THE SOUND EXPOSURE LEVEL FOR ANALYSIS
OF IMPULSE NOISE AND CONTINUOUS NOISE

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SOUND EXPOSURE LEVEL

The method for assessing the risk to hearing by noise, described in ISO 1999 [1], is only applicable for continuous noises. This limitation is due to the technology of the present sound level meters (IEC 651 [2]), which are appropriate only for this kind of sound. The squaring network does not work correctly for signals presenting a crest factor (ratio between peak and rms values) greater than five. It appears therefore, that precision sound level meters do not allow the correct measurement of the sound pressure level (SPL) when the noise is not a continuous noise, when the crest factor is too high, or when the sound signals are shorter than the selected time constant $T_0$.

For these reasons a new approach is necessary to eliminate the imperfections of the present measuring techniques and the subsequent disparity in hearing conservation methods. This idea is supported by a recent study [5] stating that the procedures from ISO 1999 [1] could be applicable for rating the risk of non-continuous noise, provided adequate measuring equipment is used. This method is based on generalization of the noise dose by use of the sound exposure level (SEL). The noise dose, combining in a single parameter, the sound pressure level and the duration of exposure to the noise may be determined by the Sound EXPOSURE, that is, the time integral of the squared (eventually weighted) sound pressure $p(t)$ over a stated time period $T$, according to Eq. (1). A convenient unit for the sound exposure is one pascal (squared) second (1 Pa$^2$s).

The sound exposure level is the expression in decibels of the ratio of the weighted sound exposure to the reference sound exposure. The reference sound exposure is equal to the product of the squared reference sound pressure ($p_0 = 20 \mu Pa$) and the reference duration ($t_0 = 1 \text{s}$). The symbol is $L_{AE}$ when the A-weighting is used.

$$ L_{AE} = 10 \log_{10} \frac{\int_0^T p^2(t) \, dt}{p_0^2 \, t_0} \quad (2) $$

$$ E = \int_0^T p^2(t) \, dt \quad (1) $$
The equivalent A-weighted sound pressure level $L_{A\text{eq}}$ is then defined by Eq. (3):

$$L_{A\text{eq}} = L_{A\text{E}} - 10 \log_{10} (Z/t_0)$$  (3)

A uniform DRC can be implemented by choosing a threshold value for the 8-h daily sound pressure level: A A-SPL equal to 90 dB applied during 8 hours may be regarded as a realistic DRC for continuous noise. The corresponding A-SEL is then 135 dB. The 45 dB correction results from Eq. (3) for $Z = 8$ h (or 28800 s).

**EXPERIMENTING THE SEL FOR IMPULSE NOISE**

We propose thus the use of the Sound Exposure Level associated with the weighting filters or the octave band analyses, for evaluating the damage-risk to hearing produced by impulse noise. These proposals have been evaluated by means of an impulse simulation applied to a mathematical model of the human hearing mechanism [5]. The results of this simulation agree with the most recent experiments on impulse noise and fully support the proposed rating methods. We concluded from this simulation that the procedures from ISO 1999 [1] could be applicable for rating the risk of non-continuous noise or different types of noise during the same daily duration, provided adequate measuring equipment is used. A few real impulses recorded in different environments were analyzed using these new techniques.

**Analysis of several small firearms**

Thirteen small firearms were submitted to a comparative trial by NATO in 1977. They were individual weapons with calibers 7.62, 5.56, 4.85, and 4.75 mm. The acoustical results were evaluated according to the CHABA [3] and Pfander [4] criteria, at the firer's ear position. Two groups did emerge which could be termed "most" and "least" hazardous to hearing. Except for weapon W10, both evaluation methods agreed on these groupings. Weapon W10 is considered much more hazardous to hearing by CHABA than by Pfander. The peak pressure level is equal to 159 dB; the durations are 0.5 ms according to Pfander and 3.5 ms according to CHABA. The simulated ear, the spectral methods (see Table I) and the Pfander criterion give similar hazard predictions: ten rounds a day, whereas none at all is allowed for the unprotected ear by CHABA.

**Sealing pistol**

The noise produced by the sealing pistol is characteristic of the majority of impulses produced by industrial sources, like power hammers, drop forges, and punch presses: a short and intense impulse followed by a long resonance of the metal structure with quasilinear decay. The flat-weighted peak pressure level reaches 140 dB. The results of the CHABA and Pfander criteria are consistent and limit the number of
SEL FOR IMPULSE NOISE AND CONTINUOUS NOISE

<table>
<thead>
<tr>
<th>Weapon</th>
<th>TIME CRITERIA</th>
<th>SPECTRAL METHODS</th>
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<tbody>
<tr>
<td></td>
<td>CHABA (dB)</td>
<td>PFANDER (dB)</td>
</tr>
<tr>
<td>W1</td>
<td>+ 12.8</td>
<td>+ 4.0</td>
</tr>
<tr>
<td>W2</td>
<td>+ 11.9</td>
<td>+ 4.8</td>
</tr>
<tr>
<td>W3</td>
<td>+ 8.0</td>
<td>- 10.4</td>
</tr>
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<td>W4</td>
<td>+ 7.0</td>
<td>- 10.3</td>
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<tr>
<td>W5</td>
<td>+ 5.4</td>
<td>- 10.0</td>
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<tr>
<td>W6</td>
<td>+ 9.2</td>
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<td>W7</td>
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<tr>
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<td>W9</td>
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<td>+ 8.6</td>
<td>- 9.2</td>
</tr>
<tr>
<td>W13</td>
<td>+ 5.5</td>
<td>- 11.7</td>
</tr>
</tbody>
</table>

Table 1: Ranking order of the small firearms (dB re (20 μPa)².s)

rounds to about 30 a day for the unprotected ear. A similar result is obtained with the "fast" SPL measurement according to ISO 1999. The simulated ear and the SEL coincide fully with these results. The most dangerous frequency components for the ear, in the vicinity of 2 kHz, are produced by the resonance of the metal structure.

Rating ear protection devices for impulsive noise

Octave band analysis is very enlightening when protective devices are to be evaluated. As an example, we chose the most dangerous to hearing among thirteen weapons studied by NATO in 1977: this weapon has a 161 dB peak pressure level. The detailed calculations appear in Table II. The maximum is five rounds a day for the unprotected ear according to the CHABA criterion. This figure is too small for a person standing on a firing place, who is submitted to rounds of this own weapon and the rounds of adjacent firers. Ear protection is required in order to allow an exposure of 100 rounds in the same day. Using octave band analysis, the resulting A-SEL is equal to 128 dB without protection and is reduced to 98 dB with EP 100 plugs. These devices give an excellent protection if correctly fitted: 5000 rounds are allowed. The cotton-wool plugs give an average reduction of 12 dB; the allowed exposure is 80 rounds a day.

CONCLUSION

Evaluation of hazard to hearing produced by impulse noise has been derived from the noise dose principle using the sound exposure level.
Table II: Protection of EP 100 and cotton-wool plugs for gunshot: dB re (20 \mu Pa)².s.

This method permits the determination of a unique damage-risk criterion applicable for any kind of noise, including continuous and fluctuating noises as well as industrial and gunfire impulse noises. Equipment needed for measuring the sound exposure level produced by impulse noise is the A-weighted integrating sound level meter. Octave band analysis for impulse noise requires a digital Fourier processor. Standardization of these new measurement techniques is imperative to support future work on the unification of noise control procedures.

REFERENCES