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German Criteria for Selection of Hearing Protectors in the Interest of Good Signal Audibility

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The German transport and personal protective equipment (PPE) technical committees of the German Social Accident Insurance have laid down criteria, which have since become established, for hearing protectors to be used in railway systems and road traffic in Germany: only hearing protectors which do not significantly impair the audibility of auditory warning signals may be used. In addition, the Institute for Occupational Safety and Health of the German Social Accident Insurance (BGIA) has proposed a simple criterion for the selection of hearing protectors for workplaces outside railway systems and road traffic which perform well with regard to signal audibility (general), speech intelligibility, and perception of informative operating sound (AIP). This criterion is based upon the research carried out in the field of signal audibility in railway systems and road traffic and upon an additional study. It has been established by the German PPE technical committee and is presented here.

hearing protector   ear muff   ear plug   speech intelligibility   signal audibility
criteria for good audibility

1. INTRODUCTION

Perception of sound coming from the environment is much more important for orientation than people are aware. Whereas our eyes can only observe the area in front of the head, the ears register sound even if it comes from behind. The perception of auditory warning signals is particularly important in preventing accidents.

Hearing protectors can affect the perception of sound and auditory signals because they attenuate the sound. Employees in Europe are currently obliged to wear hearing protectors in noise zones in which daily noise exposure levels are equal to or higher than the upper action level of 85 dB(*A*) [1], or at lower levels where required by national regulations. Before Directive 2003/10/EC [1] was introduced, Directive 86/188/EEC required hearing protectors to be worn where the daily noise exposure levels reached or exceeded the upper action level of 90 dB(*A*) [2].

Although hearing protectors are mandatory in noise zones, employees refuse to wear them. They argue that hearing protectors may impede or prevent the perception of sound emanating from the environment, e.g., a forklift truck's audible warning signal from behind the user. Hearing protectors may actually decrease the audibility of auditory warning signals and the intelligibility of speech, since most of them change the spectral composition of the sound transmitted. Therefore, only hearing protectors with suitable attenuation values and frequency curves should be used in areas in which signal *audibility*, speech *intelligibility* or *perception* of informative operating sound (AIP) are important. There are

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many environments in which sound perception is as important as visual perception in avoiding accidents.

Aspects concerning perception of sound emanating from the working environment encompass informative sounds in the working process, warning signals, and speech communication. Standard No. EN 458:2004 recommends that preference be given to "hearing protectors having a uniform sound attenuation characteristic over the frequency range" (p. 14) in cases in which perception of the aforementioned sounds may be impaired [3]. This standard does not specify such characteristics, though. To provide such a specification, the Institute for Occupational Safety and Health of the German Social Accident Insurance (BGIA) has proposed a simple criterion for the selection of AIP hearing protectors (cf. section 4). It relates to methods, results, and criteria obtained in two studies carried out in the field of railway systems and road traffic (cf. sections 2 and 3). The AIP criterion considers the aforementioned requirement of Standard No. EN 458:2004.

2. REQUIREMENTS FOR SIGNAL AUDIBILITY IN RAILWAY SYSTEMS AND ROAD TRAFFIC

2.1. Hearing Protectors in German Railway Systems

In order for accidents to be avoided, in certain noise zones within railway systems, the audibility of auditory warning signals must be guaranteed—or at least not reduced by the use of hearing protectors. Hearing protectors may, however, impair the audibility of auditory warning signals. A conflict thus arises between hearing conservation in noise zones and the prevention of accidents.

Until 1989, the institutions responsible for statutory accident insurance and prevention in Germany exempted the employees in question from the obligation to wear hearing protectors if wearing those protectors increased the risk of accidents. This exemption was based upon Regulation No. BGV B 3 [4], i.e., the German transposition of Directive 86/188/EEC [2]. The exemption resulted in the situation observed in 1989: the average tracklayer exhibited higher hearing losses than other workers exposed to noise in the construction sector [5].

A daily listening check is required since a specific PTS (permanent threshold shift), a TTS (temporary threshold shift), and nontypical sounds may cause a decrease in the audibility of auditory warning signals, in addition to predictable deteriorations [6].

