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THE LOUDNESS OF IMPULSE NOISE : AN INTERNATIONAL COMPARISON

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Subjective estimates of loudness of a variety of impulse sounds are compared with the indications of direct-reading instruments, including the impulse sound level meter.

1. INTRODUCTION

The work described was instigated by Study Group TC43/SC1/SGB of the International Organization for Standardization as an international research programme to increase the experience and volume of data on the measurement and calculation of the loudness of impulsive noise. It is hoped that the results will enable the study group to take further action towards standardization, by an extension of ISO R532 which at present applies to continuous sounds only. All participants were asked to make subjective and objective evaluations of the comparative loudness of 20 noises under certain specified conditions. Actual methodology and numbers of subjects were left to individual laboratories but prerecorded test and calibration magnetic tapes were supplied by the laboratories of IRT, Hamburg. Common specifications were laid down by the organizers at the Technical University of Denmark for the electro-acoustical reproduction of the tapes, and the levels of the noises, in order that data from all laboratories could be combined. This paper describes only the results obtained at NPL.

2. PROCEDURE

21 otologically normal subjects took part in the tests which were held in a large free-field room. The 2-track magnetic tapes were composed with test noise in channel 1 and reference noise in channel 2 recorded alternately with suitable time spacing to allow comparison of the noises in pairs.

Test noises 1-9 consisted of quasi-stable sounds with impulsive characteristics, each compared with a 1/3-octave band of random noise centred on 1 kHz. Test noises 15-20 consisted of 1 kHz tone bursts compared with a similar tone burst of twice the duration. Test noises 10-14 consisted of impulse noises of different durations, in this case compared with a tone burst from the series 15-20. Finally, the 1/3-octave band reference noise was paired with a 1 kHz pure tone of 900 ms duration.

The method of adjustment was used with the subject having control of the test sound in channel 1 in 1 dB steps over a 40 dB range. The tests were conducted at three levels of the reference noise, 55, 75 and 90 dB SPL. To compensate for order effects the 21 subjects were split into three groups who heard the noises in three different orders at the three different levels.

Objective measurements were made as follows:

a) A-weighted "impulse hold" readings designated L_{AI}.

b) A-weighted "fast" and "slow" readings designated L_{AF} and L_{AS} respectively.

c) 1/3-octave band analysis using a direct integration technique.

Measurements a) and b) were taken with a Brüel and Kjaer sound level meter type 2606. The apparatus for c) consisted of an analogue squarer and integrator, with digital readout. The symbol $L_{A\ int}$ is used to denote the result of dividing the integrator readings by the signal duration, applying the A-weightings appropriate to the band centre frequencies, summing over the frequency range, and converting the answer into the decibel scale.

3. RESULTS

The way in which the various noises were paired in the plan of the experiment leads to complication in interpreting the results. It is convenient first to consider tests 1-9 separately since these alone utilized a common reference sound.

3.1 Noises 1-9

This is the set of which each member was compared with a 1/3-octave band of random noise centred on 1 kHz, and with the aid of the final comparison of the 1 kHz 1/3-octave band of noise with a 900 ms burst of 1 kHz tone, the subjective results are readily converted to phon. A direct comparison between the subjectively determined loudness levels (L_L) and those determined objectively (L_{obj}) can thus be made.

Regarding the standard deviation of the difference (L_L-L_{obj}) over the range of noises tested as an inverse figure of merit, there is little to choose between any of the different ways of assessing the noises objectively. However the values in phon calculated from the 1/3-octave spectra, using either of the two methods described in ISO R532, approximate much more closely to the absolute loudness levels than is the case with any of the direct-reading instruments. L_{TD} and L_{GF} symbolise the loudness levels calculated from ISO R532 (See Table 1, left hand part).

3.2 Noises 10-14

Determination of the energy spectra of these noises, which were truly impulsive, is easily performed but the results cannot be converted into equivalent-continuous sound pressure spectra unless appropriate durations can be assigned to the noises. Inspection of the waveforms shows that this step cannot be logically performed; thus for this group comparison can only be made on the basis of the sound level meter readings and the subjectively determined loudness. Again using standard deviation as an inverse figure of merit the very large values obtained show that there is little to choose between the various configurations of sound level meter, Table 1, right hand part. No doubt part of the reason for these large deviations lies in the double subjective comparison entailed in arriving at the subjective loudness level. This was a consequence of the way the experiment was constructed by the organizers and does not necessarily imply that the subjective determination of this class of sounds is more difficult or less accurate.

