# Noise evaluation based on loudness-perception characteristics of older adults

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**ABSTRACT**

The frequency-weighting A used for noise measurement was determined based on hearing characteristics expressed as equal-loudness-level contours. The time-averaged, A-weighted sound level ($L_{Aeq}$) of a sound corresponds well with the perceived loudness. However, good correspondence between $L_{Aeq}$ and the perceived loudness is confined to cases in which listeners are young people with normal hearing. This study used a psychoacoustic experiment to investigate loudness of various sounds perceived by older people aged over 60. Analyses of results revealed that sound levels weighted by listeners' hearing characteristics matched the judged loudness better than $L_{Aeq}$ values did. This report describes the development of a noise evaluation method that can evaluate noises for senior citizens more accurately than the conventional method using A-weighting.

Keywords: Loudness, Aging effect, Noise evaluation     I-INCE Classification of Subjects Number(s): 63.1

## 1. INTRODUCTION

### 1.1 Aging of Hearing Characteristics

As humans age, their hearing characteristics change in various respects. Hearing threshold elevation at high frequencies is a particularly well-known phenomenon related to aging effects. In addition, the loudness sensation shows a gradual change.

Figure 1 displays a set of equal-loudness-level contours (ELLCs) that the authors have determined from assessment of young and older adults for pure tones of frontal incidence under binaural listening conditions in a free field (1). Although the listeners were all otologically normal, the respective contours of the two age groups diverged at frequencies higher than 1000 Hz, as might be expected from difference in their hearing thresholds.

### 1.2 Noise Evaluation Considering Aging Effects of Hearing

Good correspondence of the time-averaged, A-weighted sound level ($L_{Aeq}$) to the perceived loudness of the sound has been demonstrated repeatedly (2). Nevertheless, considered theoretically, good correlation is expected only when young people with normal hearing judged the loudness because the frequency-weighting A has been determined based on equal-loudness-level (ELL) characteristics of young people.

Figure 2 shows the A-weighting curve overlapped with an inverse of 40-phon ELLCs of young and older adults in Figure 1. Although the ELLC of young adults matches the A-weighting curve reasonably well, that of older adults exhibits a large deviation from the curve at high frequencies. Consequently, $L_{Aeq}$ is anticipated as a good measure of loudness for young people, but it might not be such a good measure for older people with presbycusis.

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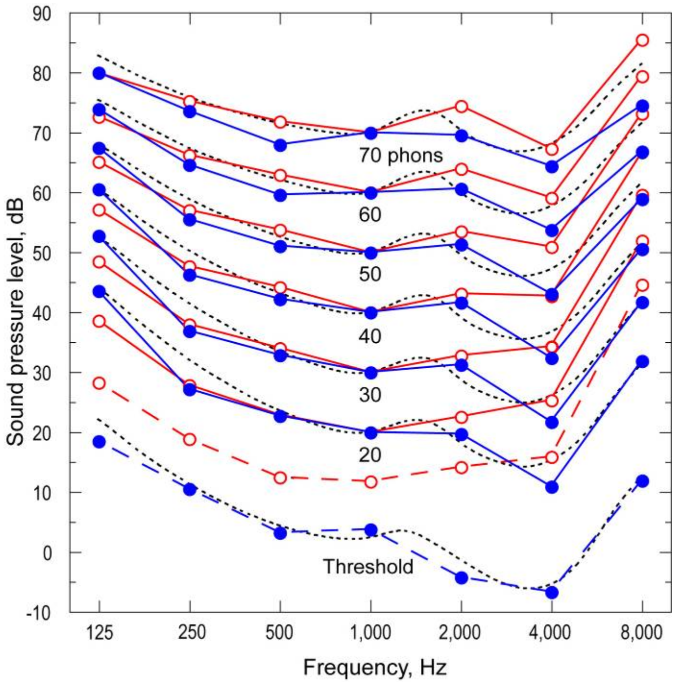



Figure 1 – ELLCs of young and older adults having otologically normal hearing (1): blue lines with filled circles, young adults; red lines with open circles, older adults; broken lines, hearing threshold; dotted lines, the ELLCs and threshold curve in ISO 226 (3)