2.2. Hearing Protectors in German Road Traffic

Inside the driver's cab of some vehicles, especially those licensed as work machines, daily noise exposure levels exceeded 85 or even 90 dB(A). In such situations the employer was obliged, in the first instance, to identify noise zones and to provide suitable hearing protectors; employees were obliged to wear them when exposed to a daily noise exposure level ≥90 dB(A) [2, 4]. The number of situations in which the upper action level of 85 dB(A) is exceeded has since increased owing to new regulations [1, 7]. Conversely, the German rules and their interpretation do not permit the use of hearing protectors when driving in road traffic. Chapter 23 of the traffic regulation imposes a responsibility upon drivers to ensure that their visual and auditory perception are not impaired by the manning, load, equipment, or condition of the vehicle [8].

In this situation, a conflict arose again between hearing conservation and safety at work/road safety. Until 1996, hearing protectors were not permitted when driving in road traffic in Germany. The traffic regulation [8] had legal precedence over Regulation No. BGV B 3 [4]. Therefore, the latter, applied successfully in industrial plants, was not applicable to employees driving vehicles in road traffic. The German authorities responsible (the technical committee for road traffic of the federal and regional authorities) found a solution in the form of a requirement for a clearance certificate. This certificate must be issued by the relevant German institution for statutory accident insurance and prevention, which is responsible in the case concerned. It must be presented during police checks.

2.3. Preselection of Hearing Protectors and Listening Tests

In Germany, hearing protectors intended for use in railway systems or road traffic must be preselected on the basis of special calculations, to prevent significant impairment of the audibility of auditory warning signals. These calculations (cf. sections 3.5 and 3.6) are carried out by the BGIA, which applies the criteria presented in sections 3.7 and 3.8. Typical and specified audible signal and work sound spectra must be used in the calculations. Lazarus, Wittmann, Weißenberger, et al. validated these calculations for people with normal hearing under laboratory conditions: PTS (permanent threshold shift), TTS (temporary threshold shift), nontypical work noise and the differences between the attenuation of hearing protectors determined in test laboratories and attenuation found in practice were eliminated [11]. The preselected hearing protectors must, therefore, be additionally verified with a listening test under operating conditions at the workplace concerned. This listening test is necessary because the following aspects already referred to cannot be taken into account in the preselection: PTS, TTS, nontypical work noise, and the differences between the attenuation of hearing protectors determined in test laboratories and the attenuation found in practice. For the employer, the preselection saves time necessitated by the listening test by restricting it to the hearing protectors found to be suitable by the calculations.

3. METHODS FOR ESTIMATING SIGNAL AUDIBILITY IN RAILWAY SYSTEMS AND ROAD TRAFFIC

3.1. Hearing Protectors Affect Signal Audibility

A private car is approaching a truck-mounted crane. During the operation of the crane, the sound pressure level (SPL) of the car horn increases at the crane operator's workplace with progressively decreasing distance. If the approach is stopped at the point at which the crane operator just registers the horn signal, the spectra in Figure 1 are obtained at the ear of the crane

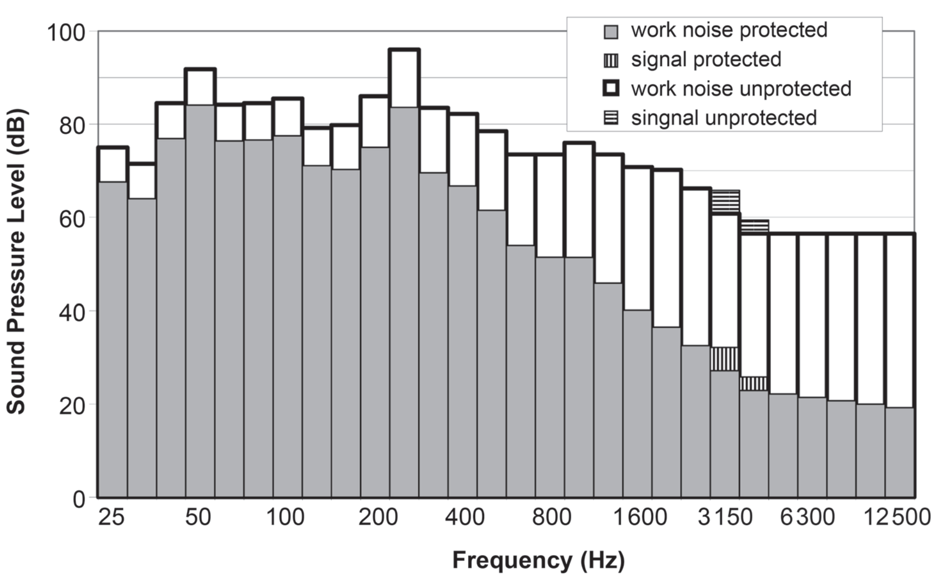

Figure 1. Spectra of the noise in the driver's cab of a truck-mounted crane at the driver's ear during operation under full load (work noise) and spectra of the horn of a private car (signal), without hearing protector and with hearing protector.

operator. Those spectra represent the situations with and without a hearing protector.

