noise emission from machinery at workplaces, which are measured and communicated by the manufacturer in accordance with the requirements of the Machinery Directive 98/37/EC ([41]), are adjusted for the effects of sound reflection (environmental factor) for the sake of comparability. In order to assess, during the planning process, whether workplaces are likely to be noisy, this environmental factor has to be reincorporated into the equation. The average environmental factor for conventional factory buildings is about 5 dB(A). The aim of acoustic improvements is to reduce the extra noise generated by reflection to between 1 and 2 dB(A). Since oral communication is particularly important in training and production workshops for people with disabilities, the use of ear protectors can pose problems. For this reason, particular importance attaches to measures designed to improve the acoustic properties of the working area. The purpose of this article is to outline the problem and to present a useful model for the effective acoustic design of workshops.

The importance of acoustics in sheltered workshops

Training people with disabilities to develop their specific skills and enabling them to progress to mainstream employment are paramount social obligations of the entire human community. People with disabilities require special support, and their health and safety in the workplace require special protection. There is therefore good reason why people with disabilities should enjoy the special protection accorded to risk groups under Article 15 of Framework Directive 89/391/EEC. The new directive on exposure to noise at work, Directive 2003/10/EC, cites that provision in its Article 5(5), which requires employers to adapt noise-abatement measures to the requirements of workers belonging to particularly sensitive risk groups.

So what does this mean in terms of protection from noise exposure in sheltered workshops? The people working in these facilities need considerably more guidance and attention than employees without

([41]) Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery (OJ L 207, 23.7.1998, pp. 1–46).

disabilities. This implies a need for more frequent communication by word of mouth. The noise that is generated in workshops by metalworking or woodworking, for example, severely restricts oral communication. Carers have to speak more loudly, and their clients find it far harder to understand the spoken word. This puts the carers at risk of straining their voices. As a result, carers may have to give up their work prematurely because of vocal problems. Clients are liable to misunderstand advice and instructions. This leads to more frequent mistakes in the performance of their work or even to accidents caused by failure to identify a source of danger in time. Workshops with no built-in sound-absorption measures often sound reverberant. This impression is borne out by lengthy reverberation times. Long reverberation times diminish people's ability to locate sound sources. Unfamiliar sources of sound, in particular, become harder to pinpoint. A sense of increased insecurity is created, which people try to overcome by frequently looking around. By taking their eyes off their work, they increase the risk of accidents. Sound-absorption measures in the fabric of the building reduce this problem by making it easier for people to tell where noises are coming from and giving them the necessary sense of security that comes from being able to locate the source of unfamiliar sounds simply by hearing them.

These noise-related problems do not only materialise at the limit value for hearing impairment defined in the relevant legislation but even at lower noise levels exceeding 70 dB(A). It is therefore important to ensure that the general acoustics of the premises in which people with disabilities work are improved with a view to creating optimum physical conditions for oral communication and acoustic orientation. This can be achieved with relatively little additional outlay by retrofitting existing workshops. The most economical solution, however, is to ensure that acoustic requirements are taken into account at the planning stage whenever new workshops are built.

The main sources of noise in sheltered workshops are typically metalworking and woodworking processes. Where these activities occur, sound-absorption measures should always be taken, including retrofitting of operational workshops. In the case of new buildings, it must be borne in mind that the sort of contracts awarded to sheltered workshops can change frequently, with the result that facilities for noisy processes can be required at short notice. Experience has shown that areas previously used for quiet assembly work are pressed into service as woodworking or metalworking shops even though these areas do not meet the appropriate acoustic standards. Given that new workshops may be expected to have a lifespan of about 20 years, they should be designed for maximum adaptability to a changing workload. It is therefore recommended that all workplaces, including those not initially used for noisy processes, should be designed in accordance with the acoustic criteria described below.

ACOUSTIC DESIGN CRITERIA FOR SHELTERED WORKSHOPS

In joint projects on the protection of workers from exposure to noise, the Institute for Occupational Health and Safety of the German Employers' Accident Insurance Schemes (Berufsgenossenschaftliches Institut für Arbeitsschutz ([42])) and the accident insurer covering employees in the field of health and social services (Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW)) have piloted acoustic improvements in numerous sheltered workshops and, on the basis of these pilot schemes, have developed criteria for optimum workshop design.

([42]) http://www.hvbg.de/d/bia/.

According to their findings, the average sound-absorption coefficient $\bar{\alpha}$ in workshops should be at least 0.3. This means that the enclosure boundaries, i.e. floor, walls/windows and ceiling taken together, should absorb an average of at least 30 % of the sound. Conventionally constructed workplaces with no sound-absorption measures have been shown to absorb between 8 and 10 % of sound ($\bar{\alpha}$ = 0.08 to 0.1). Since neither the floor nor the window surfaces can be used to improve sound absorption, it is standard practice to incorporate highly sound-absorbent surfaces into the ceiling. The sound-absorbent materials used for this purpose should have an average sound-absorption coefficient of at least 0.9 in the octave bands with centre frequencies of 500, 1 000, 2 000 and 4 000 Hz. The appropriate performance ratings are indicated by the suppliers of sound-absorbent materials.

In an acoustically optimised workshop, the effect of distance on the reduction in sound propagation can be measured by using a point sound source over a linear distance of at least 6 m. The measurement distance is doubled from each reception point to the next (these points are located at 0.75, 1.5, 3 and 6 m from the sound source). The measured sound-level difference is the average of the three differences between the noise levels from adjacent reception points and should amount to at least 4 dB(A). If this measurement is made in an existing enclosure to which no additional sound-absorbent material insulation has been fitted, the propagation of sound will normally be reduced by only 1.5 to 2 dB(A) when the distance from the sound source is doubled. These figures compare with a noise decrease of about 6 dB(A) in the open air, where sound is not reflected by enclosure boundaries.

These empirical values, which have already been corroborated by practical experience in numerous sheltered workshops in Germany, should be used to calculate the required area of sound-absorbent material. In the case of new buildings, such absorption areas should be directly integrated into the wall and ceiling design; in existing workplaces, it should be added in the form of a suspended ceiling.

EXAMPLES OF ACOUSTIC IMPROVEMENTS IN SHELTERED WORKSHOPS

Except in cases where they are housed in old factory buildings, sheltered workshops are generally built as single-storey flat-roofed sheds. The basic architectural model is often a concrete- or steel-frame construction roofed with profiled steel. The wall surfaces comprise concrete slabs or steel panels and windows.

A newly erected carpentry workshop (see Figure 1 — flat-roofed industrial unit, concrete-frame construction, profiled-steel roof with roof lights) proved to be highly reverberant once it became operational. The noise emitted by machinery exceeded the limit value for hearing impairment, which meant that hearing protectors had to be worn. The sound-propagation characteristic was reduced by an average of only 2 dB(A) when the distance from the sound source to a receiver was doubled. The mean sound-absorption coefficient $\bar{\alpha}$ was assumed to be 0.1, which corresponds to 10 % sound absorption. In order to achieve the average sound-absorption coefficient of 0.3, there was therefore a need to fit additional sound-absorbent material that would absorb another 20 % of the noise within the enclosure.

