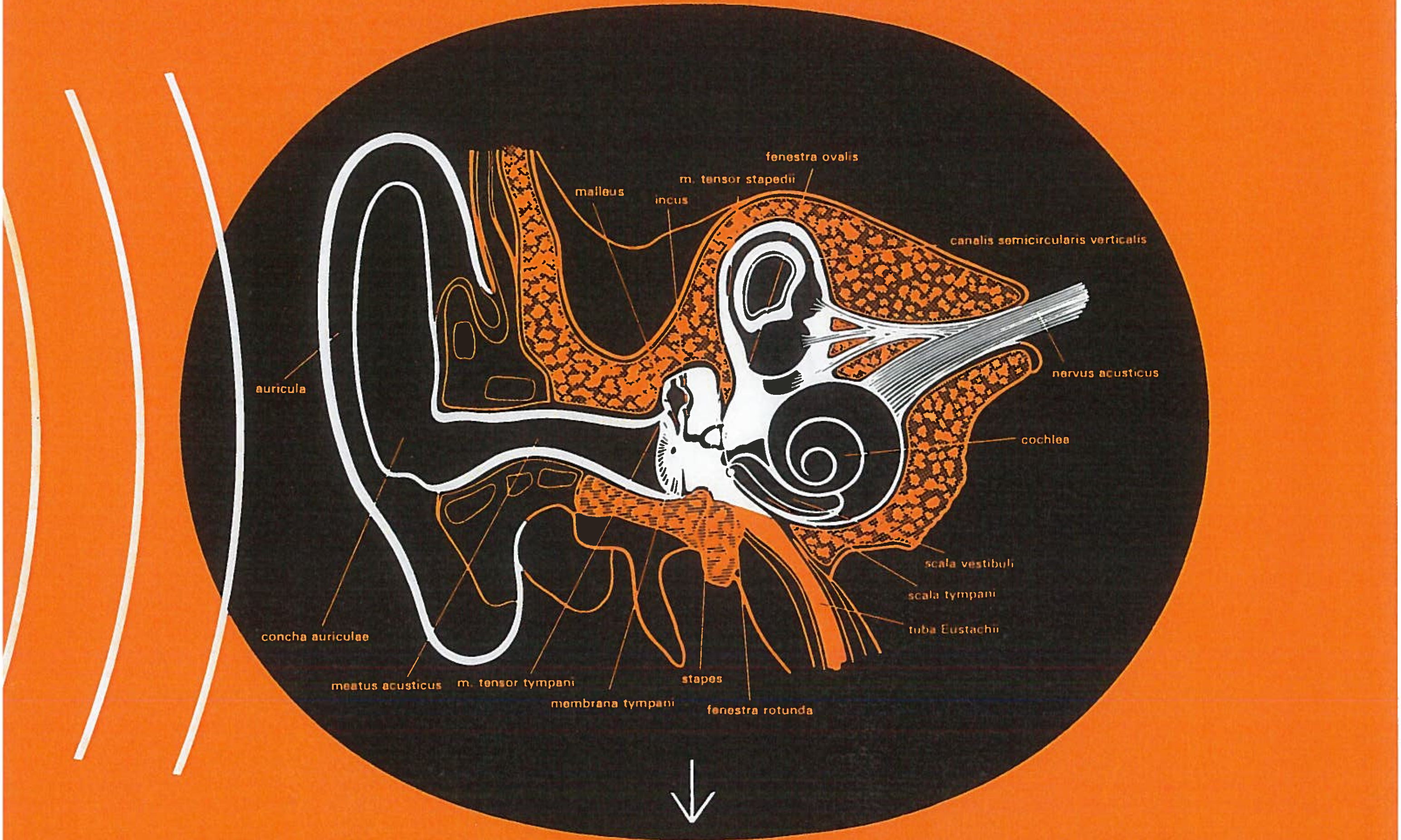
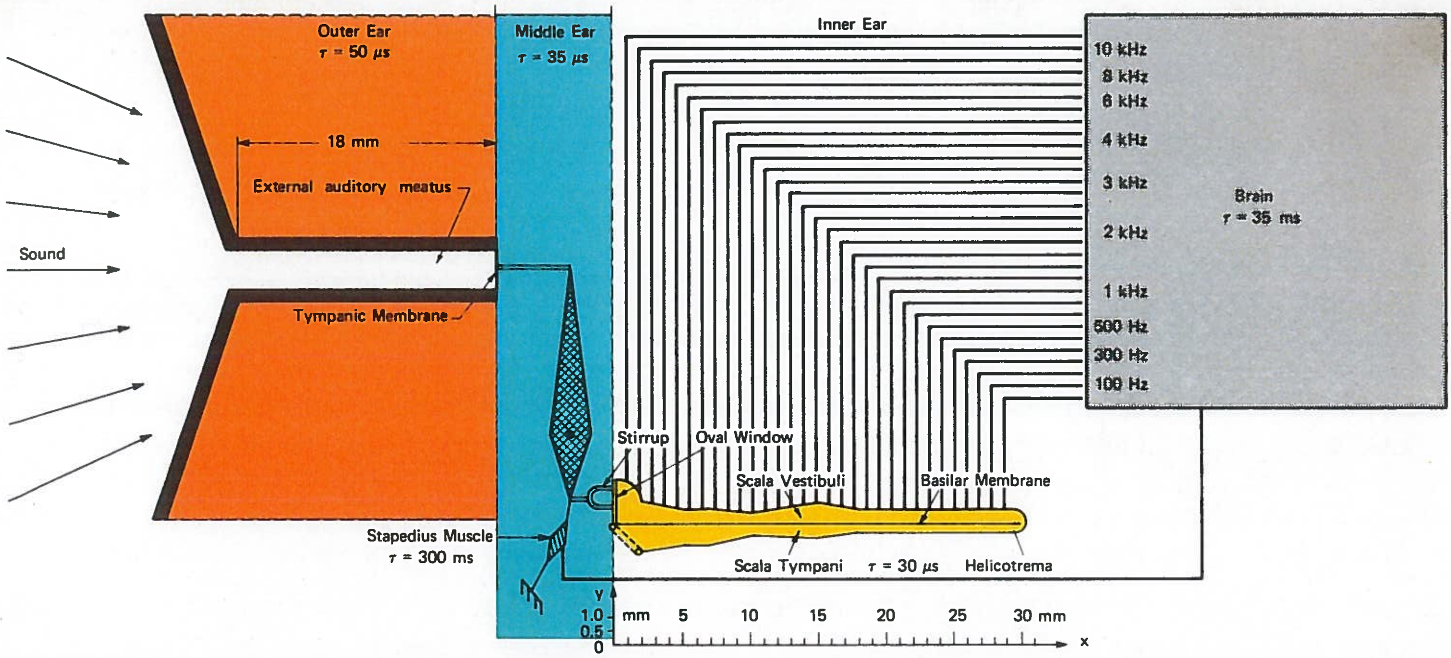
# Do We Measure Damaging Noise Correctly?*