3.3 Noises 15-20

The comparisons involved here are all between 1 kHz tone bursts and absolute loudness levels and are readily obtained once a value has been assigned to the first link in the chain. Figure 1 shows the average results for the three levels together with the corresponding curve obtained by Study Group B in their preliminary report on the collected data, the results from some earlier unpublished work at NPL and the curve for the impulse sound level meter.

Unfortunately the experiment as laid down did not provide for subjective comparison between 320 ms, the longest duration in the group of noises, and 900 ms tone bursts. For tone bursts of equal amplitude and these durations it might be supposed that any difference between the loudness would be small since aural integration is complete within a period shorter than either of these. The literature on loudness as a function of tone burst duration reveals a great dispersion of integration times, a lack of data for tone bursts longer than 250 ms and a marked effect of psychophysical methodology. The results obtained suggest that loudness is still growing at 320 ms and a graphical extrapolation has been made to produce Figure 1.

The results are level-dependent, the curve for the lowest level being considerably steeper than the average (-36 dB at 5 ms). This effect is more evident between 55 dB and 75 dB than between 75 dB and 90 dB due to the so-called "mid-level bulge" or "low-level deficit". (2)

On the basis of these results one concludes that the relative subjective loudnesses of the tone bursts were not correctly determined, in which case the status of L_{AI} as a measure of loudness remains indeterminate, or that L_{AI} is a poor measure of loudness when the term is defined by the operation of matching tone bursts in pairs. This, however, is only to say, in another way, that for sounds of this type "loudness" has no fixed meaning, but depends upon the procedure used for determining it. The limitations of the present experiment preclude further speculation along these lines.

4. CONCLUSIONS

a) The results are level-dependent, suggesting that aural integration time is shorter at 55 dB than at higher levels. For this reason no linear objective meter can accurately reflect the loudness of impulses of different amplitude.

b) None of the meter measurements reflects particularly well the relative or absolute loudness of the 20 test noises as subjectively determined. For the quasi-stable noises numbers 1-9, calculation methods designed for steady non-impulsive sounds still give good approximation to loudness. The impulse sound level meter showed no particular advantage over the conventional instrument for any of the noises tested.

REFERENCES

1. International Organization for Standardization, Geneva 1966. Method for calculating loudness level. ISO Recommendation R532

2. STEVENS, S.S. (1961) Procedure for calculating loudness: Mark VI. J. acoust. Soc. Amer., 33, 1577

	NOISES 1-9		NOISES 10-14	
	Overall Mean	Overall S.D.	Overall Mean	Overall S.D.
$SPL-L_L$	- 11.7	3.6		
$L_{Aint}-L_L$	- 13.8	3.0		
$L_{AI}-L_L$	- 11.7	4.0	- 2.7	8.2
$L_{AF}-L_L$	- 14.1	3.2	- 7.5	6.8
$L_{AS}-L_L$	- 16.5	3.1	- 15.2	6.1
$L_{TD}-L_L$	1.1	3.4		
$L_{GF}-L_L$	2.7	3.4		

Table 1

Comparison of various objective measures relative to subjective results

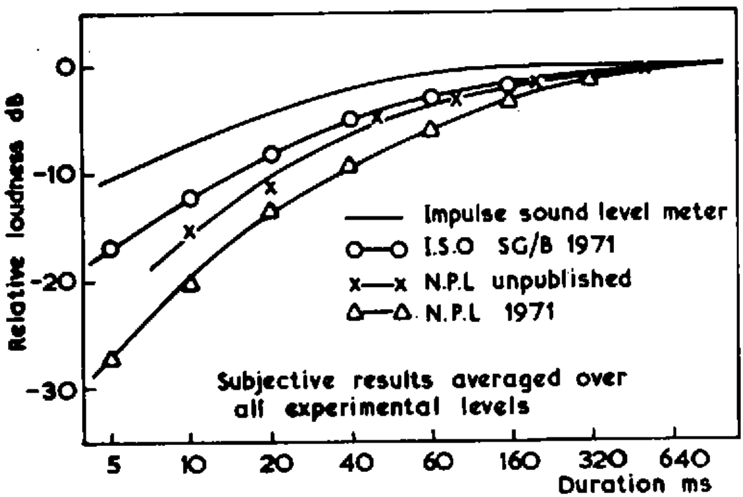

FIG.1 Growth of loudness with duration for 1kHz tone burst