The highly absorbent material selected for this purpose comprised fleece-coated rigid mineral-wool panels which met the sound-absorption criterion of $\alpha > 0.9$ in the frequency range of 500 to 4 000 Hz (octave band centre frequencies). The panels were laid in a grid of light aluminium rails and suspended about half a metre below the ceiling.

Figure 1: Sound-absorbent suspended ceiling in the carpentry workshop

Underneath the skylights, transparent plastic grating was inserted into the supporting grid in place of the absorption panels. The sound-absorbent suspended ceiling did not impair the downward circulation of the air sucked out by the machinery. The subsequent measurement of the reduction in sound propagation showed that sound levels were reduced by an average of 4 dB(A) when the distance between the source and receiver was doubled.

It costs less to integrate sound absorption into the ceiling at the planning stage. In the case of a steel-framed workshop unit for metalworking operations, this was done by selecting a sound-absorbent form of profiled-steel roofing (see Figure 2).

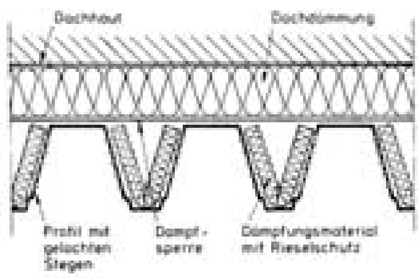


Figure 2

Sound-absorbent profiled-steel roofing modules: In this cross-section, the roof insulation is sandwiched between the roof sheeting and the barrier layer. Below this is the V-shaped profile with perforated web containing the absorbent material enveloped by sound-transmissible film to protect against fall-out of fibres.

Because of the structural support function of the ceiling, only part of the metal surface can be perforated, and for this reason the ceiling surface has a lower sound-absorption coefficient, ranging from 0.75 at 500 Hz to 0.55 at 4 000 Hz. This is still significantly better, however, than the non-perforated profiled-steel roof of the carpentry workshop described above, which is almost completely reverberant. Even without the addition of any further absorbent material, the mean sound-absorption coefficient in the flat-roofed production unit amounts to $\bar{\alpha} = 0.25$. Only a small area of additional absorbent material needs to be incorporated into the wall surfaces to achieve a mean sound-absorption coefficient of $\bar{\alpha} = 0.3$.

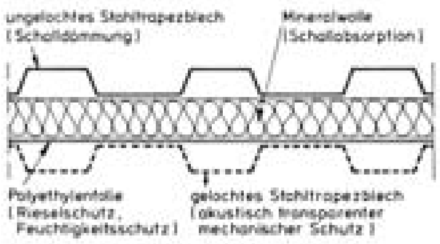


Figure 3

Sound-absorbent profiled-steel wall modules: In the cross-section, there is the non-perforated profiled-steel plate (sound insulation) on the top of the section ('ungelochtes Stahltrapezblech) above the mineral wool (thermal insulation sound absorption), with a layer of sound-transmissible polyethylene foil — humidity protection and protection against fallout of mineral fibres. over the perforated profiled-steel plate that provides mechanical protection. A larger area of this wall can be perforated than is the case with a profiled-steel roof, which means that this type of wall achieves a mean sound-absorption coefficient ranging from 0.9 at 500 Hz to 0.7 at 4 000 Hz.

Figure 3 shows a type of profiled-steel wall cladding in which a layer of mineral-wool thermal insulation, which is a standard component of the product, also serves to absorb sound. A larger area of this wall can be perforated than is the case with a profiled-steel roof, which means that this type of wall achieves a mean sound-absorption coefficient ranging from 0.9 at 500 Hz to 0.7 at 4 000 Hz. Figure 4 shows the equipped metalworking unit with the sound-absorbent profiled-steel ceiling. Figure 5 shows details of the ceiling elements.

Figure 4: Metalworking unit with sound-absorbent profiled-steel ceiling

Figure 5: Close-up of the sound-absorbent profiled-steel ceiling

Both the addition of a sound-absorbent suspended ceiling and the more cost-effective option of including ceiling and wall elements with integrated sound absorption in the original building fully achieved the desired aim of creating an atmosphere in which people with disabilities could work in production facilities with noisy machinery without acoustic discomfort.

Finnish Institute of Occupational Health ([43]), Tampere University Hospital ([44]), Finland

Esko Toppila, Heli Laitinen and Ilmari Pyykkö

Effects of noise on classical musicians

In modern society, oral communication has an increasing importance. If hearing problems exist, they make communication more difficult especially in noisy working environments. For classical musicians, hearing is an important tool. Even minor problems increase stress and decrease job satisfaction. The music and entertainment sectors face particular challenges over the exposure of workers to noise as the function of many workers is to produce sounds. This article looks at some of the issues relating to the exposure of musicians to noise.

Noise exposure of classical musicians

Although from a musician's point of view it is inappropriate to talk about noise, this term is used throughout this article. For acousticians, noise means unwanted or harmful (to hearing) sound. In this sense, it is justified to speak about noise when discussing a classical piece. Among musicians, there is a general belief that classical music cannot cause hearing loss and thus cannot be called noise.

Measurements show that classical musicians are exposed to quite high noise levels (see table). The exposure occurs during performances, group rehearsals and personal rehearsals. Measurements have shown that all of these are equally important in the total exposure. The typical daily exposure time of a musician varies from five to six hours.

Typical exposure level of classical musicians in an opera orchestra

Instrument	Exposure (dB(A))
Viola	86
Cello	86
Double bass	83
Flute/piccolo	95
Other woodwind instruments	89
Brass	92–94
Harp	87
Percussion instruments	95

Hearing symptoms among musicians

High-level studies on the hearing loss of classical musicians have given controversial results. Many researchers have found that musicians' hearing levels correspond to those of the non-exposed population. Some researchers have found signs of noise-induced hearing loss in audiometry. However, it is safe to state that the hearing loss of classical musicians is less than exposure measurements have led us to expect.

Among musicians, hearing loss is often coupled with permanent tinnitus. Neither of these can be cured. In some cases, permanent tinnitus may disappear after some years. When hearing loss is moderate to severe, it leads to speech distortion and reduced word discrimination. Reduced oral communication is a social handicap. Hearing loss also reduces the awareness of warning signals, environmental sounds and music. Consequently, hearing loss may lead to social isolation, decreased worker productivity and morale, and an increase in job-related accidents. Especially for musicians, hearing loss may cause difficulties in playing and understanding speech in rehearsals.

To develop a hearing loss may take several years. But in some cases the hearing losses and tinnitus may appear suddenly. Recently in Finland, several musicians have suffered permanent tinnitus when playing classical music and too high blasts were used as special effects.

Less attention is being paid to 'minor' hearing symptoms such as permanent tinnitus, hyperacusis, and temporary tinnitus after playing. These symptoms can influence musicians' ability to work to full capacity, and therefore they should be acknowledged as an important part of musicians' healthcare.

In a study carried out in Finland, temporary tinnitus was experienced by 41 % of the musicians studied after group rehearsals and 18 % after personal rehearsals. In addition, 15 % of the musicians had permanent tinnitus. These figures are quite high compared with normal populations about 15 % of whom experience temporary tinnitus and 2 % permanent tinnitus. Although annoying, tinnitus is seldom disabling. In the worst cases, tinnitus may disrupt normal sleep.