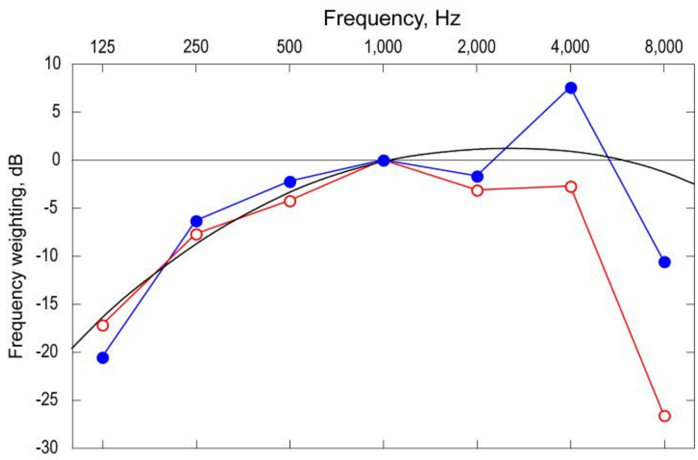
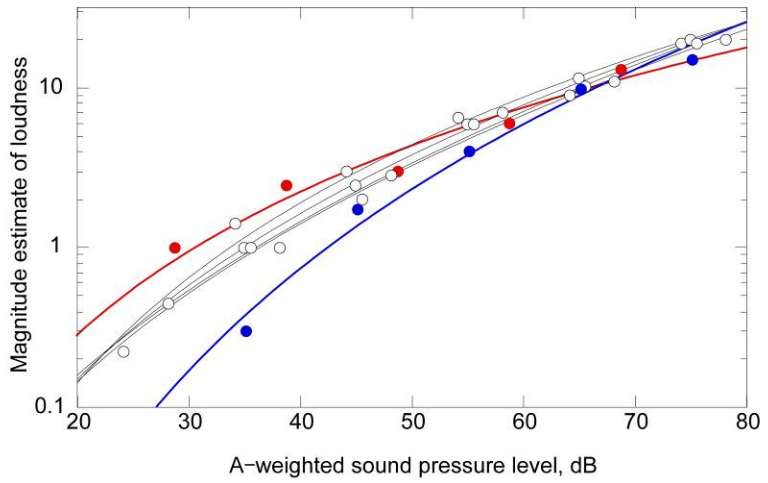
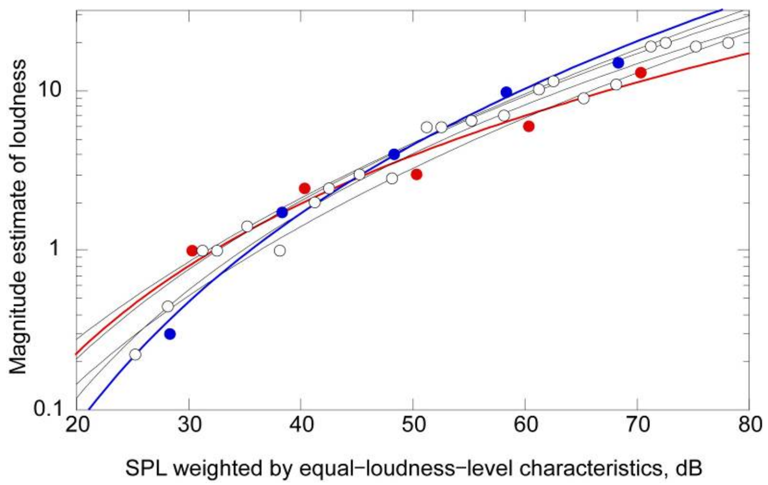



Figure 2 – Comparison of the A-weighting curve and the inverse of the 40-phon ELLCs of young and older adults in Figure 1 (1): black line, the A-weighting curve; blue line and red line, inverse ELLCs of young and older adults

Kurakata et al. (4) asked adults older than 60 to estimate the loudness of low-pass filtered noises (LPNs) that varied in their cut-off frequency from 125 Hz to 8000 Hz at one-octave intervals. Figure 3 shows that the loudness perceived by listeners was underestimated as the cut-off frequency increased, i.e. as the energy of sound increased at higher frequencies, when evaluated in terms of $L_{\mathrm{Aeq}}$. However, when an inverse of their 40-phon ELLC was used in place of the A-weighting, the weighted levels of noises matched the perceived loudness better, irrespective of their cut-off frequency.