The signal-to-noise ratio in the situation without a hearing protector in Figure 1 is ~5 dB at 3 150 Hz. The use of a hearing protector does not change it; the signal must, however, be increased by ~6 dB when the hearing protector is worn in order for the signal to be equally audible when a hearing protector is not worn. This corresponds to halving the earshot in a free sound field.

The signal-to-noise ratio of sounds cannot be used to describe signal audibility. In fact, calculations aimed at predicting signal audibility must consider masking. Masking had been investigated in numerous studies and the results were used in writing Standard No. ISO 532:1975 (Part B, Zwicker's diagram) [9, 10].

Lazarus et al.'s two methods (sections 3.5 and 3.6) are based upon methods for calculation of the loudness levels from the sound spectrum (Zwicker method) [11]. This method operates selectively in independent critical bands and considers masking of adjacent critical bands in a practical manner. It is, therefore, suitable for a theoretical investigation of the masking of warning signals.

3.2. Railway Systems

Lazarus et al. investigated the influence of hearing protectors upon the audibility of auditory warning signals for track layers [11]. The audibility was examined during exposure to typical noise whilst hearing protectors were worn. For this purpose, differences in audibility were determined for ~200 types of noises on the basis of the Zwicker loudness calculation method [9, 10], using two dedicated methods and a third one according to Standard No. ISO 7731:2003 [17]. Wittmann and Meißner [13] developed a computer program for calculating the audibility of track-layer warning signals during exposure to typical noise. The Doppler effect, which may arise as a result of the relative velocity between the signal source and listener, was ignored. In German railway systems, this effect is not relevant to signal audibility, since the signal source and the listener do not exhibit relevant relative movements. The frequency-dependent absorption by air was likewise ignored.

The threshold of perceptibility depends not only upon the signal-to-noise ratio, but also upon physical and mental parameters such as the level of attention or physical fatigue. Because the calculation methods for audibility consider only the acoustic conditions of the signal and the noise, distinct levels of perceptibility were considered, too. Selected examples, i.e., four typical kinds of noise, two signals (Tyfon), and three types of hearing protectors, were tested in the laboratory with persons with both normal and impaired hearing ability (n = 63). The subjects, wearing appropriate hearing protectors, were presented with typical noise from track work and with track-layer warning signals through loudspeakers (for a detail description of the experimental setup and procedures see Lazarus et al. [11, 12]). The calculated results (three methods, several distinct levels of perceptibility) were compared to Lazarus et al.'s laboratory results [11]. This enabled Deutsche Bundesbahn and the Tiefbau-Berufsgenossenschaft (institution for statutory accident insurance and prevention for civil engineering) to select good calculation methods and safe levels of perceptibility.

Deutsche Bundesbahn and the Tiefbau-Berufsgenossenschaft specified the track-layer warning signal as a criterion for selecting hearing protectors to be used in railway systems in Germany. The preselection of hearing protectors to be used by track-layers was performed by means of calculations [14] using Wittmann and Meißner's computer program [13], typical and specified audible signal spectra and work sound spectra, and the data in the BGIA hearing protector database.

3.3. Road Traffic

The BGIA carried out a project to find a selection of suitable hearing protectors for road traffic [15]. This was done for persons with normal hearing using methods developed for railway systems [11, 12, 13] involving work noise (135 spectra) and audible warning signals typical of German road traffic [15]. The calculation methods were used to predict signal audibility in specific situations found in road traffic, i.e., specific masking sound spectra, specific signal spectra, and specific cab attenuation if relevant. Within the calculations, the Doppler effect and the frequency-dependent absorption by the air were ignored.

The mental acoustic tests, i.e., selected examples tested in the laboratory on human subjects [11], were not repeated for situations found in road traffic (for further details see Pfeiffer, Hoormann, and Liedtke [15]). A list of preselected hearing protectors was published as a result of the project [16].

An appropriate criterion for the situations in road traffic had to be specified, since they differed significantly from those in railway systems. For example, the signal used by Lazarus et al. exhibited pronounced components at 220 and 660 Hz [11], whereas the four signals used by the BGIA had high-level components at 400, 500, 630, 1000, 1250, 2000, 2500, and 3150 Hz. The work noise in road traffic more frequently exhibits low-frequency components (e.g., exposure to diesel-engine noise in the driver's cab) compared to the work noise in railway systems. The transport technical committee of the German institutions for statutory accident insurance and prevention responsible for prevention in the field of health and safety at work specified "warning signal in road traffic" as the selection criterion for hearing protectors to be used by drivers in road traffic. This criterion is presented in section 3.8.