Almost half of the musicians had experienced hyperacusis (43 %). The pain was described as smart, sharp pain, ripping, grating, jarring pain, sense of pressure, distortion of sounds, humming in the head, stuffed ears, nausea, and warm feeling in the ear.

Until recently, it was not acceptable among musicians to discuss hearing problems. The first symptom that was generally acceptable was tinnitus. A lot of information was gathered before this happened. Today, a musician can speak freely about tinnitus but still hearing loss and other symptoms are not discussed freely among colleagues. This has considerably delayed research on musicians' hearing.

([43]) http://www.ttl.fi/internet/.
([44]) http://www.tays.fi/.

MUSICIANS' RELATION TO WORK

Musicians like their work. In the study, 78 % of the musicians thought that their work is inspiring and meaningful and 80 % are devoted to playing. Nevertheless, the work is considered to be strenuous by 40 %. The work is also quite stressful, with only 5 % not feeling stress and 33 % suffering considerable stress. There are many causal factors of stress, such as tight schedules and health in general. Musicians who suffered more from stress also felt that their health was worse than those who had less stress.

Musicians' relation to work

In the study:

- 38 % of musicians found group rehearsals and performances noisy;
- 15 % found their personal rehearsals noisy;
- 70 % of musicians worried about their hearing.

USE OF HEARING PROTECTORS AMONG MUSICIANS

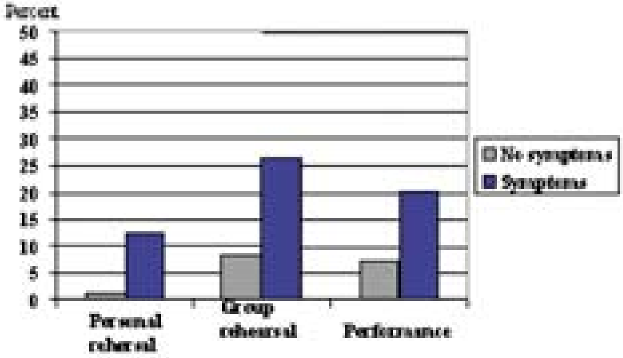
For musicians, special hearing protectors with flat attenuation have been developed. Most of the types are custom-moulded plugs but reusable plugs also exist. Although many orchestras have provided them to musicians free of charge, they have been abandoned after only a short period of use. Those who used hearing protectors explained that they did so because they were afraid of hearing loss or tinnitus. Other reasons were to avoid pain, to protect ears from fatigue and to decrease stress and irritation.

The following reasons were identified for not wearing hearing protection:

- hinders own performance;
- difficult to hear others play;
- sensation from hearing protectors is unpleasant;
- difficult to fit;
- existing hearing loss makes use difficult;
- communication problem in rehearsals;
- belief that music cannot harm the hearing.

The unique feature strongly affecting the use of hearing protectors is the requirement to be able to hear low levels (pianissimo) and high sound levels purely. Good hearing of high sound levels is restricted by hyperacusis. This can often be eliminated by the use of hearing protectors. However, high attenuation of hearing protectors has an impact on the hearing of low levels especially if hearing loss already exists. Another problem with hearing protectors is related to how sound enters the ear. Partially, the sound of the musician's own instrument enters the ear via bone conduction. This has the consequence that the balance between the own instrument and the instruments of others is different from that which the audience hears. This balance is naturally affected by the use of hearing protectors; more sound is coming via bone conduction. Thus, when a musician starts to use hearing protectors, he/she has to get used to a different balance between his/her own instrument and other instruments. This takes time and therefore needs high motivation. The problem worsens if the hearing protectors have a high attenuation. The musicians should indeed use hearing protectors that attenuate as little as possible.

For musicians, symptoms of hearing impairment seem to be the best reason to use hearing protectors. Those who had symptoms used hearing protectors up to 10 % more often than those without (see figure). This indicates that many of the obstacles presented above can be overcome if there is more time to get accustomed to hearing protectors. Still, the usage rates are quite low. Only 20 to 25 % of musicians with hearing impairment symptoms used hearing protectors in group rehearsals and performances. The usage rate is even lower in personal rehearsals. These low usage rates make the effect of hearing protectors negligible. However, the increased usage rate described in the previous section can be achieved if there is a good reason to use hearing protectors.



The effect of hearing impairment symptoms to use of hearing protectors on different occasions among musicians

Hearing impairment symptoms have a clear impact on stress. Stress was three times more common among musicians with hearing loss than among those without. Stress caused by hyperacusis was nine times more common and the corresponding figure for tinnitus was five. Also, the working environment was felt to be three to ten times noisier among those with hearing impairment symptoms. Thus, hearing impairment symptoms have a clear negative impact on musicians' well-being at work.

CONCLUSIONS

The economic basis of our society — the way that people make their living —underwent fundamental changes during the last half of the 20th century. The important changes include dependence on communicative skills and increase in environmental noise exposure. In the past, we depended largely on manual labour. Today, we are an increasingly service economy and we rely more and more on communication skills — hearing, speech and language. About 13 % of Europeans have a communication disorder that almost exclusively results from hearing impairment. It is the main disability in western countries. It compromises education, job opportunities, productivity and satisfaction, and leads to isolation and a significant decrease in quality of life.

Classical musicians are a good example of people who are highly dependent on their hearing. Hearing gives them the feedback about their playing. In addition, they have to listen to the conductor in rehearsals.

Returning to the question of whether or not classical music is noise, although evidence about hearing loss is contradictory, there is a high prevalence of tinnitus and hyperacusis. These symptoms increase stress and thus make the working environment feel noisier. Therefore, classical music is by definition noise.

AkustikNet A/S ([45]), Denmark

Palle Voss

Noise in children's daycare centres

Palle Voss has been responsible for a large number of national and transnational projects concerning noise and vibration in the working environment. He is now the chief executive officer for AkustikNet A/S, a company of consulting engineers specialised in acoustics, noise and vibration. AkustikNet A/S is the Danish partner in Associated European Acoustics Consultants.

Noise in children's daycare centres has been a very frequent topic of discussions, and is ironically very often seen from the adult point of view. It is, at least in Denmark, the noise exposure of the staff that is most often discussed. Physicians have debated about the magnitude of the risks of hearing impairment as a result of the noise arising from many children in the same area. Regardless of these risks, it is a fact that economic considerations together with change in family patterns have created factory-like institutions where our children are taken care of, often daily for long periods of time, while the parents are busy providing the two full incomes that are considered necessary for the young modern family.

The activities of many children in small spaces create noise, which most experts would consider harmful for the people working with the children. It is rarely discussed what effect this daily exposure to high noise levels has on the children themselves.

Investigation of the interior environment

During the winter of 1997–98, the staff's union of employees in children's daycare centres took the initiative to investigate the interior environmental parameters in Danish daycare centres for children ([46]). The centres were divided into nurseries (age $^1/_2$ to 3 years), kindergartens (age 3 to 6 years) and the so-called SFOs ('skole og fritidsordning' — leisure centres for schoolchildren to attend after school).

A large number of institutions were chosen so that they together were statistically representative of all such centres in Denmark. The physical parameters chosen to describe the interior environment were:

- noise;
- reverberation time;
- CO_2;
- relative humidity;
- room temperature.

