Loudness of a single burst of impact sound: 
Results of round robin tests in Japan (I)

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(Received 22 June 1985)

1. INTRODUCTION

Impact sounds which we encounter in daily life, except sonic booms, are characterized by high peak levels and extremely short durations.13 Thus, impact sounds make little contribution to the value of $L_{Aeq}$ for environmental noise. However, the loudness or the annoyance of impact sounds are usually greater than expected one from their contribution to the value of $L_{Aeq}$.

ISO/TC43 had planned a round robin test on the loudness of impact sound in 1967, and the test was carried out all over the world.5,6 However, as some of the stimuli in the test were actual noise with wide frequency range, the relation between the loudness and the physical parameters of impact sound seems not to have been cleared. Besides many researchers have studied on the loudness or on the noisiness of impact sound1,3–29: some of them stated that the loudness of impact sound was well expressed by its sound energy, and some stated that other factors such as duration, rise time and peak level etc. were also important to the loudness of impact sound. Thus, how to evaluate impact sounds has been one of the unsolved problems in treating the environmental noise.

At present two methods of evaluating the impact sounds are well known: (1) impulse correction as described in ISO R 1996,30 and (2) evaluation using the circuit with "I" detector-indicator characteristic of a sound level meter as prescribed in IEC651.31 However, neither method is based on the established data for evaluating impact sounds, and there is ample room for further investigation.

Eleven laboratories in Japan undertook cooperative research and participated in a round robin test for the evaluation of impact sounds. This paper reports and discusses the results of the test planned...
for a single burst of impulsive sound.

2. OUTLINE OF THE EXPERIMENT

Table 1 is a list of the names of 11 laboratories and the researchers that participated in this test. Table 2 shows the experimental conditions adopted in the test.

Examples of definitions of impulsive noise can be seen in ISO 22043 and IEC 179A. According to those documents, impulsive noise is (1) either a single pressure pulse or a single burst having a duration of less than 1 s, or (2) a series of noise bursts with short intervals. In this study, we treat only the single burst of impulsive sound. Furthermore, impact noise which we encounter in daily life such as noise from diesel pile hammers or the shutting of doors, generally has a steep rising part and an exponentially trailing part. Taking these features into consideration, we adopted test stimuli with such characteristics.

Figure 1 shows the time pattern of a pair of the stimuli. The experiment was carried out using the constant method. The comparison stimulus was at one of 11 levels with 2 dB intervals. Presentation of pairs of sounds were of two types, a test stimulus followed by a comparison stimulus or a comparison stimulus followed by a test stimulus. The stimuli originated from a model impact sound generator which produced signals having exponentially rising and decaying parts. Thus, they had logarithmically linear rising and decaying parts. With this equipment, which was previously employed by Kumagai et al., the amplitude modulation method was used to generate signals. Output of this equipment was once recorded on a magnetic tape with a PCM recorder, and then copied for use in an ordinary tape recorder at 38 cm/s. On a tape, 198 pairs of test stimuli were recorded in random order.

Two kinds of carrier signal were used. One of them was a 1 kHz sinusoidal wave. The other was a mixture of two asymmetric rectangular waves. Fundamental frequencies of the waves were 440 Hz and 1,175 Hz. Amplitude ratio of the 440 Hz component to the 1,175 Hz component was three to two. The duty cycle of both components was set at 0.85. The relation between the components was set to be inharmonic, and the amplitude ratio was selected so as to maintain fusion of both components. This

![Fig. 1](image_url)
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Table 3  Experimental conditions peculiar to each laboratory.

<table>
<thead>
<tr>
<th>Names of laboratory</th>
<th>Method of recording</th>
<th>Room</th>
<th>Noise level</th>
<th>Tape recorder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muroran Institute of Technology</td>
<td>Formatted Paper</td>
<td>Semi-anechoic room</td>
<td>18 dB</td>
<td>DENON DH710F</td>
</tr>
<tr>
<td>Tohoku University</td>
<td>Push Botton</td>
<td>Anechoic room</td>
<td>&lt;35 dB</td>
<td>Technics RS 1500U</td>
</tr>
<tr>
<td>Sendai National College of Technology</td>
<td>Push Botton</td>
<td>Anechoic room</td>
<td>&lt;35 dB</td>
<td>Technics RS 1500U</td>
</tr>
<tr>
<td>The University of Tokyo</td>
<td>Push Botton</td>
<td>Anechoic room</td>
<td>&lt;20 dB</td>
<td>TEAC A-6700</td>
</tr>
<tr>
<td>Electrotechnical Laboratory, MITI</td>
<td>Push Botton</td>
<td>Hearing-test room</td>
<td>&lt;20 dB</td>
<td>Technics RS 1500U</td>
</tr>
<tr>
<td>Yokohama National University</td>
<td>Push Botton</td>
<td>Anechoic room</td>
<td>18 dB</td>
<td>SONY TC-R7-2</td>
</tr>
<tr>
<td>Kyoto University</td>
<td>Formatted Paper</td>
<td>Semi-silent room</td>
<td>25~30 dB</td>
<td>SONY TC-D5M</td>
</tr>
<tr>
<td>Osaka University</td>
<td>Push Botton</td>
<td>Semi-silent room</td>
<td>&lt;30 dB</td>
<td>Technics RS 1500U</td>
</tr>
<tr>
<td>Kyushu Institute of Design</td>
<td>Formatted Paper</td>
<td>Semi-anechoic room</td>
<td>&lt;10 dB</td>
<td>DENON AP266</td>
</tr>
<tr>
<td>Kumamoto University (Electr. Eng.)</td>
<td>Push Botton</td>
<td>Semi-anechoic room</td>
<td>27 dB</td>
<td>Technics RS 1500U</td>
</tr>
<tr>
<td>Kumamoto University (Arch.)</td>
<td>Push Botton</td>
<td>Anechoic room</td>
<td>&lt;NC10</td>
<td>Technics RS 1500U</td>
</tr>
</tbody>
</table>