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# Do We Measure Damaging Noise Correctly?*

*For steady industrial noise without excessive impulses, the risk for hearing loss is reasonably well related to the total noise dose criterion. However, the inadequacy of the criterion's assessment of the hearing loss risk for fluctuating industrial noise with relatively high peak values has led to the investigation of impulses encountered in industrial environments. The majority of industrial noise has a higher intensity in the 250 Hz to 500 Hz frequency range than at 6 kHz, while the short duration peaks contain a significant amount of energy in the 4 kHz to 6 kHz frequency region. Because the frequencies in the 4 kHz to 6 kHz range are also amplified in the outer and middle ear, the short duration peaks seem to play a dominant role in contributing preferential damage in this range.* ***P. V. Brüel***† *proposes a simple method for setting limits for hearing loss risk: considering the crest factor of noise when weighting the noise dose criteria.*

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Noise, according to a rather hackneyed expression, is undesired sound; that is, sounds that disturb, annoy, and even impair hearing. Nevertheless, the internationally standardized sound level meter has been developed entirely on the basis of arbitrarily agreed equal loudness contours (inverted), without due consideration of the sounds that disturb or annoy, and (which is much worse) none at all to those which involve a risk for hearing damage. When one therefore asks, Do we measure noise correctly? the answer must be that where hearing level is concerned, the scale in use today is applicable because it was originally developed on the basis of hearing level. If, however, one considers the annoyance caused by noise, then our noise scale is no longer appropriate, and even less acceptable when used to stipulate permissible noise limits to prevent hearing loss. The latter is rather serious, since large sums are offered for prevention of hearing loss caused by industry and traffic.

If the risk of hearing loss is to be determined for highly fluctuating industrial noise, gunshots, and hammer blows, the results of readings from such a sound level meter can be completely misleading. This is because the high sound impulses with significant energy content in the 4 kHz to 6 kHz frequency region are short enough that they are not loud, and as a result, do not give a significant reading on our sound level meter which is developed to yield an approximate indication of loudness. Because of the relatively long time constants of the sound level meter, it cannot handle the high peak values (which are to a large extent responsible for hearing loss), and therefore fails to give an appropriate indication of the risk of hearing damage. To assess the risk of hearing loss, the sound level meter should be 1000 times faster than even the present-day impulse sound level meter, so that the peak values of the short impulses could be measured and read off using a Hold circuit incorporated in the instrument.

Finally, it has been shown that in evaluating the damaging effects of noise, and thereby setting the limits for maximum permissible noise levels, not only must the sound levels be determined with a normal sound level meter, but the impulsive content of the noise must be determined with a sound level meter that has a peak-holding capacity. The risk limits can then be set in several ways; this article proposes a rather simple method which has the further advantage that all material available today, gained from experience with the correlation between measured noise and hearing loss, can be utilized by a simple correction for the content of peak values in the noise.

## Present-Day Sound Level Meters

Around 1928 Fletcher and Munson published their well-known investigations of the human ear's sensitivity to pure tones of different frequencies and intensities.[1,2] These investigations apply only to the hearing level of continuous pure tones that are compared with the 1000 Hz tone. They do not take into account annoyance or the variation of loudness with time. However, their curves form the basis for the A, B, and C weighting networks (inverted Fletcher Munson Curves) found in present-day sound level meters. The rectifier normally used is the rms rectifier, to correctly add the different frequency components, energywise. The meter time constants are standardized to be 125 ms (termed Fast) and 1000 ms (termed Slow), for use on signals with fluctuating levels.[3] These time constants are chosen arbitrarily and bear no relation to the hearing mechanism of the human ear.

In the mid-sixties it became clear that the normal sound level meter did not measure fluctuating noise appropriately, possibly because of incorrect time constants; this led to the development of the so-called impulse sound level meter.

The loudness of a sound perceived by the ear is a function of amplitude and the duration of the stimulus presented to the ear. Under some circumstances, continual growth in loudness for a stimulus with constant amplitude may occur for up to 10 seconds. If, on the other hand, the same stimulus existed for a shorter time (less than 200 ms), there would be a reduction in loudness, and the shorter the duration of the stimulus, the less loud it would be.

Several researchers have investigated this phenomenon, and many of their results are shown in Fig. 1. The results were obtained by psychoacoustic experiments in which the loudness of impulses of different duration were compared to those of steady sounds. The sound pressure level difference ($L_i - L_D$), in dB, between the impulse level $L_i$* and that of the steady sound $L_D$, which was judged to be equally loud, is used as ordinate in the figure. The $x$ axis shows the duration of the pulse. As long as the duration of the pulse is longer than a certain amount, the sound pressure level of the pulse and that of the steady sound are equal for equal loudness judgment ($L_i - L_D$) = 0. However, for pulses shorter than this duration, the level of the pulse must be increased to give the same loudness sensation as the steady sound. The breaking point at ($L_i - L_D$) = 0 then corresponds to the effective averaging time of the ear. The slope of the majority of the curves shows an increase of 3 dB in sound pressure level (doubling of pulse intensity) for halving of the duration of the pulse. Since energy = intensity × time, the ear would seem to be an energy-sensitive device, as the increase in intensity has to compensate for the decrease in pulse duration.

A considerable spread in the results can be seen in the figure. However, it has

*As impulse level $L_i$, the level of the signal from which the pulse was cut out was used.

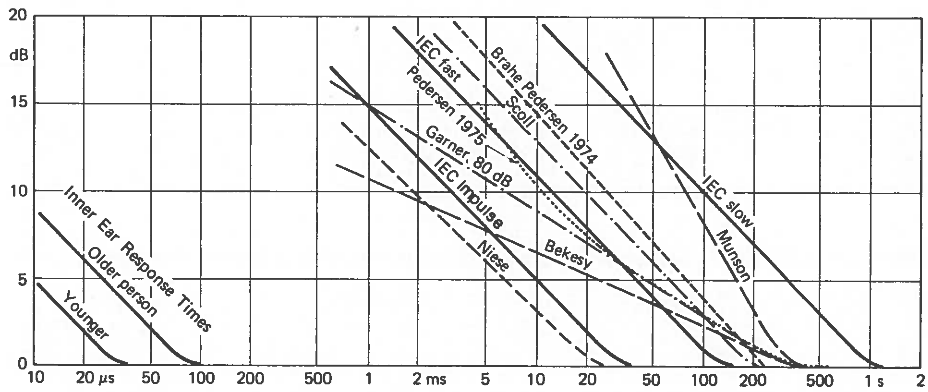


*Figure 1 — Results from different researchers of the subjective perception of short impulses compared with the integration curves for time constants Fast, Slow, and Impulse of the sound level meter*

