inter·noise 96
25th Anniversary Congress – Liverpool

INCE: 69.3

THE ASSESSMENT OF TONAL COMPONENTS IN THE ENVIRONMENTAL NOISE: FEATURES AND LIMITATIONS OF THE ITALIAN LEGISLATION

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1. INTRODUCTION

Procedures for the detection of tonal components in the environmental noise and for the assessment of the annoyance due to these components have been proposed in national standards and legislation. However these two problems are still under investigation in the attempt to develop an international common procedure which can be also easily applied in the field measurements. Such a procedure has to deal with the following two main aspects:

i) defining an objective method for the detection of tonal components which is adequately related to the subjective auditory perception;
ii) setting a procedure for the assessment of the increased annoyance due to the tonal components.

How these two aspects are handled in the Italian legislation is described in this paper, which presents also the main results obtained in a pilot study undertaken to investigate improvements of the current procedure. For this purpose laboratory listening tests have been carried out, in which subjects heard a set of sound stimuli through headphone and gave ratings on the annoyance, tonality and impulsivity of these stimuli. The results show that the objective procedure for detecting tonal components often disagrees with the subjective auditory perception, even when the tonality is judged as being either clearly audible or prominent. The increased annoyance due to the either impulsive or tonal character requires a penalty which decreases with increasing L_{Aeq}.

2. THE ITALIAN LEGISLATION ON TONAL COMPONENTS

At present the detection of tonal components and the assessment of their annoyance is based on the procedure established in the DPCM 1/3/1991 [1], dealing with the limits of noise exposure both in the outdoor and indoor environment.

The detection of tonal components requires a preliminary test based only on the subjective auditory perception, like stated in other standards such as BS 4142 [2] and BS 7445 [3]. If the tone is subjectively perceived, then 1/3 octave frequency band analysis has to be performed. The further step requires to look at the differences of the sound pressure levels SPLs in the adjacent bands. If the SPL in a band is 5 dB greater than the SPL of both the two adjacent bands, then the presence of a tone which increases the annoyance is acknowledged. In this case a penalty of 3 dB must be added to the equivalent continuous level L_{Aeq} of the noise. In addition, when tonality and impulsivity are present at the same time, then an extra penalty of 3 dB has to be added to L_{Aeq}.

A particular feature of the Italian legislation is the introduction of the differential criterion which has to be applied in the indoor environment. The difference between the L_{Aeq} of the ambient noise, including penalties if applicable, and the L_{Aeq} of the residual noise, must not exceed 5 and 3 dB at day (6÷22 hours) and night (22÷6 hours) time respectively. This requirement must be respected in addition to that concerning the limits on the outdoor noise exposure.

3. EXPERIMENTAL STUDY

For investigating improvements of the procedure above described, an experiment has been carried out including objective measurements of 8 environmental sounds and laboratory listening tests. The sounds, recorded on DAT tape, were selected to represent different types of noise commonly heard in the environment (neither impulsive nor tonal, impulsive, tonal). They have been played back at three different L_{Aeq} levels, namely 45, 55 and 65 dB(A), giving 24 sound stimuli, each lasting 20 s (Table 1).

Table 1. Sound stimuli and identification codes

L_{Aeq} dB(A)	Road traffic	Gunfire	Fan noise	Electric power group	Compressor	Shaped pink noise	Hair dryer	Beard trimmer
45	TR45	GF45	FN45	EP45	CP45	SP45	HD45	BT45
55	TR55	GF55	FN55	EP55	CP55	SP55	HD55	BT55
65	TR65	GF65	FN65	EP65	CP65	SP65	HD65	BT65

These stimuli have been arranged in a balanced Latin square design and presented through an high-quality headphone to 24 subjects, tested one at time. Verbal instructions and three orientation stimuli were given to the subjects before the listening session in order to explain the test procedure and provide examples of the variety of sounds to be assessed in the experiment.

After each sound stimulus the subject was asked to rate the annoyance, the impulsivity and the tonality using numerical scales labelled at their extremes, as shown in the questionnaire given in Appendix I.

As far as objective measurement concerns, 1/3 octave frequency band analysis has been carried out on each sound stimulus, determining the L_{Aeq} band levels integrated over the time length of the signal. For this purpose the sound stimuli have been played back into a Brüel & Kjær artificial ear by means of the same headphone used for the listening tests and the output of the artificial ear was fed into a Brüel & Kjær frequency analyser.