(a)




(b)

Figure 3 – Magnitude estimates of loudness for LPNs perceived by older adults (4), evaluated in terms of (a) A-weighted sound pressure levels and (b) sound pressure levels weighted by an inverse of the listeners' ELLC of 40 phons. Cut-off frequency of LPNs: red line, 125 Hz; blue line, 8000 Hz; black lines, other frequencies between 125 Hz and 8000 Hz

### 1.3 Aim of This Study

Findings presented in the previous sections can be summarized as listed below.

- The characteristics of loudness perception by older adults differ from those of young adults.
- The $L_{\mathrm{Aeq}}$ of sound does not always show good correspondence with the loudness perceived by older adults.
- Sound pressure levels (SPLs) weighted by an inverse ELLC of older adults match their perceived loudness of sound better than the $L_{\mathrm{Aeq}}$.

However, the LPNs used in the experiment above differed considerably in their frequency characteristics and time variations from sounds that we encounter in our daily lives.

This study used a psychoacoustic experiment to examine whether the weighting method based on the ELLC of older adults is applicable in the same manner to loudness evaluation of various sounds in real environments.

## 2. EXPERIMENT

### 2.1 Method

**Stimulus** Fifteen sounds in living and working environments were selected from a sound library (5). For each sound, a portion with duration of 7 s, having its maximum amplitude, was cut out to produce a stimulus and was recorded on a compact disc (CD; 44.1 kHz sampling, 16-bit resolution). These stimuli were reproduced from a CD player (DCD-755AE; Denon), input into a frequency equalizer (DEQ2498; Behringer), and amplified using a power amplifier (AVC-1508; Denon). Then, they were presented through a loudspeaker (i8; Tannoy Ltd.) that was set 3 m from the listener's position in an anechoic room (W: 4.35 m, D: 6.00 m, H: 2.95 m) of AIST. The sound level was decreased from the original level at which the sound had been recorded to a moderate level since some sounds were too loud for the purpose of experiment. Table 1 shows stimuli and their presented level. Figure 4 shows one-third-octave band levels of the stimuli.

Table 1 – Sound stimuli used in the experiment

| No. | Stimulus | $L_{Aeq}$, dB |
|---|---|---|
| 1 | Music played by a string quartet | 73.6 |
| 2 | English text read by a female speaker | 52.3 |
| 3 | Automobile noise | 53.5 |
| 4 | Aircraft noise | 65.3 |
| 5 | High-speed vessel noise | 57.5 |
| 6 | Factory noise | 66.7 |
| 7 | Construction noise | 67.9 |
| 8 | Sound of a merry-go-around | 57.8 |
| 9 | Vacuum-cleaner noise | 65.1 |
| 10 | Railroad noise | 68.7 |
| 11 | Sound of railroad-crossing alarm | 70.6 |
| 12 | Shopping-street noise | 56.0 |
| 13 | Alarm-clock sound | 63.9 |
| 14 | Amusement-arcade noise | 71.7 |
| 15 | Sound of a festival | 72.0 |

**Procedure** To measure the loudness of sound stimuli, the magnitude estimation (ME) method without a modulus was used. The listener sat on a chair, facing the loudspeaker directly. After each sound presentation, the listener orally reported a positive number that they thought corresponded to the magnitude of loudness that they perceived. Each stimulus was presented to the listener in random order. The first trial was for practice. Responses of the second and third trials were adopted for the analyses described below.

The experiment was conducted after approval by an AIST ethics committee. Each listener participated in measurements individually after providing informed consent.

