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Annoyance of impulsive sounds – a psychoacoustic experiment involving synthetic sounds

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ABSTRACT

Impulsive sound can be perceived more annoying than a steady-state sound having the same L_{Aeq}. The difference in perceived annoyance can be compensated by adding an appropriate penalty to L_{Aeq}. Nordtest method NT ACOU 112 describes an impulse by using two measures: level difference (D_L) and onset rate (R_{on}). A psychoacoustic laboratory experiment of 32 participants was conducted to determine the penalty for different values of D_L and R_{on}. Sounds were synthetic and periodic impulsive sounds with two alternative spectra. Impulsive sounds were presented at 55 dB L_{Aeq}. Steady-state sounds at levels from 49 to 70 dB were used to derive the penalty of impulsive sounds. The observed penalty values ranged between -2 and +8 dB. The observed penalty increased with increasing D_L and R_{on}. The penalty predicted by Nordtest method usually overestimated the observed penalty when $R_{\mathrm{on}} \geq 200$ dB/s. Therefore, the future development of Nordtest penalty calculation scheme might be justified. Our results can be used to develop the future penalty schemes of impulsive sounds.

Keywords: Impulsive sound, noise annoyance, penalty

1. INTRODUCTION

Impulsive sound can be perceived more annoying than a steady-state sound having the same L_{Aeq}. This suggest that L_{Aeq} does not alone represent the annoyance of an impulsive sound. The limitation can be compensated by adding a penalty value to the measured L_{Aeq}. The penalty should correlate with the increased annoyance caused by impulsiveness.

Impulsivity of sound can be measured by using different methods. Nordtest method NT ACOU 112 (1) describes an impulse by using two measures: level difference (D_L) and onset rate (R_{on}). D_L measures the increase of sound pressure level (SPL) during an impulse. R_{on} describes how rapidly the SPL increases. NT ACOU 112 is already implemented in a British standard of assessment of environmental sound (2) and is currently under preparation to be implemented as an ISO standard (3).

The appropriate penalty to be associated with impulsive noise measured by using NT ACOU 112 has been very little studied (4). Our aim is to determine the penalty at different values of D_L and R_{on} of periodic impulses with two different spectra.

2. METHODS

2.1 Overall design

The study was a psychoacoustic laboratory experiment where the participants rated the annoyance of 74 experimental sounds. All participants rated all experimental sounds. The experimental sounds included impulsive sounds and reference sounds (non-impulsive steady-state sounds). The independent variable was the experimental sound and the dependent variable was the subjective measure annoyance. The reference sounds were used to determine the penalty associated with the impulsive sounds.

2.2 Participants

The participants were recruited via different university mailing lists and Turku University of Applied Sciences. The requirements for the participant were: age within 20 – 45 years, Finnish as a

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native language, and normal hearing. It was instructed that one should not participate the experiment during a flu or any other illness. Thirty-two voluntary persons (13 men and 19 women, mean age 29 years) participated in the experiment. The participants received a 20 euro gift token as a compensation after the experiment. None of the participants was professionally related to our research group.

2.3 Experimental sounds

The experiment was constituted on 66 impulsive sounds and 8 reference sounds. The impulsive sounds were presented at L_{Aeq} of 55 dB. The L_{Aeq} of the reference sounds varied between 49 and 70 dB in 3 dB steps. Figure 1 shows the one-third octave spectra of the reference sounds. The length of each experimental sound was 18.5 seconds.

The acoustic descriptors of the impulsive sounds were D_L (7 levels), R_{on} (10 levels), and spectrum (2 values). Table 1 expresses the D_L and R_{on} values included in the experiment. An impulse in the impulsive sound had another of the two spectra named S1 and S2. S1 corresponded to spectrum of reference sounds (Figure 1) and S2 corresponded to spectrum of white noise.

Each impulsive sound consisted of two components: steady-state wide-band background sound and impulses. The background sound was continuously presented through the impulsive sound. The spectrum of the background sound corresponded to the spectrum of the reference sounds. An impulsive sound always consisted seven impulses. The impulse frequency was 2.5 seconds, meaning that an impulse began always 2.5 seconds after the beginning of the previous impulse. The first impulse in an impulsive sound began one second after the beginning of the background sound. The SPL of the background sound under the impulsive sound varied between experimental sounds to maintain the desirable equivalent SPL of 55 dB L_{Aeq}.

The sounds were created digitally (MATLAB R2017b, MathWorks Inc., Natick, MA, USA) to be able to achieve the desirable values of D_L and R_{on}. The reference sounds were shaped from pseudorandom noise. The impulses were created by multiplying pseudorandom noise with a function. For the onset of an impulse the sound pressure increased linearly. After achieving the top of the onset, the sound pressure was set to decay exponentially. The exponential decay mimics the decay of an impulse generated by a collision of two solid objects. The created impulse was summed to the background sound. All seven impulses in an impulsive sound were generated by multiplying the created impulse and background sound six times.