4. RESULTS AND DISCUSSION

Detection of tone(s)

In order to evaluate how the procedure for the detection of tonal components established by the DPCM matches the subjective auditory perception, the ratings on clear tonality obtained from question Q6 have been considered.

The percentage of subjects clearly detecting tonal components in the sound stimulus has been determined and the value of 50% has been assumed as threshold for the onset of the tonal character of the noise.

On the basis of this criterion 58.3% of the sound stimuli (14 out of 24) were judged to have tonal components, as shown in fig. 1. Among these sounds the DPCM procedure has detected only 5 samples requiring a penalty for tonality, indicated by white triangle symbols in fig. 1. Concerning the stimuli judged by the majority of subjects as not tonal, the DPCM procedure shows a good agreement with the subjective assessment (90% of samples). The sound stimuli showing disagreement between the objective procedure and the subjective assessment are pointed out in fig. 1 by black symbols. It can be seen that the sound stimuli chosen for the experiment are regularly distributed over a wide range of tonality. The three samples of the shaped pink noise, having a tonal component at 630 Hz to be penalized according to the DPCM, are very closed around the threshold of the onset of tonality.

More information on how the subjects perceived the tonal components, both as magnitude (question Q4) and type of auditory sensation (question Q5), can be drawn from fig. 2. In this figure the mean value and the interval at ± 1 standard deviation of the answers given to question Q4 are plotted for the 9 sound stimuli where the DPCM procedure does not match the subjective ratings. The sounds are grouped according to the auditory perception of the tonal components given by the majority of the subjects. It can be seen that only for 3 samples the tonal components were rated only just detectable, whilst the remaining (66.7%) were judged either clearly audible or prominent. This result confirms the clear disagreement

between the DPCM procedure and the subjective auditory perception of tonality.

Penalty for annoyance

Linear regression analysis of the subjective ratings on annoyance (question Q1) against L_{Aeq} has been performed for each sound to determine the dose-response relationship. The four sounds judged as tonal have been pooled, giving the regression lines plotted in fig. 3. In this figure the dose-response relationships obtained for gunfire and road traffic noise are also given for comparison purpose. Gunfire has been chosen as representative of impulsive noise, whilst road traffic has been considered as reference for neither tonal nor impulsive sound.

From the dose-response relationships the following considerations can be drawn:

i) the annoyance increases with L_{Aeq} level for all the three types of sound;
ii) at the same L_{Aeq}, noises showing a particular character, either impulsivity or tonality, are rated more annoying than road traffic noise;
iii) the rate of growth of annoyance with L_{Aeq} level depends on the character of the sound, being the greatest for road traffic noise and the smallest for gunfire;
iv) at high L_{Aeq} the energy content of the noise influences the annoyance more than its character.

Due to the behaviour described in iii), the penalty to be addedd to the L_{Aeq} of a sound either impulsive or tonal is dependent on L_{Aeq} and decreases with the increasing L_{Aeq}. To determine the magnitude of this penalty the relationships between annoyance ratings and L_{Aeq} of impulsive and tonal noises have been compared with that corresponding to road traffic noise. The following equations have been obtained for the two penalties:

$$P_{tone} = 18.3 - 0.24 L_{Aeq} \quad \text{dB} \quad (1)$$

$$P_{Imp} = 24.6 - 0.35 L_{Aeq} \quad \text{dB} \quad (2)$$

As shown in fig. 4, P_{Imp} is greater than P_{tone} for L_{Aeq} below 55 dB(A) and becomes lower for L_{Aeq} above 55 dB(A). For every increase of 3 dB in L_{Aeq}, P_{imp} and P_{tone} decrease of 1 dB and 0.7 dB respectively. Equation (2) is in a good agreement with the results obtained in previous studies for the impulsive penalty [4].

5. CONCLUSIONS

The Italian legislation establishes an objective procedure for the assessment of tonal components in the noise, once the presence of such components has been subjectively detected.

An experimental study has been undertaken to investigate reliability and improvement of this procedure. The results obtained from laboratory listening tests, carried out on 8 environmental sounds, have

shown that the procedure does not match the subjective auditory perception in many circumstances (64.3% of disagreement). Such low reliability is even more not acceptable as the disagreement occurs more frequently when the tonal components are judged either clearly audible or prominent.