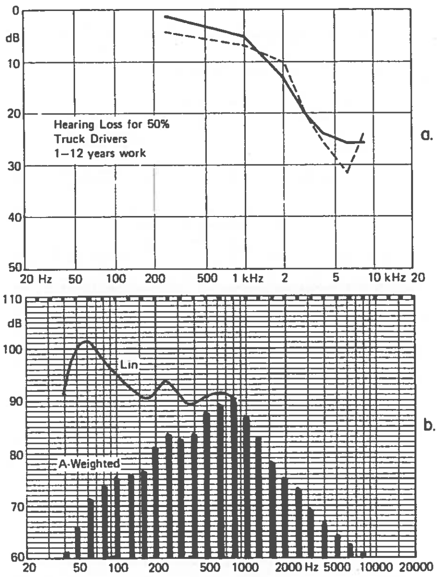


*Figure 2 — a) Average audiograms of truck drivers after approximately ten years of work. b) Frequency spectrum of tractor noise, both linear and A-weighted.* Figures represent sound pressure levels in one-third octave bands (Hansson & Kylin)

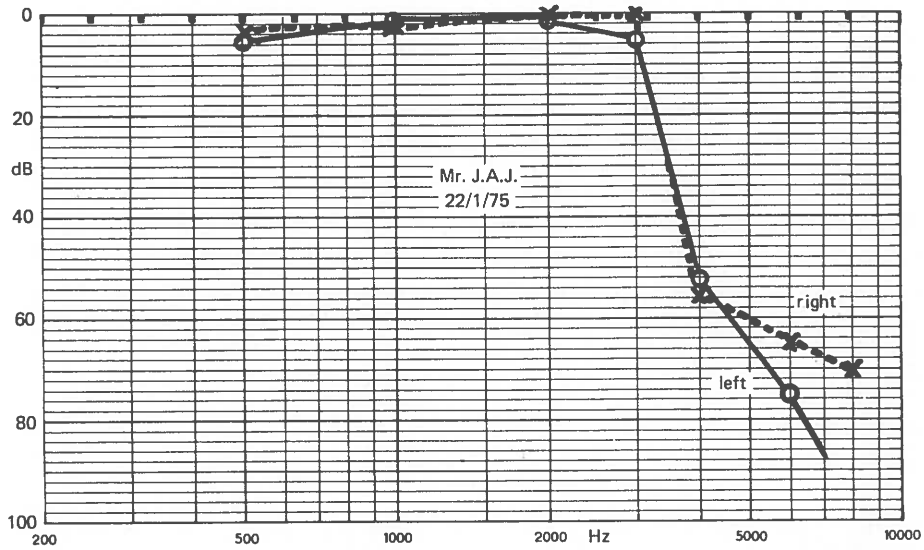


*Figure 3 — Typical audiogram illustrating hearing loss of a person exposed to a gunshot*

been agreed by the International Electrotechnical Commission (IEC) to choose 35 ms as the averaging time for the impulse sound level meter, which corresponds to the fully drawn curve shown in Fig. 1.

For all measurements referred to and shown in Fig. 1, the hearing level (subjective loudness of the corresponding sound impulses) has been used as the basis. The curves do not give insight into the degree of annoyance caused by different impulses, and they cannot be used for predicting the damaging effects of sound impulses on the human ear. It should be emphasized that many people believe the IEC standardized impulse sound level meter can be used to set acceptable noise limits that will avoid the damaging effects of noise.

The averaging time of the ear, defined to be 35 ms, is commonly accepted as the same for both increasing and decreasing levels of noise. This may be correct, though it has never been proven. Nevertheless, for the impulse sound level meter the time constant has been completely arbitrarily chosen to be 3 s for decreasing levels, which is 100 times longer than for increasing levels.[4] The long time constant of 3 s for decreasing levels has been introduced strictly from a practical point of view, to allow reading off the meter when single impulses are measured. This long time constant is in no way related to the hearing mechanism, and it is more than doubtful whether repetitive pulses can be measured correctly, whereas the response to a single impulse will generally correspond to its subjective loudness.

## Measurement Results

For more than forty years it has been known that hearing loss always starts around 4 kHz to 6 kHz ($C_5$-dip), and that as a rule it is more severe at 6 kHz, whether the damage has been caused by a single shot, firework, small explosion, or similar singular events, or whether the loss has occurred gradually due to long-term exposure in a noisy environment. The latter is very strange, since practically all familiar industrial noise has a higher intensity in the 250 Hz to 500 Hz frequency range than at 6 kHz. There has been considerable speculation as to why hearing loss due to industrial noise occurs three octaves higher on the frequency scale than the corresponding frequency region with the most energy content, and no sensible explanation has been given to date.

Fig. 2 shows typical audiograms of truck drivers with hearing loss, who have been exposed to different noise levels for long durations. Also shown is the corresponding typical spectrogram of the noise to which the worker has been exposed.

If noise is uniform, without excessive impulses, it can be shown that the human ear damage is related to the total noise dose to which the worker has been exposed in his lifetime. The percentage risk can be expressed by a formula, where the equivalent noise level for each working day is added over the number of years of exposure to the corresponding noise.[5] For fluctuating noise levels (for example, the case of a truck driver who drives in and out of a factory), it seems that the risk of hearing loss is also related to the total noise dose over the years.[6,7] However, this is not so when the noise contains short impulses, such as noise from punch presses, riveting machines, plate-straightening machines, hammer blows, and pneumatic nailing machines. For these cases, the risk of hearing loss appears to be significantly higher than that indicated by the total noise dose. Depending on how impulsive the noise is, one must correct it by 13 dB to 20 dB.[8,9]

The situation is quite the opposite in the case of permanent ear damage caused by gunshots and clicks. Very loud noise, even of short duration, can rupture some of the fine hair cells activated by the basilar membrane, whereby they become inactive either temporarily or permanently, depending upon the intensity of the noise. This kind of ear damage is completely different from that due to steady noise, where the product of intensity multiplied by time (the total noise dose) causes damage by a fatigue phenomenon.