The experimental sounds were played and the data was collected by using a program coded with MATLAB. The sounds were played from a computer by using a sound card (D-audio USB Pre-Amp, Duran Audio Ltd., The Netherlands), a headphone amplifier (Brüel&Kjær ZE 0769, Denmark), and headphones (Sennheiser HD 580, Sennheiser GmbH & Co., Germany). The SPL and the spectrum of each sound was individually verified using a head-and-torso simulator (Brüel&Kjær 4100, Denmark).

Table 1 – The black circles indicate the D_L and R_{on} values included in the experiment. The experiment always consisted two impulsive sounds having same R_{on} and D_{L}, and another of the two spectra (S1 or S2).

		R_{on}, dB/s									
		5	10	15	20	50	100	200	400	600	800
D_L, dB	5	●	●	●	●	●					
	10		●	●	●	●	●				
	15			●	●	●	●				
	20				●	●	●	●			
	25					●	●	●	●		
	30					●	●	●	●	●	
	40					●	●	●	●	●	●

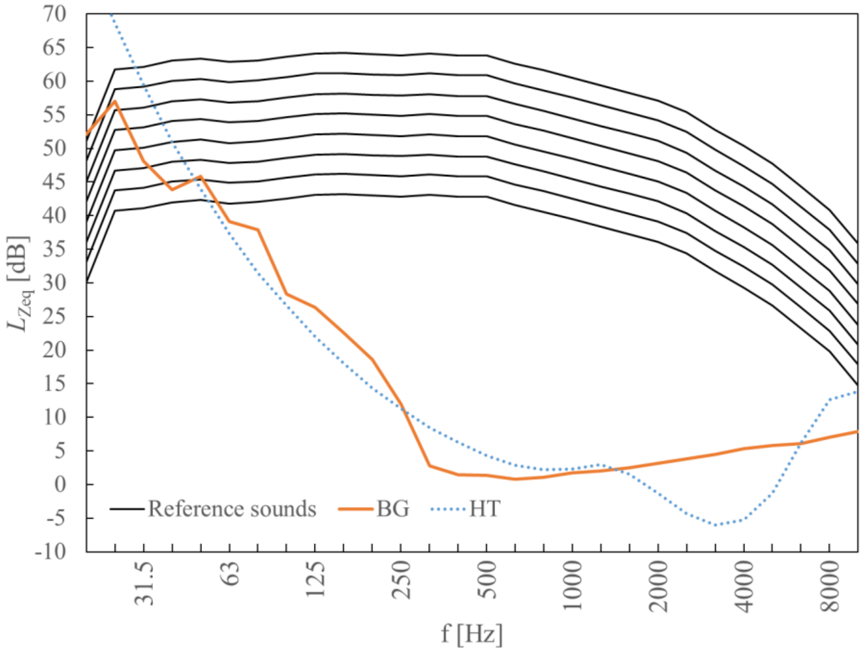

Figure 1 – The unweighted SPL, $L_{Z,eq}$, as a function of frequency, *f*, for the reference sounds, the background noise level of the experimental room (BG), and the standardized hearing threshold (HT) according to standard ISO 389-7 (5).

2.4 The experimental procedure

The experiment was conducted in the psychophysical test room Tuuli at Turku University of Applied Sciences, Turku, Finland. The background noise level of the room was 23 dB L_{Aeq} (Figure 1). One participant at a time conducted the experiment by using a computer and MATLAB based software with a graphical user interface.

The experiment consisted seven phases. Before entering the experimental room, the participants read and signed the information consent form (phase 1). The participant was informed that the scope of the study was to examine how noise should be measured. It was informed that the sounds will not be loud and there is no risk of hearing damage or getting frightened. The participant entered the experimental room after signing the consent form. The participants filled an initial questionnaire (phase 2) which gathered their background information. Each participant's hearing ability was tested (phase 3) to ensure that the hearing was normal. In the familiarization (phase 4), the participant listened six experimental sounds. The participant did not judge the sounds in the familiarization phase. The participant rehearsed the rating process after the familiarization (phase 5). The rehearsal included ten sounds and the ratings were not analyzed.

The annoyance rating phase (phase 6) represents the actual experiment. The experimental sounds were presented for the participant in one of the five predetermined pseudorandom orders. The five orders were decided so that the same sound was never presented at same point in different orders. The reference sounds were distributed among the impulsive sounds so that they were never consecutive.