3.4. ISO 7731:2003

Standard No. ISO 7731:2003 [17] specifies requirements for auditory danger signals. It includes an example for calculating the effective masked threshold when a hearing protector is worn and a signal is masked by ambient noise. Lazarus et al. [11] and Wittmann and Meißner [13], therefore, included ISO 7731:2003 methods in their investigations. The masked thresholds were determined according to (a) *A*-weighted measurements, (b) effective masked thresholds calculated according to octave-band measurements, and (c) third-octave-band measurements, as described in ISO 7731:2003.

Wittmann and Meißner [13] declared Standard No. ISO 7731:2003 [17] to be an unsuitable method for estimating signal audibility in railway systems with regard to safety. They compared the comparatively rough approximation of the effective masked threshold in ISO 7731:2003 with Lazarus et al.'s [11] methods (cf. sections 3.5 and 3.6) and the laboratory results of the investigations discussed in section 3.2. Wittmann and Meißner [13] determined the signal level showing adequate signal audibility according to ISO 7731:2003 for typical situations in railway systems with and without hearing protectors. The difference in signal level (protected ear/unprotected ear) indicated, in decibels, the extent to which a hearing protector decreased or improved signal audibility. A comparison with the results calculated with Lazarus et al.'s methods and applied to the same situations revealed large deviations. The ISO 7731:2003 results frequently failed to agree with Lazarus et al.'s findings and with present experience. The comparison revealed that possible deteriorations of signal audibility by use of hearing protection may be disregarded if methods described in Standard No. ISO 7731:2003 are used.

Lazarus et al.'s methods are described as the selective and the sound volume methods [11].

3.5. Selective Method

The selective method is based upon the selective hearing ability. The adjustment of the signal sound level, in decibels, is calculated for a situation in which a hearing protector is used to achieve the same signal audibility when the ear is unprotected.

To determine the selective power of perception W_A parameter, the Zwicker diagram [10] is first plotted for the work sound at the workplace and unprotected ears (Figure 2). The entire spectrum of the signal is shifted in its SPL, beginning at low SPLs and progressing to higher ones, provided at least the specific loudness in one critical band is equal to the specific loudness of the work noise in the same critical band. In Equation 2 M is used to indicate distinct levels of perceptibility (cf. section 3.2). Two levels were considered by Lazarus et al. [11]:

(i) $M = 0$: in one critical band, the critical band level of the signal barely exceeds the critical band level of the noise; and

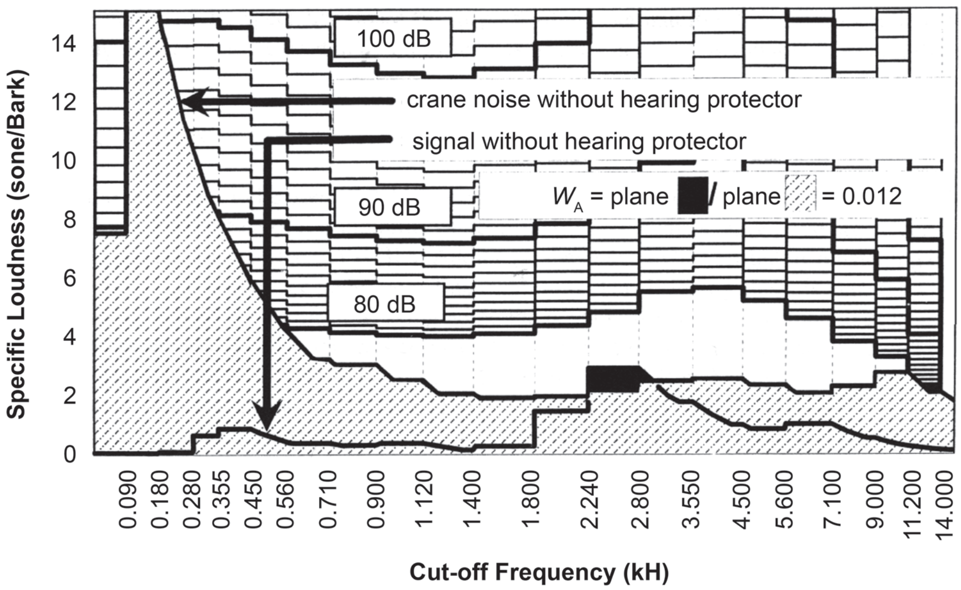

Figure 2. Selective power of perception, W_A. W_A is determined by division of the plane obtained between the two curves, where the signal exceeds the work noise by loudness (Equation 1). The 100, 90 and 80 dB levels of the Zwicker diagram [10] are indicated by the bold, stepped curves. Noise of car crane lifting loads, 87.4 dB(*A*); signal: horn of a private car.