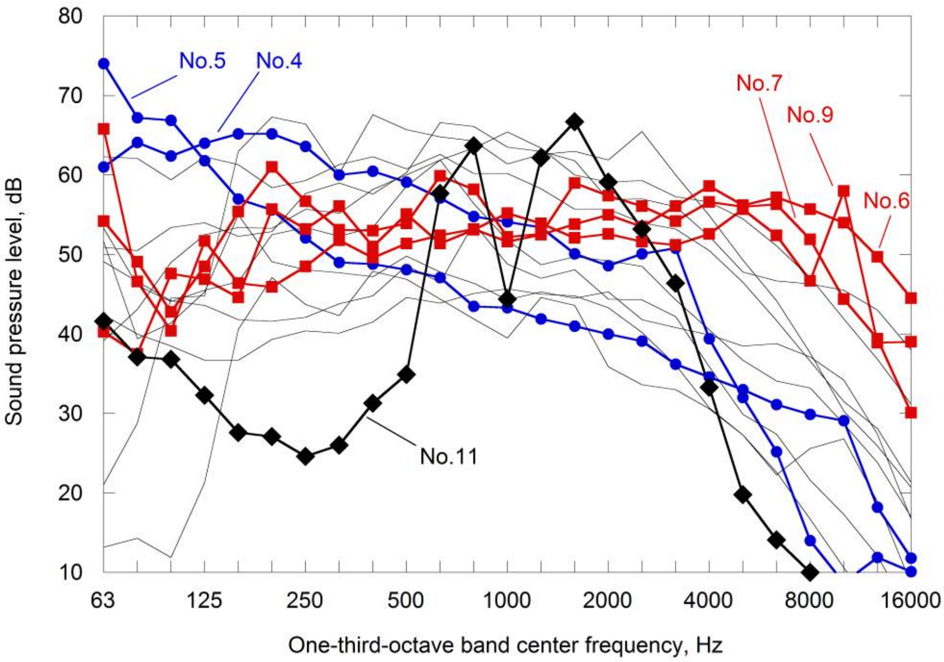



Figure 4 – Frequency characteristics of stimulus sounds

### 2.2 Listeners

Listeners were young students (16 men, 17 women) aged from 18 to 24 years and older adults (10 men, 24 women) in their 60s who had been screened for hearing abnormalities. They participated in the experiment after the measurement of ELLCs in Figure 1.

### 2.3 Results and Discussion

The geometrical means of two estimates were calculated for individual listeners. Each was adopted as the listener's ME value for the stimulus sound. Figure 5 displays medians of thus-calculated MEs for the older listener group. The MEs are shown against $L_{\mathrm{Aeq}}$ values and SPLs weighted by the listeners' ELL characteristics. The ELLC of 60 phons was adopted for the weighting.

Table 2 presents coefficients of determination when a linear regression from the levels to the MEs was assumed. The coefficients were larger for both age groups when the sound levels were weighted by ELL characteristics than by the frequency-weighting A. Therefore, the perceived loudness can be estimated more precisely using listeners' loudness characteristics than using the conventional A-weighting.

Comparison of the results with the frequency characteristics of sounds (Figure 4) reveals that improvement of loudness estimation is large for the stimulus no. 11, sound of railroad-crossing alarm. This sound had high energy at frequencies of 500–4000 Hz, where age-related changes of loudness perception are large. Improvement was also observed for young listeners (not shown in Figure 5). These facts strongly support the validity of the weighting method based on the ELL characteristics of listeners.