Fig. 3 shows an audiogram of a person

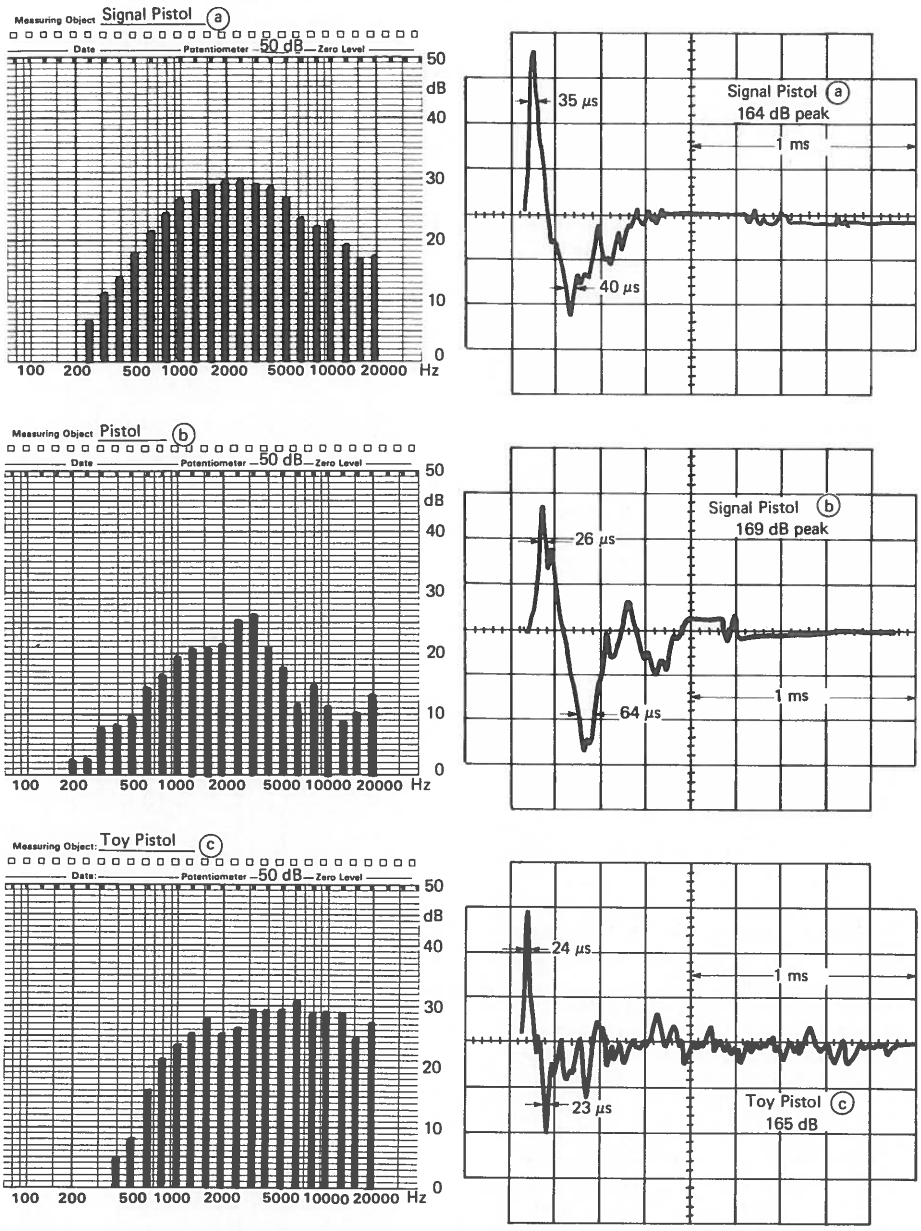


*Figure 4 — Spectrograms and oscillograms of a) shot from a signal pistol at a distance of 0.5 m, b) shot from a signal pistol at a distance of 1 m, and c) shot from a toy pistol with cap, at a distance of 10 cm*

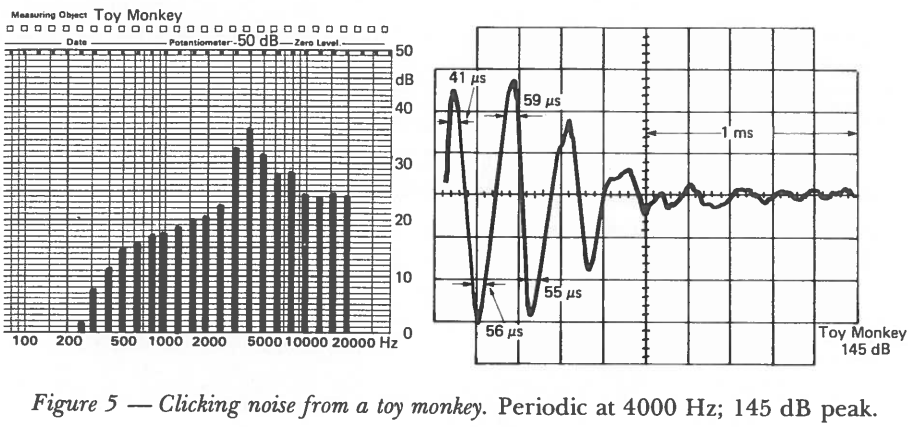


*Figure 5 — Clicking noise from a toy monkey.* Periodic at 4000 Hz; 145 dB peak.

who had been exposed to a gunshot, while Figs. 4 and 5 show some oscillograms and spectrograms of shots from a signal pistol and a toy pistol, and a clicking noise from a toy monkey.

The analyses of these sounds show that the maximum energy content lies in the frequency region 4 kHz to 6 kHz. Because of the short duration of pistol shots, the result from a normal sound level meter would give only an expression of the energy content of the shot. It would not give any information about the high instantaneous values for which a special sound level meter with Peak Hold is required. Moreover, it can be seen that the signal almost always consisted of one or more whole periods with equal positive and negative pressure peaks, in contrast to the previous assumption that an impulse was a short, high-level, positive pressure peak followed by a long, negative pressure pulse with much lower amplitude. It is therefore quite natural that the ear is most affected and damaged around 4 kHz by the response of a gunshot, an impulse, or a click. This naturally leads to the investigation of whether industrial noise contains short, high sound impulses with significant energy content in the frequency region 4 kHz to 6 kHz, but which are so short that they are neither registered as loud sounds by our hearing mechanism nor give a significant reading on a normal sound level meter.

Figs. 6, 7, and 8 show oscillograms and spectrograms of a hammer blow on a hard material, the impact between two bottles, and the sound generated during perforation of a plate by a punch press, respectively.

Analyses of these industrial noises reveal significantly high-level sound impulses with both positive and negative pressure amplitudes — usually sequences of some milliseconds with large energy content in the 2000 Hz to 5000 Hz frequency region, with maximum peaks 15 dB to 25 dB higher than the mean value measured with a normal sound level meter. The maximum pressure durations are between 30 $\mu s$ and 200 $\mu s$.

Since we do not correctly perceive the intensity of the short sound impulses, one could ask: How can the ear be damaged by impulses which sound so weak? Before the question can be answered, it is necessary to describe the ear, its integration times, and the transmission characteristics of the different parts of the ear.