(ii) $M = 5$: in one critical band, the critical band level of the signal exceeds the critical band level of the noise by 5 dB.

Situation (ii), $M = 5$, was selected by the bodies responsible for prevention in the field of health and safety of track-layers in Germany. The SPL of the signal is, therefore, increased by 5 dB. The Zwicker diagram of the signal is then added in Figure 2 and W_A is determined:

$$W_A = \frac{\frac{1}{n}\sum_{i=1}^{n} \Delta N_i''}{N_M}, \qquad (1)$$

$$\Delta N_i'' = N_{S,i}'' - N_{M,i}'' \quad \text{for} \quad N_{S,i}'' > N_{M,i}'',$$

$$\Delta N_i'' = 0 \quad \text{for} \quad N_{S,i}'' \leq N_{M,i}'',$$

where N''—value of loudness of the sampling point, N_M—value of loudness of the masking sound, *S*—signal, *M*—masking sound (work sound), *n*—number of sampling points where $N_{S,i}'' > N_{M,i}''$.

In the second step, the spectra of the signal and the masking sound under the hearing protector are calculated by subtracting the mean sound attenuation values for the hearing protector obtained according to Standard No. ISO 4869-1:1990 [18]. For one-third-octave bands with centre frequencies of <63 Hz, the mean attenuation values are made equal to the mean value determined for the one-third-octave band with a centre frequency of 63 Hz. From 63 Hz to 8 kHz, the mean values are interpolated linearly where necessary. For the bands with centre frequencies of >8 kHz, the mean attenuation values are made equal to the mean value determined for the one-third-octave band with a centre frequency of 8 kHz. The signal level is then shifted whilst the value of W_A remains equal to the value determined in the first step, for which no sound attenuation by the hearing protector was taken into account. The SPL of the signal is determined for both situations (with and without a hearing protector), in decibels:

$$A_M = L_{Su} - L_{Sp}, \qquad (2)$$

where L_{Su}—SPL of the signal at the unprotected ear, L_{Sp}—SPL of the signal at the protected ear for the same W_A.

Since situation (ii), $M = 5$, was selected by the bodies responsible in Germany [14], A_M became A_5. The difference A_5 between the two levels is important in assessing signal audibility: negative results indicate an impairment, a positive A_5 an improvement in the audibility as a result of the use of the hearing protector. Lazarus et al. assumed that when $A_M > -0.5$ dB, no worsening of the signal audibility was perceptible [11]. They denoted –0.5 dB as the limit value. Deutsche Bundesbahn and the Tiefbau-Berufsgenossenschaft set out the criteria for Germany: $A_5 \leq -0.5$ dB is perceptible, although in individual cases, a tolerable worsening of signal audibility may appear; by contrast, $A_5 \leq -1.6$ dB is regarded as unacceptable.

3.6. Sound Volume Method

The sound volume method is another method developed by Lazarus et al. [11]. It is based upon the increase in the loudness caused by superimposition of the warning signal upon workplace noise.

For a masking sound *M* and the signal *S*, for which one-third-octave band levels are known, the loudness *N*, in sone, is determined according to Standards No. DIN 45631:1991 [9] and No. ISO 532:1975 [10]. The sound level of the acoustic signal is then adjusted until the loudness N_S of the signal is equal to the loudness N_M of the masking sound. In Equation 5 *M* is used to indicate distinct levels of perceptibility (cf. section 3.2). Lazarus et al. considered three levels [11]:

(i) $M = 0$: the loudness level of the signal equals that of the noise;
(ii) $M = +5$: the SPL of the signal is 5 dB higher than for $M = 0$; and
(iii) $M = -5$: the SPL of the signal is 5 dB lower than for $M = 0$.

Deutsche Bundesbahn and the Tiefbau-Berufsgenossenschaft selected situation (i), $M = 0$ [14]. No further change was, therefore, made to the SPL of the acoustic signal, and the SPL L_{Su} of the signal was determined for the situation described at the beginning of this section.