complex signal is called as an asymmetric rectangular wave, hereafter.

As shown in Table 2, the signals had loudness levels of 75, 85 or 95 phon. That is, the level was 75, 85 or 95 dBSPL for a 1 kHz sinusoidal carrier, and 72, 82 or 92 dBSPL for an asymmetric rectangular wave. This reduction of 3 dB for the latter is to make it as loud as the former, and this value was decided after a preliminary experiment of loudness matching.

Table 3 shows the experimental conditions peculiar to each laboratory. The fundamental requirements required were as follows:
1) Ambient noise: less than 35 dB in A-weighted SPL,
2) Listening room: dead,
3) Light intensity: enough light to read books,
4) Posture of subject: sitting in a chair with closed eyes.

Stimuli were presented to both ears via headphones. The type of the headphones was YAMAHA HP1000, which is semi-open-air and is dynamically driven by a coil printed over the vibrating thin film. All the headphones were manufactured in the same lot, and their frequency response characteristics were checked for uniform quality. These headphones were distributed along with information on the respective frequency response characteristics. The standard deviation of their sensitivity was measured by use of nine samples at the Electrotechnical Laboratory. At 1 kHz, the standard deviations were 0.9 dB for left earphones and 0.8 dB for right earphones. The standard deviations at 5 kHz were 1.1 dB for left earphones and 0.4 dB for right earphones.

A special recorded tape was prepared for training purposes. This tape contained 108 pairs of stimuli which could be judged easily. Subjects were requested to judge which stimulus in a pair was louder (i.e. 2 AFC paradigm).

After finishing the listening test for all 10 sets of taped sound series, PSE’s (Points of Subjective Equality) were calculated using Müller-Urban’s weight at each laboratory. These calculated PSE’s were recorded on optical card reader sheets and sent to Tohoku University.

The first meeting for this round robin test was held in January 1981. Stimuli were distributed to each laboratory in February 1982 and results of the experiment were gathered in the early spring of 1983. A meeting to discuss on the experimental results by almost all participants was held in February 1983.

3. RESULTS

Experimental results are shown in Figs. 2 and 3 as histograms. Figure 2 shows the results for the 1 kHz sinusoidal carrier, and Fig. 3 shows the results for the asymmetric rectangular carrier. The abscissa of these figures represents PSE, i.e. SPL of comparison stimuli which were judged as loud as test stimuli,
Fig. 2 Histograms showing the experimental results of the test in which the carrier of the stimuli was 1 kHz pure tone. The abscissa represents PSE, i.e. SPL of comparison stimuli which were judged as loud as test stimuli, and the ordinate represents the number of subjects. Averages and standard deviations of PSE are also shown along with each histogram.
Fig. 2 (continued)

Fig. 3 The same histograms as in Fig. 2 except that the carrier of the stimuli was asymmetric rectangular wave.
Fig. 3 (continued)
Fig. 4 Relation between evaluated sound pressure levels of test stimuli (abscissa) and their PSE's (ordinate). The abscissa represents the sound energy level of stimuli. This figure shows the results of the experiments in which the carrier of stimuli was a 1 kHz sinusoidal wave. The dashed line represents the relation provided PSE's are equal to the values obtained for the specific type of evaluation (i.e. sound energy levels). Therefore, if all points were placed parallel to the dashed line, the evaluated values could well explain the loudness of the test stimuli.

Fig. 5 The same relation as in Fig. 4 except that the carrier was the asymmetric rectangular wave.

and the ordinate represents the number of subjects. Averages and standard deviations of PSE are also shown with these histograms.

Fig. 6 The same relation as in Fig. 4 except that the abscissa indicates the maximum reading of output through an r.m.s. circuit whose time constant is 35 ms (detector indicator characteristic “I”).

Fig. 7 The same relation as in Fig. 5 except that the abscissa indicates the maximum reading of output through an r.m.s. circuit whose time constant is 35 ms (detector indicator characteristic “I”).