The *annoyance* was measured according to the technical specification ISO/TS 15666 (6). The question presented for the participant was: "*How much does the sound bother, disturb or annoy you*?" The eleven step response scale was from 0 to 10, where 10 was labeled as "Extremely" and 0 as "Not at all". The participants were instructed to use the full scale and try to make their answers as consistent as possible. The participants had to listen the sound for 18.5 seconds before they were able to give the rating. The same sound continued until the participant had responded.

After the experiment (phase 7) the participants received a gift token and a short introduction of the goals and impacts of the conducted experiment. The participants stayed in the laboratory on average 65 min.

The ethical board of Finnish Institute of Occupational Health has accepted the research plan concerning this experiment (ETR 6/2015 5.11.2015).

2.5 Analysis

The *annoyance* penalty caused by impulsivity was determined by using the method developed by Oliva et al. (7). The penalty of an impulsive sound is determined by using the annoyance ratings of the reference sounds. The penalty value k of an impulsive sound (L_{Aeq} = 55 dB) is the number of decibels that should be added to the SPL of the reference sound (L_{Aeq} = 55 dB), so that the reference sound would be perceived equally annoying as the impulsive sound.

The penalty calculation is executed in five steps:

1. The mean annoyance $\overline{y_{ri}}$ for every reference sound is calculated from all ratings given for the reference sound.
2. The mean annoyance $\bar{y}$ for every impulsive sound is calculated from all ratings given for the impulsive sound.
3. *Annoyance A* is defined as a first order linear fitting to $\overline{y_{ri}}$ and L_{Aeq} of reference sounds:
$$A = a \cdot x + b, \tag{1}$$
where x is the A-weighted SPL, and a and b are the coefficients of the fitted line.
4. The A-weighted SPL corresponding $\bar{y}$ (the apparent SPL) is determined using the coefficients from the fitted line:
$$L_{\mathrm{Aeq}}{}' = (\bar{y} - b)/a. \tag{2}$$
5. The penalty k is achieved by reducing the actual L_{Aeq} of the impulsive sound from the apparent A-weighted SPL:
$$k = L_{\mathrm{Aeq}}{}' - 55 \text{ dB}. \tag{3}$$

NT ACOU 112 (1) defines the penalty by using predicted prominence P
$$P = 3 \cdot \lg(R_{\mathrm{on}}) + 2 \cdot \lg(D_L). \tag{4}$$
The penalty is calculated by using the formula:
$$k_N = 1.8 \cdot (P - 5), \qquad \text{for } P > 5. \tag{5}$$

3. RESULTS

Figure 2 shows the penalty values k calculated according to Section 2.5.

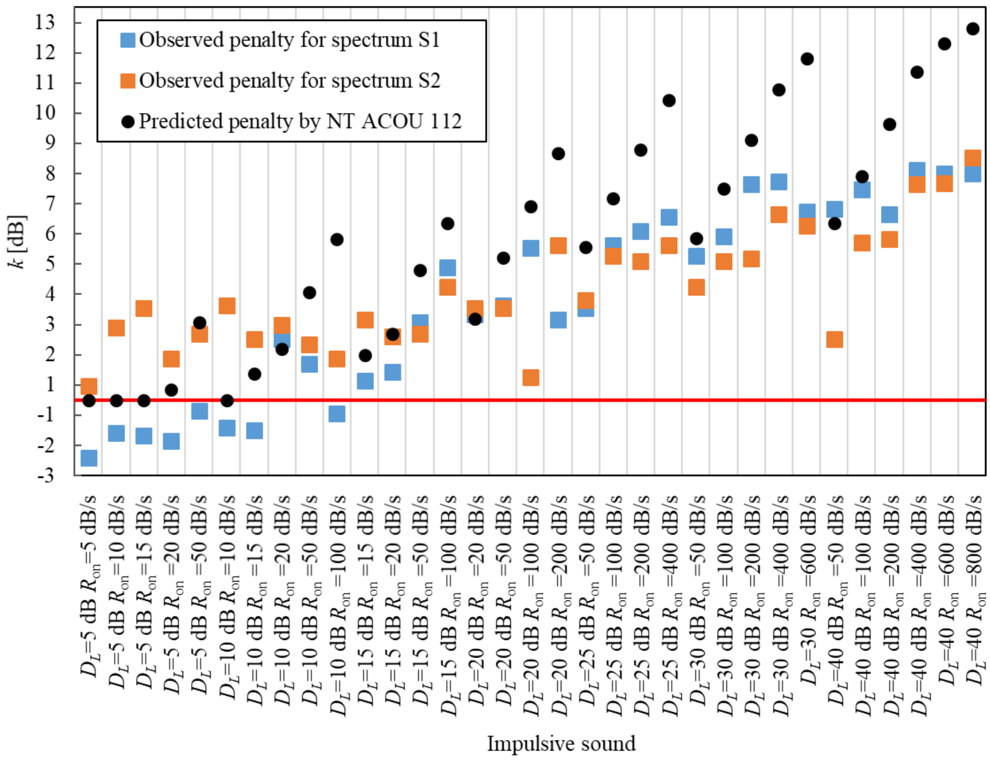

Figure 2 – The observed and the predicted penalty values, k, for the impulsive sounds calculated according to section 2.5. Horizontal red line indicates the penalty of 0 dB.