For the total spectrum, the total loudness N_{S+M} was calculated as a result of the masking sound with loudness N_M superimposed by the signal with loudness N_S and level L_{Su}. The relative increase in loudness W_{Bu} caused by the signal superimposing the masking sound for the unprotected ear is now determined with

$$W_{Bu} = \frac{N_{S+M}}{N_M} - 1. \quad (3)$$

The calculation is subsequently repeated using the same masking sound and the same signal. In this case, however, the attenuation of the hearing protector used is taken into account. The mean attenuation values according to Standard No. ISO 4869-1:1990 [18] are considered in the same way for the selective method (cf. section 3.5). The relative increase in loudness W_{Bp} is determined, which is caused by the signal superimposing the masking sound for the protected ear:

$$W_{Bp} = \frac{N'_{S+M}}{N'_M} - 1, \quad (4)$$

where N'_{S+M}—loudness of the masking sound superimposed by the signal, in sone, under the hearing protector, N'_M—loudness of the masking sound, in sone, under the hearing protector (without signal superimposing the masking sound).

The measure for the improvement of signal audibility, according to Lazarus et al. [11], is as follows, in percentage:

$$B_M = (W_{Bp} - W_{Bu}) \times 100, \quad (5)$$

where p—protected ear, u—unprotected ear.

Negative B_M values indicate that the use of the hearing protector impairs signal audibility in comparison with a situation for unprotected ears. A considerable deterioration of the signal audibility is assumed if $B_{-5} \leq -2.5\%$ or $B_0 \leq -5\%$ or $B_5 \leq -10\%$ [11]. Lazarus et al. described these B_M values as limit values. Since situation (i), $M = 0$, was selected by the responsible bodies in Germany [14], B_M became B_0.

To determine L_{Sp}, the signal level is adjusted until the relative increase in loudness under the hearing protector W_{Bp} is equal to W_{Bu}. In other words, signal audibility is the same for protected and unprotected ears.

3.7. Criteria for Selecting Hearing Protectors Concerning the Warning Signal in Railway Systems

According to the criteria of Deutsche Bundesbahn and the Tiefbau-Berufsgenossenschaft for the use of hearing protectors in railway systems [14], a hearing protector is suitable if (a) an impairment of the signal audibility of $A_5 \leq -1.6$ dB does not occur for any masking sound/audible signal/hearing protector combination, and simultaneously there is (b) an insignificant impairment of the signal audibility of -1.6 dB $\leq A_5 \leq -0.5$ dB or $B_0 \leq -5\%$ not exceeding 11% of the considered masking sound/audible signal/hearing protector combinations per hearing protector.

The establishment of these criteria was based firstly upon a comparison of calculation results [13] with results obtained for the selected examples within the investigations referred to in section 3.2 [11]; and secondly upon consideration of calculation results that the BGIA obtained with the calculation procedure developed by Wittmann and Meißner [13] applied to ~80 hearing protectors [14], instead of the three hearing protectors considered by Wittmann and Meißner.

Lazarus et al. [11] pointed out that the selective and the sound volume methods result in different frequencies with which the values fall below the limits specified by them. They assumed this to depend upon the selection of the limit values. However, the trends exhibit broad agreement.

Among the frequencies with which the values fell below the limit for the two levels of perceptibility of the selective method (values A_0 and A_5) and for the three levels of perceptibility of the sound volume method (values B_0, B_{+5}, and B_{-5}), the highest frequency was found for A_5 [11]. Finally, consideration of those investigation results, safety issues, and practical reasons resulted in a combination of A_5—as the most rigorous criterion—and B_0 being established as the criteria.

Mention should be made of the fact that in railway systems, the hazard presented by failure to hear auditory warning signals is much greater than in road traffic, since visual perception is generally not essential in this case. That is why a daily listening test is required in railway systems in Germany.

3.8. Criteria for the Selection of Hearing Protectors Concerning Warning Signals in Road Traffic

The criterion set out by the transport technical committee for hearing protectors to be used in road traffic is that a hearing protector is suitable if an impairment of the signal audibility of $A_5 \leq -1.6$ dB does not occur for any masking sound/audible signal/driver's cab/hearing protector combination [15].

Should the signal be attenuated by a cab, the attenuation must be taken into account when signal audibility is determined. The attenuation is measured in one-third-octave bands and subtracted from the measured signal spectrum.