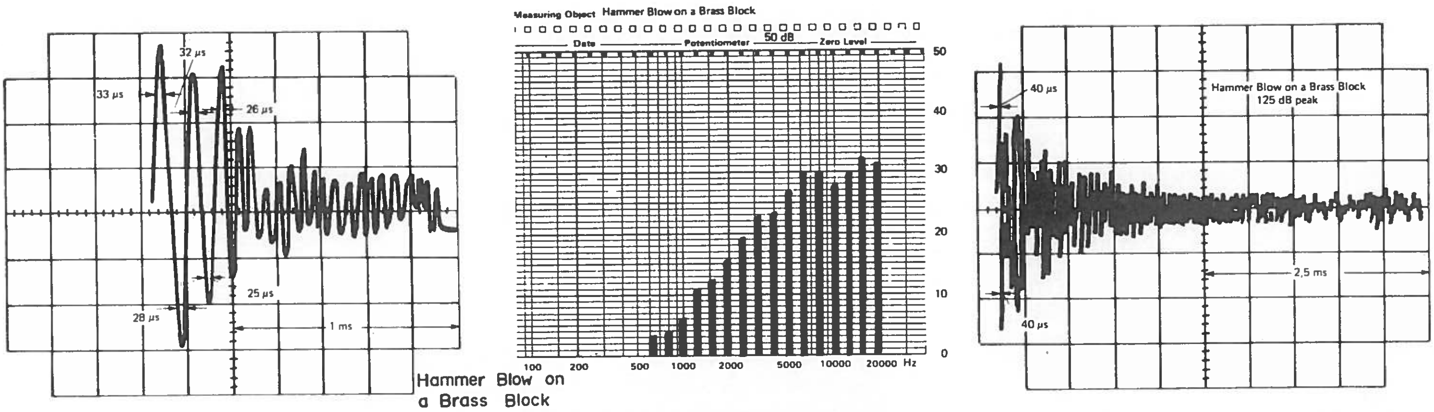


*Figure 6 — Hammer blow on a brass block*

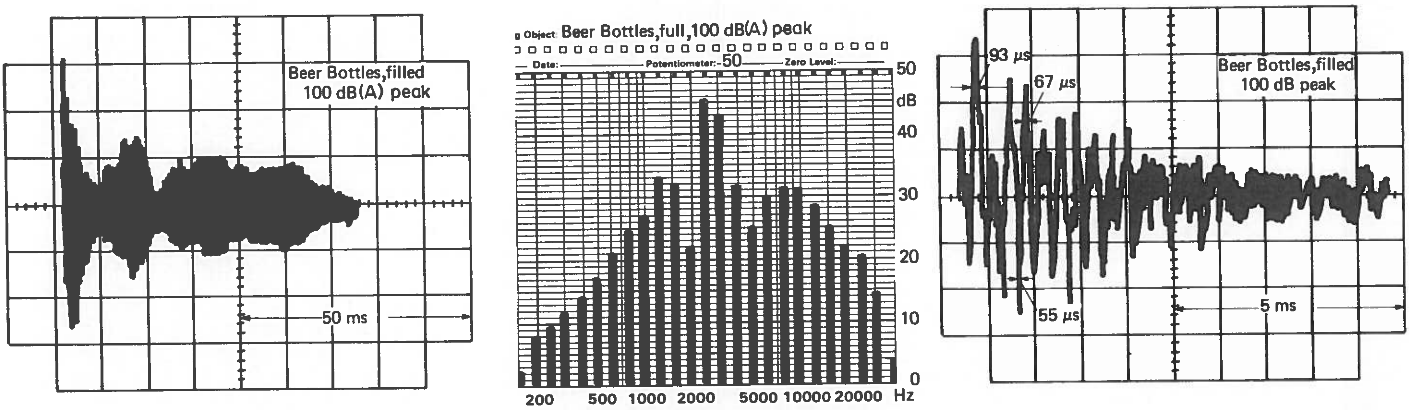


*Figure 7 — Noise from impact between two bottles*

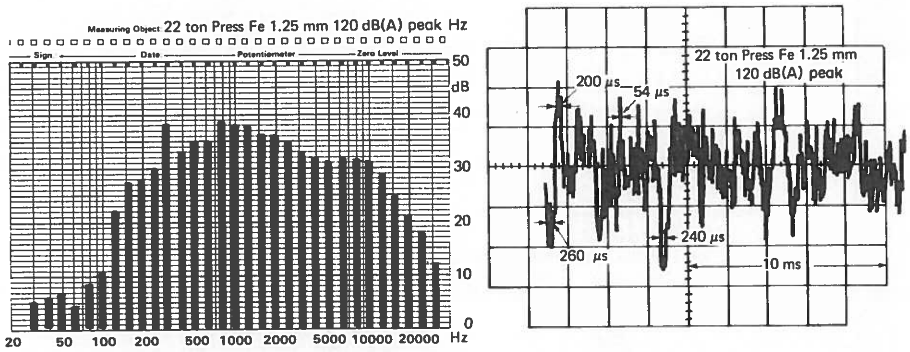


*Figure 8 — Sound during perforation of a plate by a punch press*

## The Ear and Its Integration Time

Fig. 9 shows a schematic drawing of the human auditory system. The drawing is rather unorthodox, accentuating the elements and characteristics that have special significance from a communication technologist's viewpoint.

The lever arm mechanism of the middle ear is sketched with only a single lever arm. Such a transmission system, with stiffnesses (of eardrum and oval window), masses, and moments of inertia (of lever arm and membranes), together with friction (mostly from the inner ear), does not transmit all frequencies equally well. The stiffnesses impede the transmission characteristics of low frequencies and inertia impedes the higher frequencies; transmission is best at resonance (approximately 1200 Hz). Since friction contributes to the major part of the impedance, the resonance is not particularly sharp, and transmission is good between 500 Hz and 8000 Hz.[10,11] In the middle ear there are two muscles, the stretching muscle of the eardrum and the stapedius muscle, which by contraction can increase the stiffness of the lever arm mechanism. These muscles are set into operation by loud sounds; they start around 75 dB and are fully activated around 90 dB to 95 dB re $2 \times 10^{-5}$ Pa. Since the muscle contraction can increase only stiffness and not inertia, the sensitivity at only low frequencies is decreased, under 1500 Hz to 1800 Hz. However, this does not occur instantaneously, since it takes time for the signal to pass from the muscle, ear, and nerves to the brain, where it is perceived and sent back to the muscle. Therefore, for long impulses only, the amplitude may be diminished at low frequencies if the muscles have time to respond. Nevertheless, the high peak values may rupture some of the fine hair cells before the muscles have time to respond.

The shape of the outer ear, with the auditory muscle and ear canal, also has a resonance amplification due to the shape of both the head and the auditory muscle; the ear canal, especially, gives a quarter wavelength's amplification around 4 kHz.[12] Like that of the middle ear, this resonance is not particularly sharp.