In addition, the use of a fixed penalty of 3 dB for assessing the increased annoyance due to the tonal character of the noise is not in agreement with the subjective ratings. The results have shown that, in the L_{Aeq} range 45÷65 dB(A), this penalty decreases of 0.7 dB for every increase of 3 dB in L_{Aeq}. A similar trend has been obtained for the impulsive penalty, namely a decrease of 1 dB for every increase of 3 dB in L_{Aeq}, confirming once again previous results.

To overcome the limitation of the DPCM procedure improvements are strongly needed. They require a deeper understanding and a better modelling of the subjective auditory perception of tonal components.

References

[1] DPCM 1/3/1991, Gazzetta Ufficiale n.57 (1991)
[2] British Standards Institution BS4142 (1990)
[3] British Standards Institution BS7445 (1991)
[4] G. Brambilla, M.R. Carretti, NOISE-CON 90 Proc., 279 (1990)

Appendix I

QUESTIONNAIRE

1. How annoying would you find the noise you have just heard if it was present at home in the evening?
   Not annoying at all 0 1 2 3 4 5 6 7 8 9 Extremely annoying
2. How impulsive would you say the noise was?
   Not impulsive at all 0 1 2 3 4 5 6 7 8 9 Extremely impulsive
3. Would you say the noise you have just heard is clearly impulsive?
   Yes / No
4. How tonal would you say the noise was?
   Not tonal at all 0 1 2 3 4 5 6 7 8 9 Extremely tonal
5. How would you judge the tonal components of the noise you have just heard?
   In-audible Only just detectable Clearly audible Prominent
6. Would you say the noise you have just heard is clearly tonal?
   Yes / No

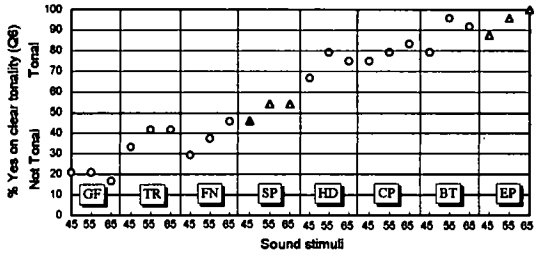

Fig. 1. Percentage of subjects clearly detecting tonal components in the sound stimuli

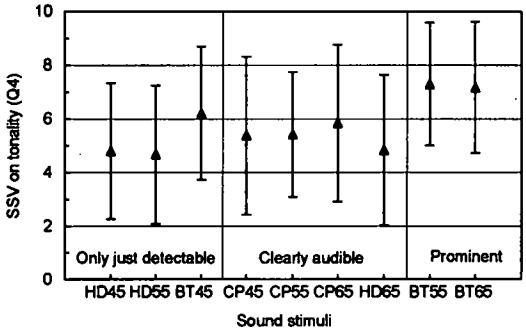

Fig. 2. Mean value and ± 1 standard deviation of ratings on tonality for sounds where the DPCM procedure is in disagreement with the subjective perception

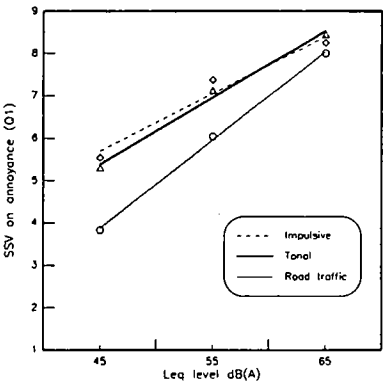

Fig 3. Dose-response relationships on annoyance for different types of sound

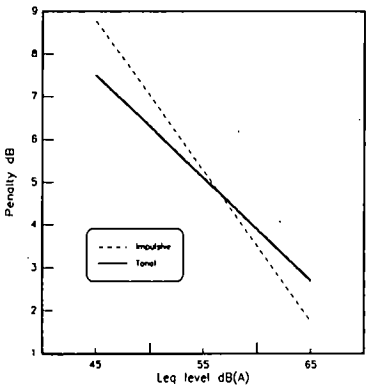

Fig 4. Tonal and impulsive penalties as function of L_{Aeq} level