The sound volume method was applied to those hearing protectors fulfilling criterion (a) and the specific situations found in road traffic were considered. However, this application did not result in significant distinctions in signal audibility, if the measurement uncertainty of the hearing protector's attenuation in the laboratory was taken into account [15]. Consequently, only criterion (a), with modification (i.e., consideration of cab attenuation), is used in selecting suitable hearing protectors in road traffic; criterion (b) of section 3.7 is not used.

4. CRITERION FOR HEARING PROTECTORS WITH GOOD AIP

4.1. Definition of AIP

Using its hearing-protector database, the BGIA explored several options to find a simple AIP criterion for selecting hearing protectors for workplaces other than those in railway systems and road traffic, which performs well with regard to signal audibility (general), speech intelligibility, and perception of informative operating sound. The aims were to find criteria based upon the research presented in section 3, which substantiate the requirements in Standard

No. EN 458:2004 [3]. To attain this goal, the following requirements were specified:

(i) the hearing protectors should have an obvious "uniform sound attenuation characteristic over the frequency range" (p. 14) [3], and
(ii) all hearing protectors selected for railway systems and for workers driving in road traffic in Germany should also fulfill the criteria for AIP.

The criterion which best fulfills both requirements is as follows: where the gradient of the linear regression of mean values of attenuation (obtained according to Standard No. ISO 4869-1:1990 [18]) for 125 Hz up to 4 000 Hz is <3.60 dB per octave, the hearing protector is suitable in terms of AIP.

The AIP criterion was to be the more general criterion, whereas the criteria for hearing protectors for use in railway systems and road traffic were more specific. This implied that all hearing protectors suitable for railway systems and road traffic should also fulfill the AIP criterion.

Masking phenomena are also relevant for speech intelligibility. Standard No. EN 458:2004, therefore, recommends "hearing protectors having a uniform sound attenuation characteristic over the frequency range" in order for good speech intelligibility to be attained (p. 14) [3]. The AIP criterion is also expected to permit selection of hearing protectors which provide good speech intelligibility and good perception of informative sounds in the working process, since the frequency range relevant to speech and informative sounds in the working process is covered by the AIP criterion.

Figure 3 indicates the mean and standard deviation of the sound attenuation curves of those hearing protectors which do and do not fulfill this requirement (f and nf, respectively). As recommended by Standard No. EN 458:2004, the discrete sound attenuation curves of the f hearing protectors exhibit a "uniform sound attenuation characteristic over the frequency range" (p. 14) [3]. The discrete curves of the nf hearing protectors do not exhibit such a characteristic. Since type nf hearing protectors exhibit a low-pass characteristic, sounds perceived by the user with low-frequency components are less attenuated than those with high-frequency components. This may result in signals, speech and informative operating sound being masked by low-frequency ambient noise.

In Germany, the personal protective equipment technical committee established this AIP