This article focuses on the issues related to noise.

Measurements of acoustics and noise

For each of the 176 participating institutions, a single room was selected. In this room, noise was measured for one working week. At the same time, noise was monitored in one more activity room in order to check that not all noisy activities had been moved to the room where a large amount of measurements were made.

Noise measurements were performed using both personal noise dosemeters on the staff working in the chosen room (one to three dose measurements per day) and a PC-based monitoring system with a fixed microphone position in the room. The measurements with a fixed microphone position were used for two purposes:

1. to compare with the dosemeter measurements in case of unexplainable events; and
2. to provide a better statistical background to describe the variation in the noise during both the workday and over the full week.

No attempt has been made to choose special periods in which all the children were in the room. If the children were out of the room (e.g. playing outside), then, of course, the dosemeter would follow the carrier but the static microphone would reveal the lack of activity in the room.

Simultaneous with the noise measurements, the staff filled out a log (once an hour) noting the number of children in the room, the number of attendants in the room and the nature of the activities.

The staff were instructed to maintain the normal procedures, meaning that, if they went away for a day, no measurements were performed on that day. This was considered part of the statistics in forming the full picture of the noise situation.

A total of 10 PC-based noise-surveillance monitors and 35 noise dosemeters were applied. In addition, the reverberation time was measured for all rooms in this project (176 = one per centre).

The dosemeter measurements led to a direct determination of a person's noise exposure, defined by the Danish authorities as the A-weighted, energy equivalent sound pressure level for an eight-hour working day ($L_{A\,eq,\,8h}$ in dB re 20 µ Pa). For both types of measuring equipment, noise can be measured for any chosen duration of time. $L_{A\,eq,\,1\,min}$ was chosen as the basic measurement parameter.

The stationary equipment was also set up to measure $L_{A\,eq,\,1\,min}$ values. Thus, the two types of equipment facilitate the possibility of having time-matched $L_{A\,eq,\,1\,min}$ values. Time-matched $L_{A\,eq}$ values calculated for one-hour periods have been applied. The result of the stationary measurements is in this way used as a sort of backup for the dosemeter measurements and as an extension of the statistical material for the single centre.

([45]) http://www.akustiknet.dk/.
([46]) The full report, entitled *Støj og indeklima*, is available for download (in Danish) at http://www.bupl.dk/web/internet.nsf/0/996CB7A911DACAB4C1256C0D004FA522?OpenDocument.

REVERBERATION TIME

The reverberation time T is defined in the following as the arithmetic average of the reverberation times for the octave bands 125 to 2 000 Hz. Danish building regulation demands that this parameter be less than 0.6 s. As can be seen from the table below, Danish building regulation requirements were met for 90 % of all daycare centres.

Reverberation time performance

	Average reverberation time (T)	Number exceeding 0.6 s
Nurseries	0.45	7 out of 49
Kindergartens	0.41	4 out of 52
SFOs	0.46	8 out of 75

NOISE EXPOSURE

The result of the dosemeter measurements can be corrected to the eight-hour equivalent noise exposure values. After averaging the result for each centre, the average for the total number of centres can be calculated.

Average noise exposure (eight-hour equivalent noise-exposure value)

	Average noise exposure	Standard deviation (dB)
Nurseries	80.3 dB re 20 μ Pa	3.1
Kindergartens	79.9 dB re 20 μ Pa	3.4
SFOs	81.6 dB re 20 μ Pa	4.4

Assuming normal distribution, the share of centres with average noise exposure above 75, 80, 85 and 90 dB can be estimated.

Estimated percentage of daycare centres with average noise exposure above 75, 80, 85 and 90 dB respectively

Centre average for noise exposure	Estimated percentage of nurseries	Estimated percentage of kindergartens	Estimated percentage of SFOs
> 75 dB	96	95	96
> 80 dB	54	50	67
> 85 dB	7	5	20
> 90 dB	0.1	0.1	1.7

Danish legislation for noise exposure in the workplace implies a noise-exposure limit of 85 dB for an eight-hour working day. For noise exposures above 80 dB, the employer must supply suitable hearing protectors.

From the information above, the percentage of centres where the average noise exposure exceeds the noise limit is as follows.

Percentage of centres where average noise exposure exceeds the noise limit

	Estimated percentage exceeding noise limit	95 % confidence interval
Nurseries	7	3–14 %
Kindergartens	5	2–12 %
SFOs	20	13–28 %

RESULTS FROM STATIONARY MEASUREMENTS, ESTIMATED ROOM NOISE LEVELS

The 'transformed' result of the measurements made with the stationary microphone provided the results for centre averages (as averages over the opening hours). In translating the results, it is important to know that while kindergartens and nurseries are centres typically open between 6.00 and 17.00, the SFOs are usually open only after school, i.e. from 12.00 to 17.00.

Mean room noise levels

	Average noise exposure	Standard deviation (dB)
Nurseries	80.7 dB re 20 μ Pa	2.8
Kindergartens	80.3 dB re 20 μ Pa	2.2
SFOs	82.0 dB re 20 μ Pa	2.2

A similar table as for the above discussion on noise exposures can be estimated for the room noise levels averaged over the full opening hours of the centre.

Estimated percentages of daycare centres with average room noise above 75, 80 and 85 dB respectively

	Estimated percentage of nurseries	Estimated percentage of kindergartens	Estimated percentage of SFOs
Average room noise level > 75 dB	98	99	99
Average room noise level > 80 dB	60	55	73
Average room noise level > 85 dB	7	2	17

ADDITIONAL CONCLUSIONS FROM THE STUDY

The study investigated the correlation between the reverberation time and the resulting room noise level. Only for nurseries was this correlation not statistically significant.

The study also investigated the correlation between the one-hour room noise levels and the number of children present (children per square metre of the room). Unsurprisingly, the correlation was highly significant for all three kinds of centre.

EFFORTS TO IMPROVE THE SITUATION

After publication of the results, the situation was decided to be greatly in need of remediation, and this led the parties involved to discuss possible methods to improve it. The discussions between the employers and employees took place under political surveillance. A programme for the improvement of the situation was agreed upon. It was decided that three main factors had to be dealt with:

- physical surroundings (buildings, rooms, etc.);
- the number of children;
- social behaviour.

The discussions have now resulted in a number of actions.

Social behaviour

The staff's labour union has been responsible for precisely aimed tests to possibly change staff interaction with the children, and to create far more focus on the noise issues and noise consequences.

Guide for daycare centres

An official guide for the establishment of daycare centres has been issued, prepared by working environmental authorities. The guide ([47]), entitled *Guide on the establishing of daycare centres*, presents all requirements from different regulations relevant to daycare centres together with practical advice on how to meet these requirements.

Guide for people working in a daycare centre

A more educational textbook and guide on noise have been prepared through collaboration between employers and employees. The book ([48]), entitled *The night here is quiet, but during the day …*, explains how to handle workday issues using everyday language and light illustrations.

FOLLOW-UP TO THE STUDY

In 2003, it was decided to repeat the noise measurements in order to see if any improvement could be seen. Although only a very small fraction of the original 176 centres were measured again, it was possible to show that all three types of institution gave statistically significant lower results. It was, however, also concluded that the fight against noise is a fight that demands a constant focus on noise issues by those who are working with children.

