DOI: 10.61782/fa.2025.0138

ANNOYANCE OF SHOOTING SOUNDS: RE-EVALUATION OF ISO/PAS 1996-3 PENALTY PROCEDURE

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ABSTRACT

In noise assessment, the annoyance caused by impulse noise is taken into account by applying a penalty to the measured A-weighted equivalent continuous sound pressure level (L_{Aeq}). The penalty is currently determined by the most prominent impulse within the measurement period. The prominence of an impulse is quantified using two parameters: the level difference and the onset ratio. These parameters are derived from the time profile of A-weighted sound pressure levels measured using fast-time weighting. Although this penalty procedure has been standardized (ISO/PAS 1996-3), it is based on a single psychoacoustic experiment having a very limited number of participants and sound scenarios. A recent psychoacoustic experiment showed that the ISO penalty procedure overestimates the true perceived penalty. This raises questions about the reliability and applicability of the ISO procedure in various impulsive noise scenarios. We conducted a laboratory experiment where participants evaluated the annoyance of shooting sounds presented over steady-state background noise. Our findings do not support the current penalty procedure for shooting sounds. Based on these results, we propose improvements and alternative procedures for a more accurate assessment of impulse noise annoyance.

Keywords: *noise, annoyance, impulsive sounds, penalty, standards*

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1. INTRODUCTION

Impulsive noise causes greater annoyance than steady-state noise. Many countries account for this elevated annoyance by applying a decibel penalty to the measured equivalent continuous A-weighted sound pressure level (L_{Aeq}).

A penalty procedure for impulsive noise is currently defined in ISO/PAS 1996-3 [1]. It states that the penalty K_I (in decibels) depends on the prominence P of impulsive sound events:

$$\begin{aligned} K_I &= 1,8 * (P - 5)\, dB; \quad & P > 5 \\ K_I &= 0\, dB; & P \leq 5 \end{aligned} \tag{1}$$

Prominence P is calculated using the onset ratio (OR) and level difference (LD) of the impulsive sound events:

$$P_I = 3 * log_{10}OR + 2 * log_{10}LD \tag{2}$$

Onset ratio OR refers to the rate of sound pressure rise to the peak level (dB/s) and level difference LD refers to the difference in decibels between the impulse peak and background noise level. OR and LD are derived from L_{AF} measurements sampled at 10–25 ms resolution. An impulse is identified when OR between consecutive L_{AF} samples exceeds 10 dB/s. Prominence values are computed for all impulsive events during the measurement period. The maximum prominence within this period determines the final penalty.

Although this penalty procedure has been standardized, the development of the procedure was based only on a single psychoacoustic experiment with a limited number of participants and sound scenarios [2]. The lack of robust scientific evidence raises questions about the procedure's reliability and broader applicability across diverse impulsive noise contexts. Prior research [3] also suggests that ISO/PAS approach may overestimate the perceived penalty of impulsive noise, highlighting the need for revising this procedure for different impulsive noise types.

The focus of this study is on the highly impulsive sounds from firearms which were explicitly excluded during the development of ISO/PAS 1996-3 [2]. Highly impulsive sounds with very high ORs were also outside of the scope of the previous study by Hongisto & Rajala [3]. Here we study perceived penalties of the discharge sounds of a rifle, which is a common firearm used in shooting ranges in Finland.

The aim of this study is to evaluate how well ISO/PAS 1996-3 penalty procedure predicts perceived penalty of shooting sounds in outdoors scenario with 55 dB L_{Aeq} and indoors scenario with 35 dB L_{Aeq}). These sound levels correspond to Finnish regulations for noise in outdoor and indoor living spaces. Comparable regulations exist in many other countries.

2. METHODS AND MATERIALS

2.1 Participants

Forty normal hearing people participated to this study. Normal hearing was verified with a pure-tone audiometry. Participants were required to read and sign an informed consent form before the experiment. They were compensated with a small monetary amount after the experiment. The study was approved by the ethics committee of Turku University of Applied Sciences.

2.2 Design of experiment

Participants were divided into two groups A and B, with 20 individuals recruited to each group.