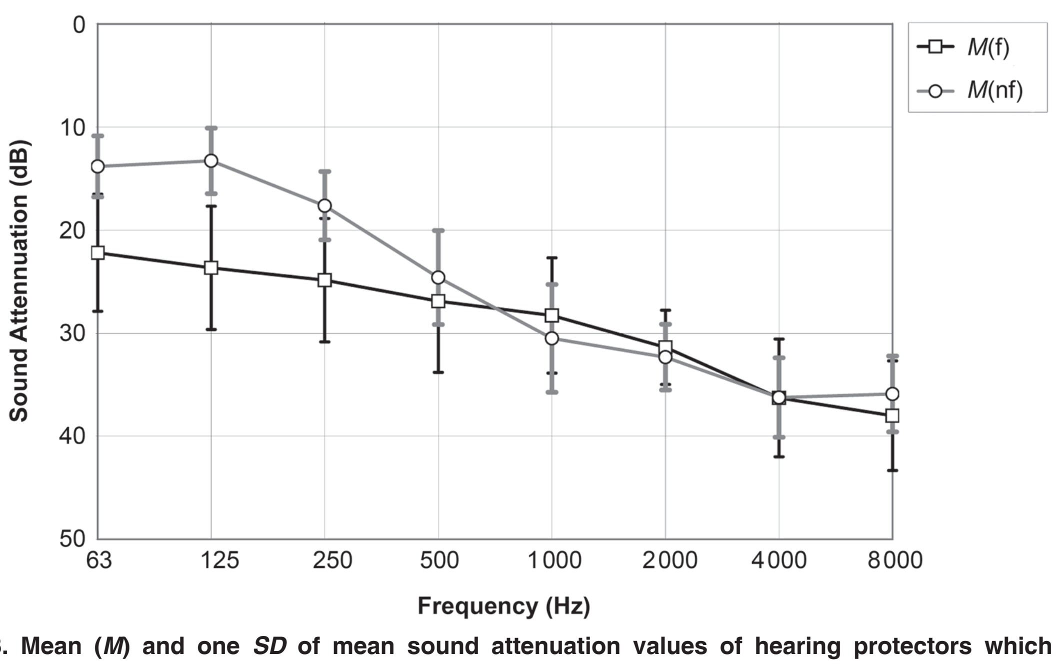

Figure 3. Mean (*M*) and one *SD* of mean sound attenuation values of hearing protectors which fulfill the AIP (signal audibility, speech intelligibility or perception of informative operating sound) requirement (f) and those which do not (nf).

criterion for selecting hearing protectors for use in situations where warning signals (general) or informative operating sounds must be registered or where speech communication is essential.

4.2. AIP Results Versus Other German Criteria

In total, 364 products from the BGIA database of hearing protectors were included in the study. Of these, 60 fulfilled the criterion for use by drivers in road traffic. The same 60 also fulfilled the criteria for use by track-layers in railway systems, as did a further 42 products.

This means that ~16% of the 364 hearing protectors satisfied the preselection criterion for road traffic, and 28% that for railway systems. In Germany, final approval is granted once a specified listening test under operating conditions at the workplace concerned has been passed [16]. All 102 hearing protectors satisfying the criteria for railway systems also fulfilled the AIP criterion. Besides those 102 protectors, a further 51 fulfilled the AIP requirements. Forty-two percent of the 364 hearing protectors are considered suitable for use if warning signals and informative operating sound must be registered or if speech communication is essential (AIP).

The figures presented in this section show the AIP criterion to be weaker than the criteria for railway systems and road traffic. Owing to the broader field of AIP applications, typical signal and noise spectra and other relevant specific workplace conditions (outside railway systems and road traffic) could not be considered in the context of the selection of hearing protectors suitable for signal audibility. In contrast to the criteria used for the selection of hearing protectors in railway systems and road traffic for which, among others, work noise (masking sound) spectra are used, the AIP is only based numerically on the sound attenuation performance of the hearing protectors and a relation to those hearing protectors selected for railway systems and road traffic.

5. USE OF HEARING PROTECTORS IN RELATION TO POOR SIGNAL AND SPEECH AUDIBILITY

The development of occupational hearing impairment in German industry reveals that noise is still a serious problem: in 2006, one third of all recognized cases of occupational disease were attributed to occupational hearing impairment [19]. Industrial practitioners observe employees who refuse to wear hearing protectors at times (or continually) while exposed to daily noise exposure levels higher than 85 or even 90 dB(*A*). Those employees frequently maintain that their hearing protectors are either are not comfortable enough, or impede communication or the perception of warning signals or informative operating sounds.

Regular short-term removal of the hearing protector inside a noise zone is very dangerous to the hearing. Where a hearing protector is removed for only one minute every half an hour, the wearing time is 97%; the effective exposure to noise is increased by >10 dB, however. A 10 dB rise in the effective exposure may increase the risk of deterioration of hearing by up to 9 times [20] depending on the outside sound level, the ear muffs and long-term exposure.

Specific conditions relating to the working environment and activity, i.e., humidity, informative sounds in the working process, warning signals, speech communication, and localization of sound sources, may be a reason for regular short-term removal. The wearing time must be increased to the exposure time in order for employees to be protected effectively against noise. The first main step is to obtain a comfortable fit. In the European Union, ~500 types of hearing protectors are available on the market [21]. It should, therefore, be possible to select satisfactory products for all activities and users.

In addition to the wearer's comfort, consideration must also be given to the sound attenuation requirement, medical disorders, compatibility with other headgear, and the relevant working environment, e.g., audibility of specific sounds. Detailed information on how all those relevant aspects may be considered is provided in Standard No. EN 458:2004 [3] and Regulation No. BGR 194 [22].

6. CONCLUSION

A simple AIP criterion for selection of hearing protectors was identified and established in Germany, and may be used in other countries, for cases in which warning signals or informative operating sounds must be perceived or speech communication is essential. It can be easily applied, provides substance to the general recommendation stated in Standard No. EN 458:2004 [3], and is compatible with other, more specific criteria for signal audibility in situations with a high risk of accidents caused by a possible failure to register a warning signal. A selection program (in German) for hearing protectors is available at the BGIA website[1]. It is based upon Standard No. EN 458:2004 and refers to the criteria described in sections 3.7, 3.8, and 4.

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