The 'sound-ear': an example of a product for and used by kindergartens and pre-schools in the educational work for increased focus on noise. At low noise levels, the sound-ear is green, at higher levels it turns yellow, and when the noise reaches too high a level it turns red.

([47]) Arbejdsmilørådet, *Branchevejledning: om indretning af daginstitutioner.* Available for download (in Danish) at http://www.bupl.dk/web/internet.nsf/0/37AC4799A425245DC1256C0D00481819?OpenDocument.

([48]) Branchevejledning om støj I daginstitutioner, *Om natten er her stille, men om dagen … .* Available for download (in Danish) at http://www.arbejdsmiljoweb.dk/Stoej_lys_og_luft/Stoej/Materiale_stoej/Om_natten_er_her_stille.aspx.

Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Germany (50)

Patrick Kurtz

Noise reduction in offices

Noise does not just cause deafness. Noise can also be a contributory factor to work-related stress. In this article, measures are described that can reduce the impact of noise on workers in offices (49).

Introduction

'Whenever Reynaldo Zavala sits at his desk, he can see the colour of the shirt of his co-worker in the next office. He can hear with whom his neighbour talks on the phone. And, if his colleague has to report to his superior he can hear all the conversation. Because working for Lucent means working in a modern and flexible environment without barriers, neither for the eye nor for the noise. The walls are made of glass and are only 2 m high. The room concept is new and trendy and comes from the US. "It is absolutely rubbish," says Lucent employee and workers' representative Zavala' (51).

This quote illustrates perfectly what noise stress in offices is all about. The situation described above is representative of all the recent acoustic excesses of modern office planning, which ignore the needs of the workers, following instead the zeitgeist of absolute flexibility, misunderstood transparency and an obsession with design. The fact that white noise was used in this case, and in many others, to suppress the audibility of voices from neighbouring work areas finally relegates this kind of office planning to the garbage heap.

General requirements for professional office planning

Office workplaces in which information is compiled, collected, processed, stored and communicated can be found in many areas, for example administrative offices, typing pools, design offices, and purchasing and sales offices.

The work is assisted by modern communications technology, turning most workplaces into VDU workstations (52). As work becomes more challenging, particularly regarding the mental demands on the worker, lower sound immissions (sound pressure levels at the workplace) must be achieved.

Professional office planning therefore encompasses:

- procuring of quieter equipment and facilities;
- achieving low levels of background noise;
- an acoustically favourable room layout;
- a greater distance between the workstations and/or the application of proper acoustical screens in open-plan offices.

Unlike in factories, where the avoidance of hearing damage is paramount, in offices the reduction of the sound pressure level is not the sole priority. It is also a question of considering the noise (sound) structure if we want to decrease the adverse effects of noise on the ability to concentrate and the stress it causes. We should note that:

- avoiding listening causes stress;
- low-frequency sound (infra-sound) from air-conditioning systems affects well-being;
- the noise generated by hard drives and PC cooling fans is irritating.

The result is that bad planning turns a basically quiet office into a noisy one. Later measures to improve the situation often worsen the conditions.

So what are the features of a quieter office?

- The current sound pressure level should not be caused by a single, clearly identifiable source such as a photocopier, a PC cooling fan or a printer.
- Speech from neighbouring workplaces should not be loud enough to be understood.
- The sound pressure level from all sources except the person at the workplace should be as low as possible.

A quiet office with background sound pressure levels between 20 and 30 dB(A) is the ideal work environment for highly demanding mental tasks. EN ISO 11690 Part 1 (53) recommends the following quality levels for office workplaces assuming that the persons in question are prepared to work and are not producing sound themselves with tasks or conversations.

Table 1: Acoustic qualification of VDU workstations

< 30 dB(A)	Perfect
30–40 dB(A)	Very good
40–45 dB(A)	Good
45–50 dB(A)	Acceptable under normal circumstances
50–55 dB(A)	Not good
> 55 dB(A)	Too loud

(49) This article was translated by Wolfgang Hübner.
(50) http://www.baua.de/.
(51) 'Spiegel-Online', 5 September 2002.
(52) Council Directive 90/270/EEC of 29 May 1990 on the minimum safety and health requirements for work with display screen equipment (fifth individual directive within the meaning of Article 16(1) of Directive 89/391/EEC) (OJ L 156, 21.6.1990, pp. 14–18).
(53) ISO 11690-1 (1996), 'Acoustics — Recommended practice for the design of low-noise workplaces containing machinery — Part 1: Noise-control strategies'.

In Germany, until recently, there was a legal limit of L_{pA} = 55 dB(A) ([54]), but as can be seen this was not acceptable for workplaces demanding high concentration. Nevertheless, employers used this limit as an argument against further noise-reduction measures. The possible costs of such measures are generally considered uneconomic. However, that a reduction below 45 dB(A) can save money due to higher quality of the deliverables, increased speed of work and lower stress-induced health costs is usually overlooked. As studies have shown, these potential savings should not be underestimated. For example, the reduction in a background noise level from 41 dB(A) to 35 dB(A) during simulated office tasks under laboratory conditions resulted in a decrease in the number of mistakes made in typical office tasks (word processing) by 52 % ([55]).

CAUSES OF NOISE IN OFFICES

If we consider office noise and ignore for the moment external sources such as traffic noise and industrial noise penetrating through the walls, windows and ventilation openings and noise caused by internal sources such as elevators and air-conditioning systems against which a lot can be done by sufficient insulation, acoustic decoupled placement and good air-flow design, there still remains:

- people talking;
- noise from telephones;
- PC cooling fans;
- computer hard drives, keyboards, printers; and
- other office equipment (scanner, fax, photocopier, etc.).

To describe the acoustic characteristics of these sound generators, which are called emission sources, two parameters are used. The sound power level L_{WA} and the emission sound pressure level L_{pA}.

The sound power level describes the total airborne sound energy emitted by the source per unit time. The emission sound pressure level is the sound pressure level at the workplace if only the direct sound from the particular source is considered. Both parameters are therefore independent of their surroundings, i.e. independent of the sound emissions of other sources in the environment and of the reflected sound from the walls and ceilings. This allows the use of these quantities to characterise emission sources.

Therefore, ISO standard 9296 ([56]) has been prepared to facilitate the choice of quiet office equipment on the basis of emission values. It describes how noise emission values have to be declared. Thus, a proper noise emission declaration has to be based on noise emission measurement standard ISO 7779 ([57]) as well as on ISO 9296 describing the declaration. It stands to reason that under equal room acoustic characteristics the sound source with the lower sound power level is also the one resulting in a lower sound pressure level at the workplace. The emission sound pressure level gives additional information about the source's ability to generate a specific sound pressure level at the workplace under 'free field' conditions that means the sound pressure level the user of the equipment normally experiences at the respective workplace in a highly sound-absorbing environment.

([54]) See also VDI Guideline 2058, Part 3.
([55]) Ising, H., Sust, C. A. and Rebentisch, E., 'Lärmbeurteilung — Extra-aurale Wirkungen', Arbeitswissenschaftliche Erkenntnis Nr 98, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund.
([56]) ISO 9296 (1988), 'Acoustics — Declared noise emission values of computer and business equipment'.
([57]) ISO 7779 (1999), 'Acoustics — Measurement of airborne noise emitted by information technology and telecommunications equipment'.