4. DISCUSSION

4.1 Findings

The calculated penalty values increased with increasing D_L and R_{on}. The penalty was depended on spectrum for some impulsive sounds. For some sounds, NT ACOU 112 penalty calculation model suggests greater penalties than we achieved. The penalty predicted by NT ACOU 112 usually overestimated the observed penalty when $R_{\mathrm{on}} \geq 200$ dB/s for both studied spectra. Therefore, the future development of NT ACOU 112 penalty calculation model might be justified.

4.2 Comparison with preceding studies

An impulse can be described by using multiple different measures. Previous studies of annoyance of impulsive noise have used different measures for impulses, making the comparison of our results to previous ones complicated.

So far, NT ACOU 112 (1) has acquired very little research interest although many countries have stated a penalty to be applied for impulsive sounds. As far as we know, our experiment is the first examining the effect of D_L and R_{on} on annoyance after reference (4) which has probably afffected the NT ACOU 112 penalty calculation scheme.

As can be observed from Figure 2, NT ACOU 112 (1) suggested penalty for our sounds for $R_{\mathrm{on}} \geq 20$ dB/s and $D_L > 10$ dB. The NT ACOU 112 limit is in good accordance with our results for impulsive sounds having spectrum S1. However, with spectrum S2 penalties were achieved with lower D_L and R_{on} than NT ACOU 112 suggests. This finding suggests that the penalty estimation model could take spectrum into account as well, not only D_L and R_{on}. The importance of spectrum on annoyance has been found in an earlier study (8). It seems justified that annoyance caused by a sound could depend on several specific features of sound.

4.3 Limitations

It is challenging to determine an ultimate penalty value for impulsive sound in general, because impulsivity is not a stationary phenomenon. Our experiment was a laboratory study with homogenous synthetic sounds. A future experiment would be useful to investigate penalties of real sounds. It is interesting if penalty should be determined by using more measures than D_L and R_{on}.

5. CONCLUSIONS

An experiment was conducted to examine the penalty of impulsive sounds having different D_L, R_{on}, and spectra. The impulsive sounds were synthetic with varying D_L and R_{on} and two different spectra were also investigated. The penalties increased with increasing D_L and R_{on}. The penalties were sometimes different for different spectra. The penalty predicted by Nordtest method usually overestimated the observed penalty when $R_{\mathrm{on}} \geq 200$ dB/s. Therefore, the future development of Nordtest penalty calculation scheme might be justified. Our results can be used to develop the future penalty schemes of impulsive sounds. Further research is also welcome since the annoyance penalty of impulsive sounds has been very little investigated. Especially real impulsive sounds could be studied.

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REFERENCES

1. Nordtest. Nordtest Method NT ACOU 112. Acoustics – Prominence of impulsive sounds and for adjustment of L_{Aeq}. Taastrup, Denmark: Nordtest; 2002.
2. The British Standards Institution. BS 4142:2014. Methods for rating and assessing industrial and commercial sound. London, United Kingdom: BSI; 2014.
3. International Organization for Standardization [Internet]. Geneva Switzerland: ISO. ISO/WD PAS 1996-3 Acoustics -- Description, measurement and assessment of environmental noise -- Part 3:

Objective method for the measurement of prominence of impulsive sounds and for adjustment of LAeq; 18.4.2019. [cited 20.5.2019]. Available from: https://www.iso.org/standard/77035.html
4. Pedersen TH. Impulsive noise. An objective measuring method for the prominence of impulsive sounds and for the adjustment of LAeq,. Danish Environmental Protection Agency. 2001. Working Report No.: 1.
5. International Organization for Standardization. ISO 389-7:2005. Acoustics. Reference zero for the calibration of audiometric equipment. Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions. Geneva, Switzerland: ISO; 2005.
6. International Organization for Standardization. ISO/TS 15666:2003. Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys. Geneva, Switzerland: ISO; 2003.
7. Oliva D, Hongisto V, Haapakangas A. Annoyance of low-level tonal sounds – Factors affecting the penalty. Build Environ. 2017;123:404-14.
8. Hongisto V, Oliva D, Rekola L. Subjective and Objective Rating of Spectrally Different Pseudorandom Noises – Implications for Speech Masking Design. J Acoust Soc Am 2015;137(3): 1344-55.