It has been shown that the human ear

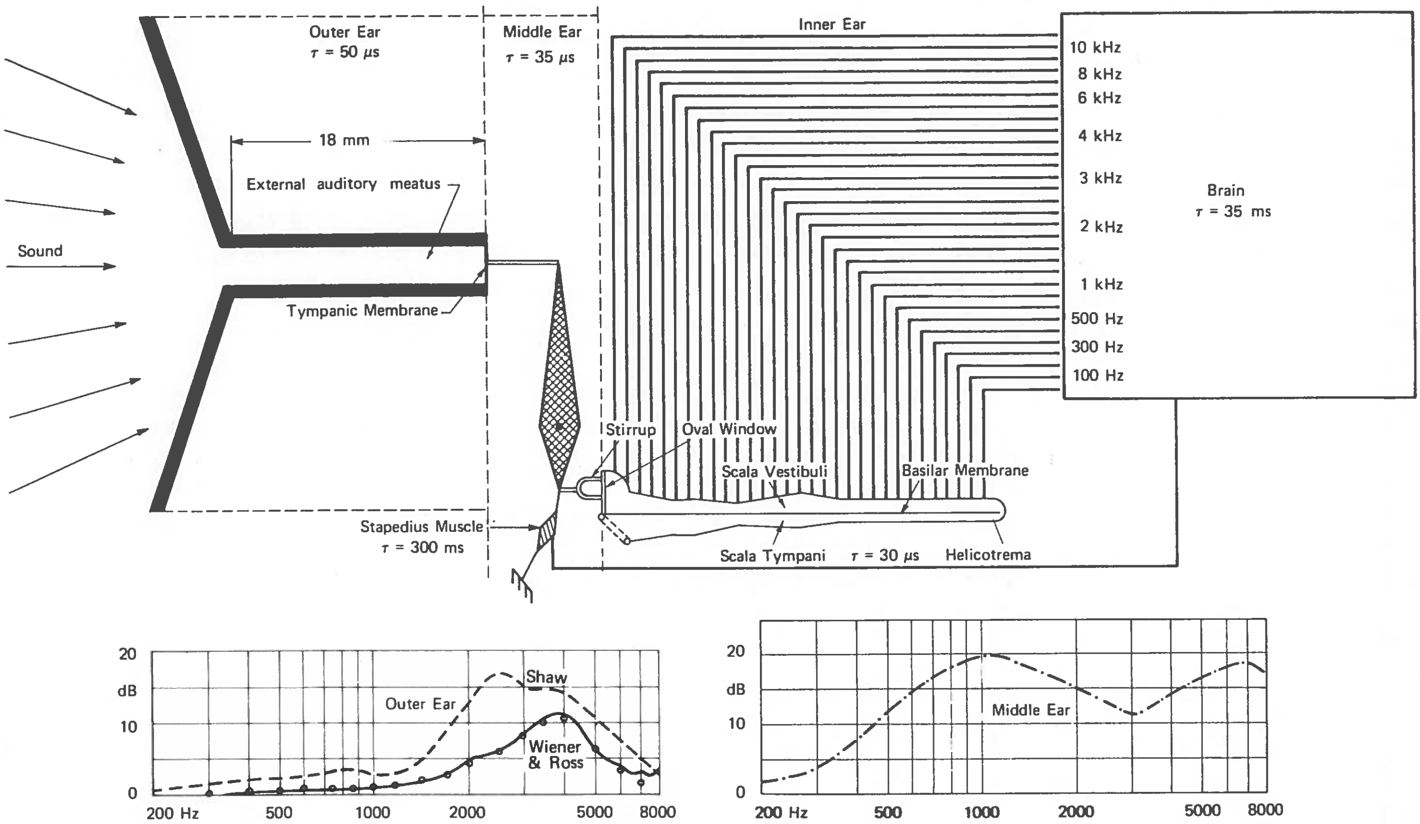


*Figure 9 — Schematic drawing of the human ear with the teletransmission system's most important time constants, and the transmission characteristics of the outer and middle ear*

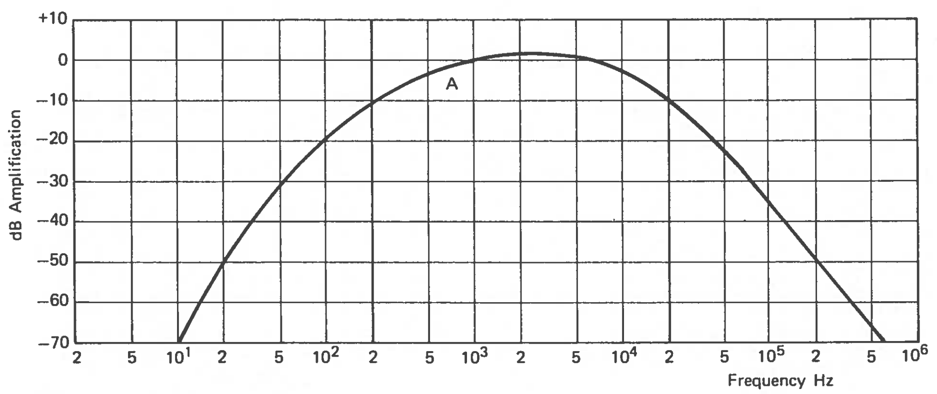


*Figure 10 — The A-weighting curve*

has an effective averaging time between 20 ms and 100 ms (Fig. 1), with a defined mean value of 35 ms. These are very long times, completely incompatible with the capability of detecting frequencies above 20 Hz to 50 Hz. If we were to perceive and analyze frequencies around 15 kHz to 20 kHz, then the response times should be correspondingly lower (around 50μs to 100 μs). The reason we perceive frequencies over 50 Hz is due exclusively to the fact that the major part of the frequency analysis is carried out in the inner ear and transmitted to different parts of the brain through parallel nerve fibers. This is completely analogous to the principle used in modern real time analyzers. Since the inner ear receives all frequencies simultaneously at its input terminal, and is able to handle and distinguish all the amplitude variations so rapidly, its response time must be of the order of 50 μs to 100 μs. On the other hand, the reason we perceive a short impulse to be less loud than a longer one is due to the averaging taking place after the frequency analysis of the signal on its way to the brain, with the defined averaging time of 35 ms.

If the A-weighting curve, Fig. 10, which is the inverse of the hearing sensitivity curve, can be considered a low-pass filter, the response time of such a filter can be stipulated, from telecommunication theory, to be proportional to $1/f$, where $f$ is the upper cutoff frequency of the filter. If the upper cutoff frequency can be assumed to be around 15 kHz for the young and 10 kHz for the elderly (who cannot hear the higher frequencies very well), the response time would be of the order of 50 μs to 100 μs.

## Discussion of Results

From examining the transmission characteristics of the different parts of the ear, it can be seen that the impulses are transmitted without attenuation through both the outer and the middle ear, to the nerves in the organ of Corti, where the nerve ends are also exposed to the full amplitude of the short sound impulses; it is in the summing up of the sound impression in the brain that a short impulse is first perceived as less loud than a longer one.