FROM EMISSION TO 'IMMISSION'

If one looks at the difference in sound power levels of the most important noise sources in offices (see Table 2), the potential for noise reduction offered by choosing relatively quiet office equipment becomes apparent. This becomes explicitly clear when one assumes that a 10 dB reduced sound power level of an office PC corresponds to an equal sound pressure level reduction at the directly assigned workstation if one considers the PC to be the major sound source.

Table 2: The sound power level of noise sources at workstations

Source	L_{WA} typical values (dB(A))
Person telephoning	55–70
PC inactive	30–50
PC accessing hard drive	35–55
Keyboard	55–65
Laser printer inactive	30–40
Laser printer printing	55–60
Photocopier inactive	50–60
Photocopier working	60–70
Telephone ringing	60–80

The sound power level as an important parameter for emission is not only useful for choosing quiet equipment, but is also an important starting value for the acoustic planning of workplaces. This is because it describes the sound energy transmitted by a sound source per second. This energy is distributed across an increasing area the further it travels away from the source, resulting in a decreasing sound intensity (i.e. it gets quieter). In a normal room, this sound pressure level decrease is stopped by the room's limiting walls. Due to the sound reflection at the walls and the existing sound absorption in the room, a more or less constant sound pressure level is reached.

For an acoustic qualification of the emission of a single machine with respect to the resulting 'immission', the sound pressure level at the workplace can be calculated by means of the two emission parameters and for a reference room with the equivalent absorption area of 10 m^2 is the result of

$$L_{Ap} = L_{pA} + 10 \log\left[1 + 0{,}4 \cdot 10^{0{,}1(L_{WA} - L_{pA})}\right] \ \text{dB}$$

By comparing the results with the values in Table 1, the sound quality of a workplace can be rated.

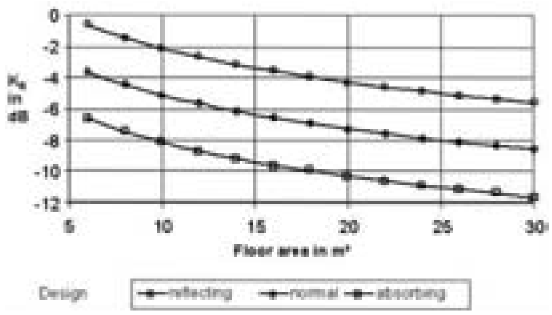
To find the proportion a single source contributes to the overall sound level in an office room, the following formula is used:

$$\mathbf{L_i = L_{WA,I} + K_R}$$

K_R is derived from the average acoustic characteristic of the room (reflecting, normal or absorbing) and the floor area of the room in accordance with the figure below.

With respect to the three categories, the term K_R can be taken from the figure for a given floor area.

- Reflecting — only few textile or sound-absorbing coverings; no fitted carpet; floor, ceiling and walls made of concrete, roughcast, glass or varnished wood.



Corrections K_R for determining the room sound pressure level from the sound power level of the source in relation to the floor area of the room

- Normal — usual design, possibly fitted carpet, walls and ceiling like above.
- Absorbing — additionally sound-absorbing ceiling.

If there are more sound sources (equipment) in the room, the relevant emission has to be calculated and the resulting sound pressure level finally results from applying the formula

$$L_{total} = 10 \cdot \log\left(\sum_{i=1}^{n} 10^{0.1 \cdot L_i}\right)$$

Detailed information about the various methods of calculation used for acoustic planning can be found in publications by the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (58) (59) (60).

PLANNING FOR NOISE REDUCTION

When planning an office, it is not only important to minimise the sound power brought by the sources into the room, but also to reduce the sound transmission from the source to the workstations. To this end, the following measures can be recommended:

- fitting sound-absorbing false ceilings with a sound-absorption coefficient of at least $\alpha = 0.8$ for frequencies above 250 Hz;
- fitting carpets which not only reduce the impact sound pressure level but also give the impression of a better noise damping in the room at high frequencies;
- putting up room dividers and acoustical screens to isolate the different parts of the room.

The acoustical screens should:

- be at least two thirds the height of the room;
- only be used in conjunction with an adequate ceiling absorption;
- absorb sound on both sides.

It is very common to wish for transparent dividing walls to permit a clear view in an open-plan office and to avoid a sense of claustrophobia. Glass or acrylic glass is then the chosen material. If such dividers are the correct height, they may be able to separate noisy working areas from quieter ones or hinder speech transmission, but, due to their high degree of noise reflection, the noise level is increased directly in front of them. If a working area is completely enclosed, then the reverberation time in this 'glass box' can rise to a level that makes normal conversation impossible. Frequently, the reverberation time then amounts to more than 1 s.

Further research and development should improve the affordability and performance of acrylic glass plates with microperforations or thin transparent films (with a thickness of, for example, 0.5 mm) as 'add-ons' to existing glass walls. These developments (61) deserve special attention because such materials provide optical transparency, good sound insulation against adjacent room areas and a sound-absorption coefficient of $\alpha > 0.7$ in the frequency range of 125 to 4 000 Hz, i.e. the range important for good speech intelligibility. The latter is important because an office presents the dual challenge of reducing audible speech from neighbouring parts of the office while simultaneously ensuring that speech can be clearly understood in other areas. Here, it is essential to minimise the reverberation time, for example, in rooms less than 100 m³ to about 0.6 s, and in rooms of 1 000 m³ to less than 1 s (DIN 18041 (62)).

A further important factor in open-plan offices is the number of workplaces in each room. As a basic rule, we can say the fewer workplaces per square metre the better. This is, of course, an important cost factor when planning an office because it requires a compromise between the use of room-dividing acoustic barriers and the space available for each workplace.

(58) http://www.baua.de/.

(59) Probst, W., 'Bildschirmarbeit — Lärmminderung in kleinen Büros', Arbeitswissenschaftliche Erkenntnis Nr 123, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund.

(60) Probst, W., 'Bildschirmarbeit — Lärmminderung in Mehrpersonenbüros', Arbeitswissenschaftliche Erkenntnis Nr 124, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund.

(61) Fuchs, H. V., Zha, X. and Zhou, X., 'Raumakustische Gestaltung einer Glaskabine', IBP Mitteilung 256, Fraunhofer Institut für Bauphysik, Stuttgart, 1996.

(62) DIN 18041 (Entwurf April 2003), 'Hörsamkeit in kleinen bis mittelgroßen Räumen' ('Reverberation time in small to medium-sized rooms)'.

CENTRAL INSTITUTE FOR LABOUR PROTECTION — NATIONAL RESEARCH INSTITUTE, POLAND (63)

Ewa Kotabińska and Emil Kozlowski

SPEECH INTELLIGIBILITY IN NOISE WHEN HEARING PROTECTORS ARE USED

Noise does not just harm a worker's hearing; it can also be a cause of accidents. Workers wearing hearing protection may not be able to hear verbal instructions and warnings. This article describes a project to work out the method of predicting speech intelligibility while wearing hearing protectors. The results of the prediction based on the speech interference level (SIL) method are presented and compared with the results of laboratory subjective tests. The percentage of words understood correctly with four different models of hearing protectors was tested on 53 listeners in 20 various 'acoustic situations'. The differences between theoretically predicted values and the measured mean percentage of words understood correctly were lower than the measured standard deviations. This observation proves that the verification of the proposed method yielded a positive outcome.