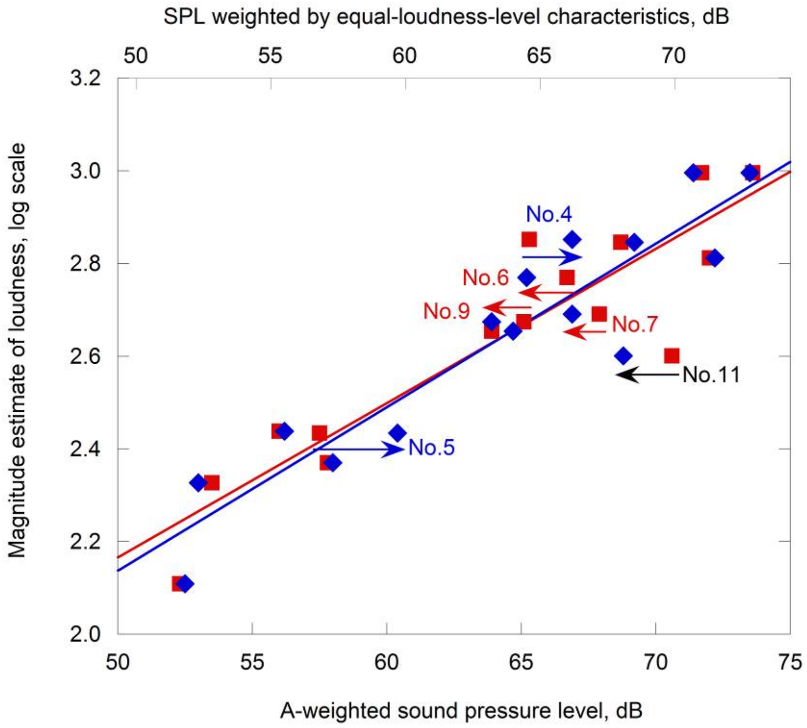



Figure 5 – MEs of loudness for older listeners shown against $L_{Aeq}$ values (red squares) and SPLs weighted by ELL characteristics (blue diamonds)

Table 2 – Coefficients of determination obtained using the two weighting methods

| Listeners | Coefficients of determination | |
|---|---|---|
| | A-weighting | This study |
| Older adults | 0.834 | 0.866 |
| Young adults | 0.796 | 0.815 |

The levels weighted by ELL characteristics became higher than A-weighted levels for stimulus no. 4, aircraft noise, and no. 5, high-speed vessel noise. These sounds had high energy at low frequencies, where aging effects on loudness are slight. This fact explains why those sounds had a larger SPL than other sounds when weighted by the ELL characteristics.

In contrast, stimulus no. 6, factory noise, no. 7, construction noise, and no. 9, vacuum-cleaner noise, shifted to a lower level. These sounds can be characterized by their high energy at high frequencies. Stimuli nos. 6 and 9 moved away from the regression line and did not contribute to the improvement of overall fitness. Therefore, to improve the weighting method, it appears necessary to estimate loudness-perception characteristics more precisely for high frequencies.

## 3. GENERAL DISCUSSION

The experiment of this study demonstrated that SPLs weighted by ELL characteristics corresponded better to the loudness perceived by younger and older listeners than A-weighted SPLs or $L_{Aeq}$. The effect was remarkable especially when the sound had stronger energy at higher frequencies, where the age-related change in hearing ability is greater.

To improve the estimation accuracy of the method using ELL characteristics, further studies must be undertaken to elucidate the following points.

[1] Precise measurement of ELL characteristics at high frequencies

The ELLCs used for this study were those estimated roughly at one-octave frequency intervals using the ME method. The age-related change of loudness perception varies at a large extent in the high-frequency region. Redetermination of ELL characteristics with high precision is expected to enhance the overall accuracy of loudness estimation using the method proposed herein.

[2] Selection of equal-loudness characteristics depending on the sound level

This study used fixed ELL characteristics irrespective of the SPL of sounds. However, the ELLC shape changes depending on the loudness level in phons (Figure 1). Furthermore, the rate of change in equal-loudness characteristics as the loudness level increases is greater for older adults because of the recruitment of loudness perception. Therefore, the loudness evaluation accuracy will increase if the ELL characteristics are selected dynamically as the SPL of the input sound changed.

Loudness calculation methods such as the Zwicker method (6) and the Moore-Glasberg method (7) are based solely on the hearing characteristics of young people. These methods might be applicable to loudness evaluation for older people by incorporating the aging effects on loudness perception, as suggested by the results presented here.

Establishing a new method of noise evaluation that takes account of aging effects raises questions about how sounds should be evaluated when people at any age might be listening, as in the case of noise assessment of residential areas. As suggested from the results in this study, the conventional method using A-weighting is unsuitable for evaluating sounds for people of mixed generations. However, it would not be easy to ascertain which measure of loudness should be adopted as a representative measure for that purpose of noise evaluation.

The method introduced in this study might not be useful for such generic purposes. The method is expected to be most effective for evaluating sounds that are measured or designed for persons in a specific age range. Designing sounds of products intended for use by older people is an example of such applications.

## ACKNOWLEDGEMENTS

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