It is shown, further, that in the outer and middle ear there is a 3 dB to 10 dB

**TABLE I**
RESULTS OF MEASUREMENTS MADE WITH SOUND LEVEL METER

| Sound Source | Fast dB(A) | Imp. dB(A) | Imp. Hold dB(A) 5 x | Peak Hold dB(A) 5 x | Δ |
|---|---|---|---|---|---|
| Sinusoidal pure tone 1000 Hz | 94 | 94 | 94 | 97 | 3 |
| Beat Music from a gramophone | 90 | 91 | 93 | 97 | 4 |
| Modern music from a gramophone | 102 | 103 | 103 | 105 | 2 |
| Electric guitar from a gramophone | 85 | 86 | 86 | 91 | 5 |
| Motorway traffic 15 m distance | 80 | 80 | 81 | 89 | 8 |
| Motorway traffic 50 m distance | 68 | 68 | 68 | 76 | 8 |
| Train 70 km/h rail noise 10 m distance | 95 | 96 | 98 | 106 | 8 |
| Train 70 km/h rail noise 18 m distance | 85 | 87 | 87 | 94 | 7 |
| Noise in aircraft Type PA 23, cruising speed | 90 | 91 | 91 | 100 | 9 |
| Noise in aircraft Type Falco F 8, cruising speed | 97 | 98 | 98 | 109 | 11 |
| Noise in aircraft Type KZ 3, cruising speed | 102 | 102 | 103 | 112 | 9 |
| Noise in car Type Fiat 500, 60 km/h | 78 | 79 | 79 | 93 | 14 |
| Noise in car Type Volvo 142, 80 km/h | 75 | 75 | 76 | 86 | 10 |
| Lawn mower 10 HK 1 m distance | 97 | 99 | 99 | 116 | 17 |
| Typewriter IBM (Head position) | 80 | 84 | 83 | 102 | 19 |
| Electric shaver 2.5 m distance | 92 | 92 | 92 | 107 | 15 |
| 75 HK diesel motor in electricity generating plant | 100 | 101 | 101 | 113 | 12 |
| Pneumatic nailing machine 3 m distance | 112 | 114 | 113 | 128 | 15 |
| Pneumatic nailing machine near operator's head | 116 | 120 | 120 | 148 | 28 |
| Industrial ventilator 5 HK 1 m | 82 | 83 | 83 | 93 | 10 |
| Air compressor room | 92 | 92 | 92 | 104 | 12 |
| Large machine shop | 81 | 82 | 82 | 98 | 16 |
| Turner shop | 79 | 80 | 81 | 100 | 19 |
| Automatic turner shop | 79 | 80 | 80 | 99 | 19 |
| 400 kN Punch press, near operator's head | 93 | 98 | 97 | 121 | 24 |
| Small automatic Punch press | 100 | 103 | 103 | 118 | 15 |
| Numerically driven high speed drill | 100 | 102 | 103 | 112 | 9 |
| Small high speed drill | 98 | 101 | 101 | 109 | 8 |
| Ventilator with filter | 82 | 83 | 83 | 94 | 11 |
| Machine driven saw, near operator's head | 102 | 102 | 104 | 113 | 9 |
| Vacuum cleaner Type Hoover, 1.2 m distance | 81 | 81 | 81 | 93 | 12 |
| Bottles striking each other | 85 | 88 | 90 | 105 | 15 |
| Bottling machine in brewery | 98 | 99 | 101 | 122 | 21 |
| Toy pistol (cap) | 103 | 108 | 108 | 140 | 32 |
| Pistol 9 mm, 5 m distance from side | 111 | 114 | 116 | 146 | 30 |
| Shotgun 5 m distance from side | 106 | 110 | 111 | 143 | 32 |
| Saloon rifle 1 m distance from side | 105 | 110 | 110 | 139 | 29 |

resonance amplification of frequencies around 3 kHz to 4 kHz (see Fig. 9). It would therefore seem natural that the damaging effects of industrial noise also start in the frequency region around 4 kHz. This is partly because the majority of high noise levels by far are found in this frequency region (although we cannot hear them with their proper intensity), and partly because the resonance of the ear at 3 kHz to 4 kHz further amplifies periodic sound pressures.

It can be seen from the analyses of the impulses shown that measuring instruments without adequate response characteristics greatly underestimate the peak levels of impulses. However, these impulses are so long that they reach the inner ear with their full amplitude. It has been shown that a short impulse propagated through the outer ear can be 6 dB to 7 dB higher at the eardrum than the highest sound pressure outside the ear. During passage through the middle ear, similar amplification can occur, so that signals with a frequency content of 3 kHz to 6 kHz would reach the inner ear with a total amplification of up to 10 dB to 12 dB. If the amplitude of the impulses is high enough, the nerve ends are damaged, even though a normal sound level meter would indicate that the noise is below the danger level.

## Risk Criteria

The consequence of this reasonable explanation of the mystery of the hearing threshold shift around 4 kHz is that in evaluating the damaging effects of noise, and thereby setting the limits for maximum permissible noise levels, we must not only determine the sound level with a normal sound level meter, but furthermore must determine the impulsive content of the noise with a sound level meter that can be charged up very quickly. This evaluation can be carried out in several ways: what follows is a rather simple method with the further advantage that all material available today, gained from experience with the correlation between the measured noise and hearing loss, can be utilized by a simple correction for the content of peak values in the noise.

A number of measurements have been taken in different industries using a B & K Sound Level Meter Type 2209 with Hold circuit for peak voltage measurements, which, with the A-filter coupled in, has an averaging time of 30 $\mu$s for peak measurements.

The results are shown in Table I. All measurements were taken according to dB(A) Fast (125 ms), dB(A) Impulse (35 ms), and dB(A) Impulse Hold, in which case the reading noted was the mean of five values measured with approximately 10-second intervals. Finally, measurements were taken with dB(A) Peak Hold (30 $\mu$s), with 5-second to 10-second intervals and the mean of five measured values noted. The most interesting aspect is to ascertain how large the Peak value is above dB(A) Fast or dB(A) Impulse (denoted by Δ in the table). The larger the difference, the more dangerous the noise.

It is now possible — from the theories developed here, together with the vast amount of practical experiences described in literature — to set up some risk criteria for different types of industrial noise.

Passchier-Vermeer has evaluated the noise-induced part of the median hearing levels at different frequencies and exposure times, from audiograms of workers in three branches of industry: wood industries with varying noise but without impulses; welding shops with percussion machines, lathes, and milling machines; and metal shops with punch presses.[9] Both the welding and metal shops had fluctuating noise containing impulsive components. The theoretical equivalent sound levels calculated from comparison of the median hearing levels of wood industry workers (levels not exceeded in 50 percent of the workers) with similar data from workers in an environment of steady-state broadband noise, agreed reasonably well with the measured $L_{eq}$. This confirms the equal energy principle for noise without peaks. However, the figures for the metal industries do not agree well, since the equivalent sound levels measured were 10 dB to 20 dB lower than those calculated from the median hearing levels.

The results obtained by Passchier-Vermeer (which show that the noise-induced parts of the median hearing levels of wood industry workers, after ten years in an equivalent noise level of 102 dB, can be related to the equal energy principle) can be used to set up the damage risk criterion shown in Fig. 11. From here, one can set up risk criteria for other types of noise, with different relations between their peak and dB(A) values. By comparing the results, given in Table I, for machines in the wood industry and other machines with constant noise levels, it can be seen that the peak values are around 10 dB higher than the dB(A) values for this type of noise. As a result, the baseline after the total energy principle, valid for three months to twenty years of noise exposure, is drawn 10 dB above the line for woodworking machines in Fig. 11.