In the work environment, a worker's safety is often determined by speech intelligibility. It is generally well known that the use of hearing protectors in noise exposure may significantly impair the audibility of warning signals and speech intelligibility. According to the personal protective equipment directive (64), 'all personal protective equipment must be appropriate for the risk involved, without itself leading to any increased risk'. ISO Standard 9921 (65) states that in alert and warning situations the recommended minimum intelligibility rating is 'poor' when workers are warned by verbal short messages of simple sentences or 'fair' if workers are warned by messages of critical words (66).

The aim of this article is to present the simple method of predicting speech intelligibility in noisy conditions when hearing protectors are worn and the comparison of the laboratory experimental results with the theoretically predicted data.

MEASURES OF SPEECH INTELLIGIBILITY

There are objective and subjective measures of speech intelligibility. Objective measures are based on the physical properties of transmission path between speaker and listener. The subjective measures are based on the subjective experimental tests making use of speaker and listener.

The SIL method is the objective method of predicting speech intelligibility in cases of direct communication in a noisy environment and it makes use of the relations between the spectrum of the speech signal and the spectrum of environmental noise in the listener position. This relation was adapted to predict speech intelligibility in noisy conditions when hearing protectors are worn — SIL_h. To calculate the SIL_h value, the octave band characteristic of noise at the work position must be measured and the sound attenuation characteristic of hearing protectors must be known.

The formula for SIL_h is:

$$\mathbf{SIL_h = L_{S,h} - L_{SIL,h}\ (dB)}$$

where:

$L_{S,h}$ is the A-weighted sound pressure level of speech under the hearing protector, in four octave bands with the central frequencies 500, 1 000, 2 000 and 4 000 Hz;

$L_{SIL,h}$ is the arithmetic mean of sound pressure levels of noise under the hearing protector, in four octave bands with the central frequencies 500, 1 000, 2 000 and 4 000 Hz, measured at the worker's position.

Subjective intelligibility tests require listeners to write down the words they hear and understand. Speech intelligibility is defined as the percentage of the words understood correctly. Table 1 gives the intelligibility rating and relations between the objective and subjective intelligibility measures. According to ISO 9921, the recommended ... listeners with normal hearing is at least 'poor'.

Table 1: Intelligibility rating and relations between the subjective and objective measures (according to ISO 9921)

Intelligibility rating	Meaningful word score (%)	SIL (dB)
Excellent	> 98	21
Good	93–98	15–21
Fair	80–93	10–15
Poor	60–80	3–10
Bad	< 60	< 3

(63) http://www.ciop.pl.
(64) Council Directive 89/656/EEC of 30 November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace (third individual directive within the meaning of Article 16(1) of Directive 89/391/EEC) (OJ L 393, 30.12.1989).
(65) Standard ISO 9921 (2003), 'Ergonomics — Assessment of speech communication'.
(66) See also Standard PN-EN 458 (1999), 'Hearing protectors — Recommendations for selection, use, care and maintenance — Guidance document'.

METHODOLOGY

Subjective intelligibility tests were carried out on 53 listeners in the laboratory. Five lists of the 40 Polish words developed for the purpose of verbal audiometry were used ([67]). The A-weighted sound pressure level of the speech signal (measured in the place of listener's position) was fixed at 78 and 84 dB(A). The speech signal at the level of 78 dB(A) represented very loud speech in 'person-to-person communication'. The speech signal at the level of 84 dB(A) stood for the electroacoustically reproduced word message. The speech signals were masked by three various background noises. The A-weighted

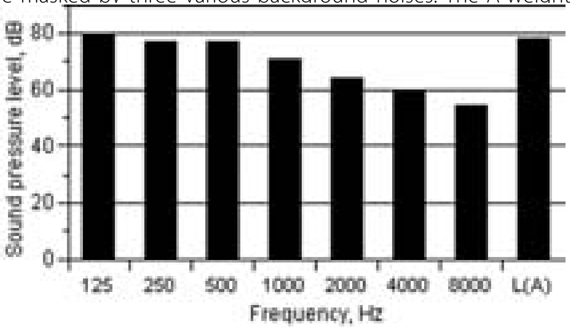


Figure 1: Spectrum of speech signal

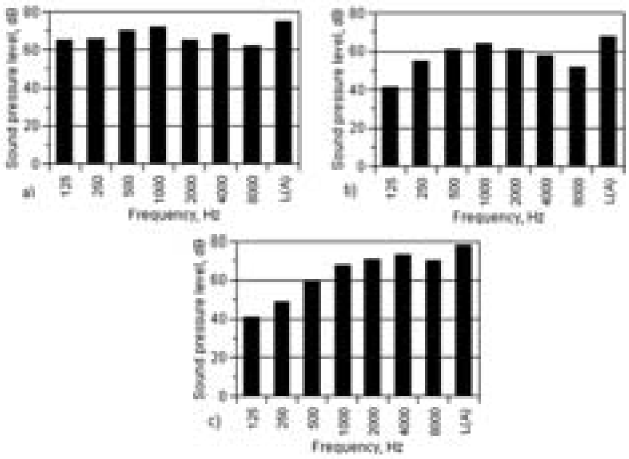


Figure 2: Spectra of background noises: (a) pink noise, (b) medium-frequency noise, (c) high-frequency noise

The selected listeners were representative of the workers' population in terms of sex, age, and education. They used the Polish language every day as their native language and they had no hearing disorders. Their hearing loss did not exceed 20 and 25 dB at frequencies below 2 000 and over 2 000 Hz. The size and shape of the head and ears were not taken into account.

The listeners used hearing protectors which are popular in the Polish working environment — Bilsom ([68]) Loton 2401 earmuffs and earplugs of three different models: Howard Leight ([69]) MAX-Lite, E-A-R Soft and [illegible] by different values of sound attenuation in the octave frequency bands. The mean sound attenuation of the tested hearing protectors

Table 2: Mean sound attenuation of hearing protectors (dB)

Model of hearing protector	Frequency (Hz) 63	125	250	500	1 000	2 000	4 000	8 000
Bilsom Loton 2401	14.8	12.9	15.2	24.8	34.2	32.0	36.1	28.4
Howard Leight MAX-Lite	26.6	26.6	27.6	29.7	27.4	32.6	42.7	43.0
E-A-R Soft	30.8	30.8	36.1	39.2	39.5	35.8	42.2	46.1
E-A-R FlexiCap	22.8	20.4	17.5	16.5	20.6	31.8	36.9	34.8

The speech signal of 78 dB(A) was masked by pink noises of 75, 78, 81 and 84 dB(A) and the speech signal of 84 dB(A) was masked by noises of 81, 84, 87 and 90 dB(A). The measurements of the percentage of words understood correctly when wearing E-A-R Soft and E-A-R FlexiCap earplugs were performed for the speech signal at the A signal level of 78 dB(A). When wearing the E-A-R Soft earplugs, speech signal was interfered with by medium-frequency noise at the A-weighted sound pressure level of 68 and 83 dB. Using the E-A-R FlexiCap earplugs, speech signal was interfered with by high-frequency noise at the A-weighted sound pressure levels of 78 and 93 dB.