Both groups followed identical experimental designs, subjective assessment methods, and procedures. Differences were limited to the stimuli characteristics (sound levels, spectra, and reference sounds) and contextual framing. Key differences between groups were:

1. Shooting noise:
   - Group A: L_{Aeq} = 55 dB (regulated level of outdoor noise). Spectra included atmospheric effects only.
   - Group B: L_{Aeq} = 35 dB (regulated level of indoor noise). Spectra included atmospheric effects and attenuation from building façade propagation.
   - Background noise is described in Section 2.4.2.
2. Reference sound levels:
   - Group A: 46 to 70 dB L_{Aeq} in 3 dB steps.
   - Group B: 31 to 63 dB L_{Aeq} in 4 dB steps.
3. Contextual instructions:
   - Group A: *"Imagine that you are outside at your own yard or terrace/balcony at home, and you hear this type of sound."*
   - Group B: *"Imagine that you are at home relaxing, reading a magazine or a book or browsing the internet and you hear this type of sound."*

2.3 Experimental variables

The independent (within-subjects) variables were the level difference (LD), shot density, and the background noise spectrum.

Level difference had nine levels: -5, 0, 5, 10, 15, 20, 25, 30 and 35 dB. The level differences between the impulsive shot sounds and the background noise were set by scaling the level of the background noise. The overall levels of the stimuli were always set to the fixed 55 dB L_{Aeq} (Group A: outdoors) and 35 dB L_{Aeq} (Group B: indoors). Therefore, the relative sound levels of shooting sounds and background noises varied depending on the LD.

Shot density, defined as shots per minute (SPM) had three levels: 12, 24, and 36 SPM.

Onset ratio (OR) was not directly controlled in this experiment because the stimuli were based on field recordings of real shooting sounds. OR increased with increasing LD, ranging from approximately 150 to 3500 dB/s.

2.4 Stimuli

2.4.1 Shooting sounds

The shooting sounds were produced using field recordings of five consecutive rifle shots (7.62' TKIV 85 with JVA0221 cartridge). Recordings were made in an open field at 63 meters from the source, at a 25-degree angle relative to the shooting direction by HMMT Partners Oy. All five shots were utilized to incorporate variability in the shooting sounds. Figure 1 illustrates the average spectrum of the shots.

Single shots were combined into one-minute-long sound streams, appearing consecutively in random order with the desired shot density. Shot density was controlled

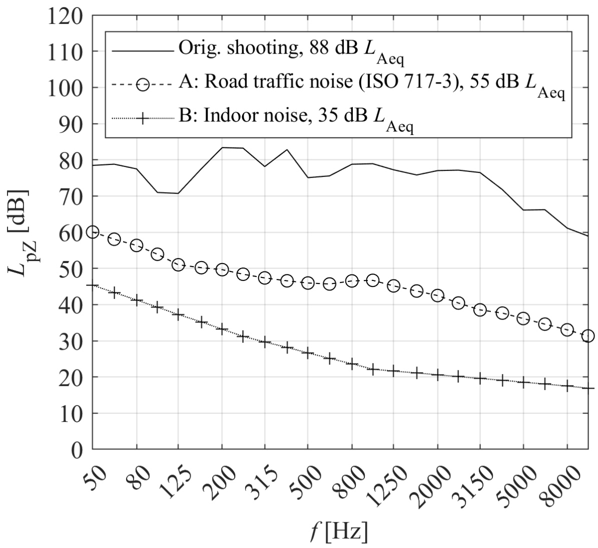

Figure 1. One-third octave band sound pressure levels for the steady-state noises and the original shooting sounds. A: Outside road traffic noise spectrum (ISO717-1:2000, [6]), 55 dB L_{Aeq}; B: Indoor background noise spectrum [7], 35 dB L_{Aeq}

by adapting the jittered sampling scheme from the velvet noise algorithm [4].

Shooting sounds were filtered using a one-third-octave band parametric equalizer, simulating spectral changes due to atmospheric attenuation at 400 meters from the source, assuming a temperature of 15°C and 70% humidity. Ground effects were not considered. The outdoor shooting sounds (Group A) included only these atmospheric spectral changes.

The indoor shooting sounds (Group B) incorporated additional sound insulation through a building façade. The spectral profile for façade attenuation (i.e., attenuation values in one-third-octave frequency bands) was selected from 26 measured façades reported in [5]. The spectrum with the worst sound reduction index was chosen.

2.4.2 *Background noise spectra*

The background noise spectra are illustrated in Fig. 1. Spectrum A represents the general road traffic noise spectrum defined in ISO 717-1:2000 [6]. It was used in Group A. Spectrum B is the average indoor noise spectrum obtained from the measurements presented in [7]. It was used in Group B.