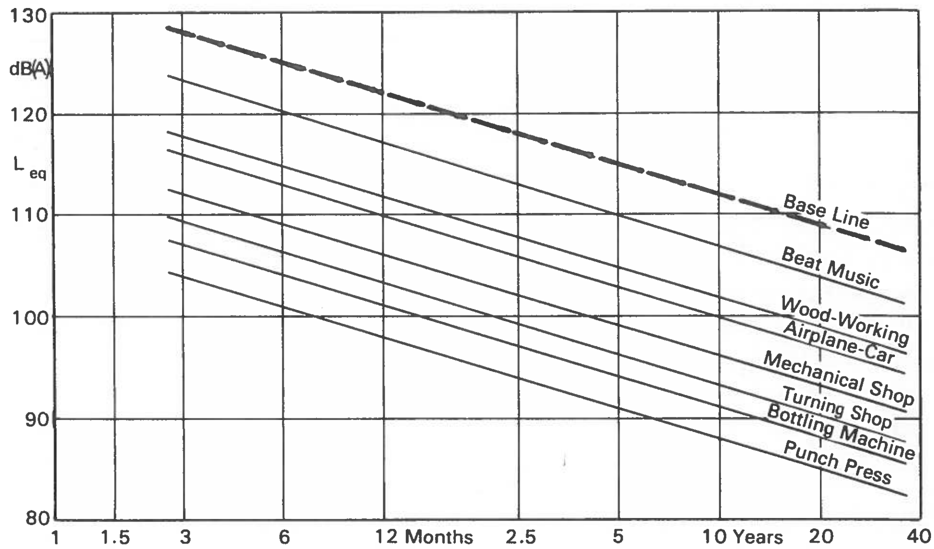


*Figure 11 — Risk criteria for different types of noise, evaluated on the basis of the relation between dB(A) value and peak value*

By referring to Table I and finding the difference between the peak value and the dB(A) value, the risk criteria for different types of noise (such as from punch presses, in turning shops, in mechanical workshops, and in aircraft) can be found. It can be seen from Fig. 11 that KZ 3 aircraft (mentioned in Table I) could be flown approximately seven years, whereas beat music with a noise level of 115 dB(A) could be endured for approximately eighteen months of total noise exposure.

The curves shown in Fig. 11 are taken from the measurement results given in Table I. When faced with a practical problem, it is best to measure the difference between the peak value and the dB(A) value of the corresponding noise. The risk criterion can then be drawn relative to the baseline and parallel to it.

In the risk criteria given in Fig. 11, the levels of the very short noise peaks contribute their full value. Its correctness might rightly be questioned. It might be possible to think of a combination where the peak values contribute only one half or two thirds of their dB values to the risk criterion. To determine this requires more measurements and practical information than we have today.

On the other hand, Passchier-Vermeer has found that for the two metal industries she investigated, the equivalent sound levels measured in the welding shop and the punch press shop were, respectively, 13 dB to 17 dB and 17 dB to 20 dB lower than those calculated from the audiograms and comparison with results of steady-state broadband noise. From the results obtained in our investigation, a 24 dB difference between punch press noise and the baseline is found, whereas 16 dB and 19 dB are found for a normal mechanical workshop and a turning shop. Ideally for our investigation, the difference should not be found between the baseline and the respective noises, but between a line approximately 3 dB below the baseline (corresponding to steady-state broadband noise as used by Passchier-Vermeer) and the respective noises. The results then agree reasonably well with those of Passchier-Vermeer, indicating that the peaks should contribute to the risk criteria with their full value.

It must be stressed that it is only in "normal" industrial noise that these risk criteria can be valid. Whenever there is an exceptionally long time between these peaks, like single shots and punch presses which are very seldom used, these risk criteria cannot be utilized directly.

## Conclusion

For industrial noise, the risk of hearing loss commences at 85 dB(A) to 90 dB(A), and 100 dB(A) presents an extremely high risk even after a relatively short time. One therefore cannot help wondering why youngsters, who dance day after day in discothèques where the noise level from beat music is often 110 dB(A) to 115 dB(A), do not, according to all available investigations, differentiate themselves from reference groups of the same age.[13] Many have noticed this phenomenon, and different explanations have been attempted (for instance, movement of the body should reduce the risk of hearing damage).[14]

Another example is the case of flying instructors who have flown for more than 5000 hours in a very noisy training aircraft of the KZ 3 type. They have always flown without radio and without ear protectors. Yet their hearing ability is normal despite the 103 dB(A) noise level in the cockpit. Their audiograms show no deviation from the normal age-related hearing loss in spite of the many hours spent in high noise levels. On the other hand, pilots who have flown noisy planes and used radio for communications, without special equipment for shielding the cockpit noise, are often known to have appreciable hearing loss.

According to Table I, both beat music and the noise in certain aircraft have relatively low ratios of peak to dB(A) values. In the case of beat music, this is due exclusively to the use of electronic amplification which has a limited capacity to deal with high peak values. The peaks are simply cut off in the amplifier system. The noise in training aircraft is by nature very steady and continuous. The peaks due to combustion in the engines are effectively smoothed out by a small exhaust muffler, while the engine's elastic suspension prevents transmission of the peaks to the aircraft body. On the other hand, the noise from radio communication systems, apart from blaring and clicks, contains many short duration high-level peaks.

Another situation, also quite inexplicable, is the wide spread in the degree of hearing loss among a group of subjects apparently exposed to the same noise. The variations are considerably larger than that in a group who have been exposed to other types of hazards, such as overexertion, hunger, cold, or weightlessness. The spread in the variations for hearing loss is approximately ten times greater.

As previously mentioned, no sensible reason has been given for the fact that industrial workers' hearing loss due to noise is always greatest and starts around 4 kHz, when the largest amount of energy in industrial noise lies in the much lower frequency region.

A possible explanation of these paradoxes and peculiarities might be that it is the noise peaks of short duration which damage the ear to a significant degree, and which reach the nerve ends near the basilar membrane but are not perceived by the brain. If this theory is accepted, we have an immediate explanation for the following:

> Industries with steady noise are less liable to cause hearing loss than industries where short, high peaks prevail. The greatest damage occurs around 4000 Hz simply because the maximum energy content of the peaks lies in this frequency region.
>
> The wide spread in the degree of hearing loss is due to the large differences in the distribution of peaks from one working place to another. Because of the high-frequency nature of noise peaks, they are damped out by air absorption, and do not propagate far. Furthermore, objects and screens (as in the case of light) shade large areas against noise peaks, while the noise level measured by a normal sound level meter is almost constant over the whole room.
>
> Beat music and the noise in training aircraft are not harmful, because of the absence of peaks.

If we take the consequences and accept that a sound level meter, developed solely to measure hearing levels, cannot be used to grade the annoyance effects and even less the damaging effects, and also accept that the short peaks in loud noise have considerable influence on the degree of risk, we must conclude that two different sound level meters are required for measuring noise correctly: a normal sound level meter to measure hearing levels (for example, during measurements on loudspeakers, concert halls, areas of speech research, and so on), and a sound level meter with a peak-holding capacity for determining the risk of hearing loss.

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