RESULTS

The percentage of words understood correctly by the listeners with hearing protectors in noise was measured. For 'each acoustic

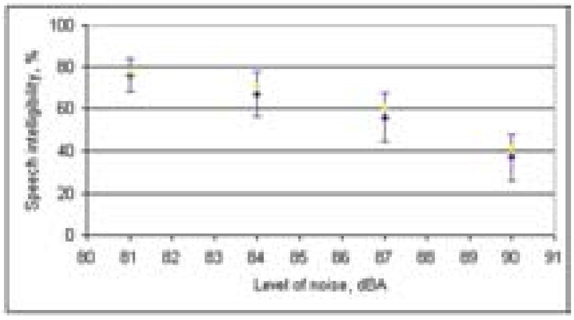


Figure 3: Speech intelligibility in pink noise with Bilsom Loton 2401 earmuffs versus the noise level (speech signal level 78 dB(A); ● — predicted values, ♦ — experimental data)

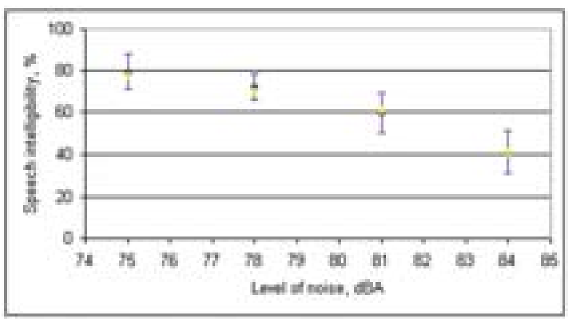


Figure 4: Speech intelligibility in pink noise with Bilsom Loton 2401 earmuffs versus the noise level (speech signal level 84 dB(A); ● — predicted values, ♦ — experimental data)

([67]) Pruszewicz, A., Demenko, G., Richter, L. and Wika, T., 'New word lists for audiometric purpose, Parts I and II', *Otolaryngologia Polska*, XLVIII, 1, 1994 (in Polish).
([68]) http://www.bilsom.com/.
([69]) http://www.howardleight.com/.

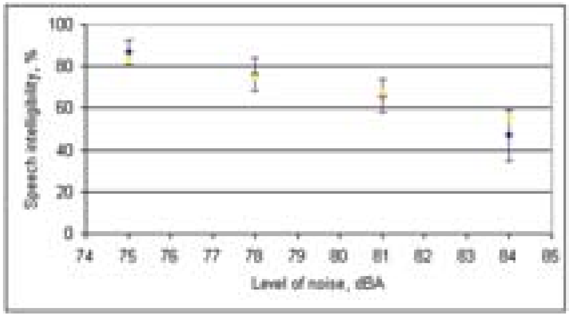


Figure 5: Speech intelligibility in pink noise with MAX-Lite earplugs versus the noise level (speech signal level 78 dB(A); ● — predicted values, ♦ — experimental data)

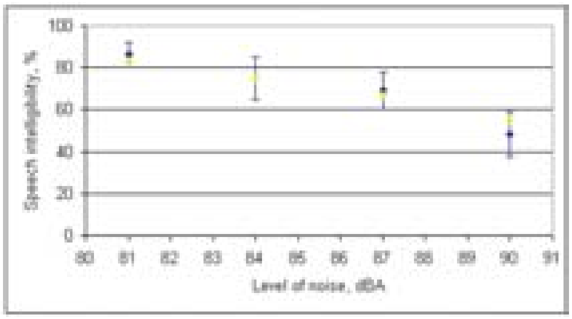


Figure 6: Speech intelligibility in pink noise with MAX-Lite earplugs versus the noise level (speech signal level 84 dB(A); ● — predicted values, ♦ — experimental data)

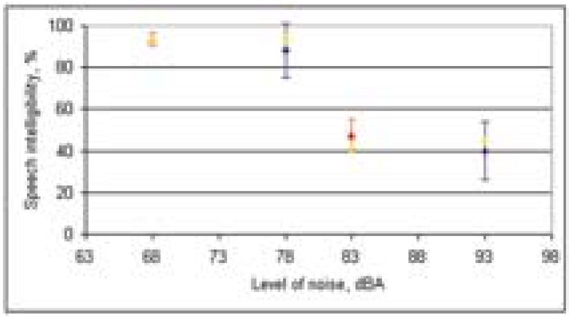


Figure 7: Speech intelligibility with earplugs versus the noise level (speech signal level 78 dB(A); middle-frequency noise of 68 and 83 dB, high-frequency noise of 78 and 93 dB; ● — predicted values, ▲ — experimental data for E-A-R Soft earplugs, ♦ — experimental data for E-A-R FlexiCap earplugs)

In all the tested 'acoustic situations', the observed differences between the measured and the theoretical predicted speech intelligibility did not exceed standard deviations of measured mean speech intelligibility. The smallest differences — from 0.1 to 1.5 % — are observed when Bilsom Loton 2401 earmuffs were used for pink noise and the speech signal level of 78 dB(A). The biggest differences — 6.3 and 6.9 % — are observed when E-A-R Soft and E-A-R FlexiCap earplugs were used for middle-frequency and high-frequency noises and speech signal level of 78 dB(A). Speech intelligibility in high-frequency noise when E-A-R FlexiCap earplugs are worn is almost the same as the speech intelligibility in middle-frequency noise with E-A-R Soft earplugs although the high-frequency noise level is 10 dB higher than in the case of the middle-frequency noise.

CONCLUSIONS

In the noisy working environment where the clear understanding of short messages is required for the safety of workers, hearing protectors should be selected taking into account speech intelligibility. The speech intelligibility in noise when hearing protectors are used depends on the relations between spectrum of noise and the sound attenuation frequency characteristic of hearing protectors.

The SIL_h method presented to predict speech intelligibility in noisy conditions when hearing protectors are worn yields satisfying results. The experimental tests show that in all 20 tested 'acoustic situations' the observed differences between the measured and the theoretically predicted speech intelligibility did not exceed standard deviations of measured mean speech intelligibility.

ACKNOWLEDGEMENT

The study is a part of the project 'An analysis of accidents in the work environment for preventive purpose' supported in the period 2001–04 by the State Committee for Scientific Research of Poland (70).

(70) http://www.kbn.gov.pl/.

The European Agency's objective, as set out in the founding regulation:

'In order to encourage improvements, especially in the working environment, as regards the protection of the safety and health of workers as provided for in the Treaty and successive action programmes concerning health and safety at the workplace, the aim of the Agency shall be to provide the Community bodies, the Member States and those involved in the field with the technical, scientific and economic information of use in the field of safety and health at work'.

European Agency for Safety and Health at Work

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European Agency for Safety and Health at Work

Gran Vía 33, E-48009 Bilbao, Spain
Tel. +34 944 794 360
Fax +34 944 794 383
E-mail: information@osha.eu.int

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TE-AA-05-008-EN-C