Figures 4~11 show the relation between evaluated sound pressure levels of test stimuli (abscissa) and their PSE's (ordinate). Figures 4, 6, 8 and 10 show the results of the experiments in which the carrier of stimuli was a 1 kHz sinusoidal wave, while Figs. 5, 7, 9 and 11 represent those of the experiments in which the carrier was the asymmetric rectangular wave.
wave. In Figs. 4 and 5 the abscissa represents the sound energy level of stimuli. In Figs. 6 and 7 the magnitudes of stimuli are indicated by the maximum reading of output through an r.m.s. circuit whose time constant is 35 ms (detector indicator characteristic "F"). Figures 8 and 9 show the similar quantities except that the time constant is 125 ms (characteristic "F"), and Figs. 10 and 11 are drawn for a time constant of 1 s (characteristic "S"). The maximum reading of the r.m.s. circuit is entirely the same as the maximum of the energy level through the time window of \( \exp(-t/T) \), where \( T \) is a time constant. Thus, there is no substantial difference among these types of evaluation.
Dashed lines in these figures represent the line when PSE's are equal to the values obtained for each specific type of evaluation. Therefore, if all points were placed parallel to the dashed line, the evaluated values could well explain the loudness of the test stimuli. In particular, if all points were plotted on the dashed line, the quantity expressed by the abscissa could thoroughly explain the loudness of all the stimuli including the comparison stimuli. If there is a plot above the line, it means that the test stimulus (i.e. impact sound) was louder than the comparison stimulus (200 ms burst) although the evaluated values are the same. On the contrary, a plot below the line means that the test stimulus was softer than the comparison stimulus though the evaluated values are the same.

4. DISCUSSION

The sound energy level (see Figs. 4 and 5) seems to result in a good evaluation. However, when the steady duration is short, we find that the points are 1~2 dB above the dashed line. This means that test stimuli were louder than the comparison stimuli even if their sound energy levels were the same. Since the longest test stimulus had a duration shorter than 1 s in this test, the maximum reading by means of the r.m.s. circuit with a 1 s time constant (see Figs. 10 and 11) was naturally similar to the sound energy level.

Figures 8 and 9 show that the maximum reading through the r.m.s. circuit with a 125 ms time constant results in a good evaluation of the loudness of the stimuli. In particular, when the carrier is the asymmetric rectangular wave, this method results in a very good evaluation. When the carrier is a 1 kHz sinusoidal wave, however, the decay time has a greater effect than expected so that the plotted points are somewhat scattered vertically.

On the other hand, if the time constant is 35 ms (see Figs. 6 and 7), most plotted points fall below the dashed line. This means that the impact sound is not as loud as expected in this method of evaluation; in other words, overestimation occurs in this case.

From the above considerations, either the sound energy level or the maximum output of an r.m.s. circuit with a time constant of 125 ms~1 s results in the most suitable evaluation of the stimuli used in our experiment. With any of these methods of evaluation, however, impact sounds were slightly louder than the burst of 200 ms long, which was used as the comparison stimulus.

If we try to relate the evaluation of impact sound with that of steady noise, we must consider the case in which the duration of the comparison stimulus is much longer than 200 ms. In that case, the loudness of the comparison stimulus is less than that expected from its energy. Supposing that the duration is 1 s, the loudness level of the sound is at most greater by a few dB than that of the sound with a duration of 200 ms, whereas the energy of the stimulus is greater by 7 dB. Therefore, it is not always appropriate to use the sound energy level when estimating impact sound, though this method of evaluation gives appropriate values as shown in Figs. 4 and 5 as far as the impact sounds are concerned. Thus, we prefer the maximum reading of output by means of an r.m.s. circuit whose time constant is 125 ms~1 s to the sound energy level.

The results obtained in this round robin test are somewhat different from results of the similar investigations in the past. This difference occurs when an impact sound does not have a steady part and has a short decay time. From this round robin test, it can be seen that loudness of such an impact sound that has no steady part and has a short decay time is evaluated well from its sound energy or similar quantities to the sound energy. On the other hand, some investigators reported that the loudness level of such an impact sound becomes several dB greater than what might be expected from its energy. Though the reason for this difference is not clear at present, we would like to point out that the method used in an experiment possibly affects the results. We used the constant method in this test, whereas the previous investigators used either the method of adjustment or the magnitude estimation.

5. CONCLUSION

We have reported here the results of a round robin test carried out in 11 laboratories in Japan.

From the above considerations, either the sound energy level or the maximum output of an r.m.s. circuit with a time constant of 125 ms~1 s results in the most suitable evaluation of stimuli used in our experiment. When either of these quantities is used, however, impact sounds are slightly (1~2 dB) louder than the burst of 200 ms duration, which was used as the comparison stimulus. When relating the evaluation of impact sound with that of steady noise, authors prefer the maximum reading of output.
through an r.m.s. circuit whose time constant is 125 ms ~ 1 s to the sound energy level.

ACKNOWLEDGEMENTS

We wish to thank all the participants in this round robin test. In particular, we are grateful to Prof. Ebata of Kumamoto University for his role in promoting this test as well as to Prof. Namba and Dr. Kuwano of Osaka University for planning the experimental conditions and for making recorded tapes with instructions for the subjects. We also acknowledge the efforts of Mr. Miura and Dr. Kado of the Electrotechnical Laboratory in devising the method for calibrating headphones.

The last phase of this study is supported by the Kajima Foundation’s Research Grant.

REFERENCES