2.5 Procedure

The penalty value for a sound is derived by mapping its perceived annoyance rating onto a reference scale. To achieve this, the subjective evaluation involved establishing the reference line with a set of reference sounds containing only steady-state background noise at different L_{Aeq} levels and collecting annoyance ratings of experimental sounds (i.e., impulsive shooting noise). Experimental sounds contained the shooting sounds and background noises in all combinations of the independent variables which are described in Section 2.3.

Participants evaluated annoyance of each stimulus by using a 11-point rating scale from 0 (“Not at all annoying”) to 10 (“Extremely annoying”). Derivation of penalty values from the annoyance results has been described in detail for instance in [3].

The experiment started with familiarization and training phases, after which each participant evaluated the annoyance of all 36 stimuli (27 experimental sounds and 9 reference sounds) one after the other.

2.6 Setup

Experiment was conducted in the psychophysics laboratory at Turku University of Applied Sciences (Turku, Finland). The stimuli were presented with open circumaural headphones (Beyer Dynamics DT 1990 Pro Mki).

3. RESULTS

The penalty of impulsive shooting sounds of groups A and B are summarized in Figure 2. Shot density did not have a significant effect on the penalty values, so we focus solely on the relationship between LD and penalty.

Consistent with previous research, the penalty increases with the LD [3]. However, an important observation is that indoor shooting sounds (Group B) incurred significantly higher penalties than outdoor shooting sounds (Group A). The penalty was up to 23 dB in the indoor noise scenario, while in the outdoor noise scenario it was 10 dB.

Thus, in the indoor scenario, impulses were perceived as significantly more disturbing than in the outdoor scenario. The lower background noise levels indoors make impulse noises stand out more prominently, leading to a higher penalty. The higher ambient noise levels outdoors partially mask impulse noises, resulting in a lower penalty.

The increased sensitivity to indoor shooting sounds (Group B) underscores the importance of considering context in noise annoyance studies. The lack of a significant influence from shot density implies that the level difference between the impulsive sound and background noise is a more critical factor in determining annoyance than the frequency of the impulses, at least within the range tested.

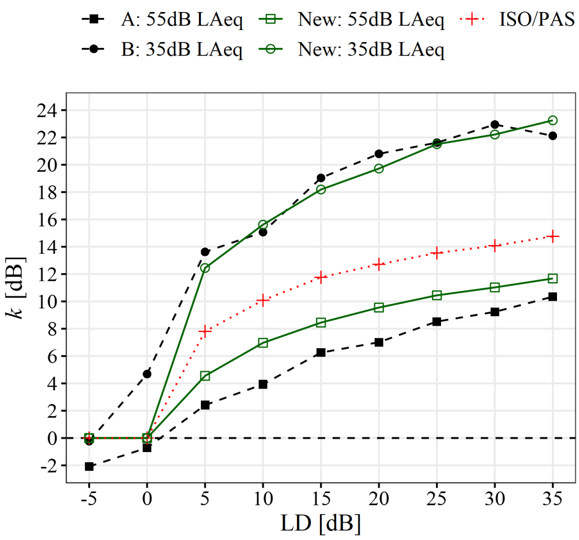

Figure 2. Results. Black dashed lines with filled markers: Penalty values from the psychoacoustic experiment. Green solid lines and open markers: Penalty estimates (New) were calculated using Eq. 3. Red dotted line with crosses: Estimates calculated with the current ISO/PAS penalty procedure (Eq. 2).

The results also indicate that the current ISO/PAS penalty procedure underestimates the penalty for impulsive noise in the indoor context, but overestimates the penalty in the outdoor context. This latter observation aligns with previous findings presented in Rajala & Hongisto [3], who did not investigate shooting sounds per se (large OR) but a large range of ORs and LDs.

The following equation predicted the observed penalty better than Eq. 2:

$$P_I = (2 * log_{10}OR + 3 * log_{10}LD) * \frac{55\ dB}{L_{Aeq}} \quad (3)$$

As illustrated in Fig. 2, this modified equation for prominence yielded penalty estimates that are relatively close to the observed values. Nevertheless, it would be worthwhile to study alternative ways for predicting the impulse noise penalty, that do not require computing OR and LD values for each individual impulse during the measurement period.

4. ACKNOWLEDGMENTS

This study was funded by Finland Ministry of Environment and Turku University of Applied Sciences. Our sincere thanks belong to Mr. Timo Markula (HMMT Partners Ltd., Finland) for the provision of shooting sound recordings and the documentation related to them.

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