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Sound Power Level Measurement of the Erhu (Chinese Violin)

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Summary

The Erhu ('Chinese violin'), a two-stringed bowed instrument, is one of the most popular Chinese traditional instruments. Its timbre can be compared with violin. In this study sound power measurements of the Erhu were performed in a reverberation chamber according to ISO standard and Chinese national standard. Two qualified musicians performed on two different Erhus. The sound output and dynamic range were investigated by means of real-time analysis. Typical values of the radiated sound power were obtained through averaging.

1. Introduction

Chinese traditional instruments have a long history over around 8000 years. Despite their important place in the world's music culture, the radiated sound power of these instruments have not been systematically investigated. Only a minor study has been published where musicians performed in a studio, not in an anechoic chamber or a reverberation room. The mean linear or A-weighted sound pressure levels and dynamic ranges of some traditional instruments in normal performance were reported [1].

Since the 1960s, studies on the radiated sound pressure or sound power levels for the most important string and wind instruments of the Western orchestra have been published [2, 3, 4]. In 1990, Meyer summarized these measuring results, including his own sound power measurements, and derived a formula to calculate the mean forte sound power level L_{wf} for orchestral instruments [5]. Based on Meyer's work, a new criterion L_{pf}, the mean forte sound pressure level of tutti-sound was suggested by one of the present authors and others for evaluation of the loudness of concert halls [6]. A formula to determine the L_{pf} distribution in a hall was also given.

In this study, measurements for determining the sound power level of the Erhu are reported. The Erhu , commonly known in the West as the 'Chinese violin', is a two-stringed bowed instrument and one of the most popular Chinese traditional instruments. It consists of a belly, neck, head, tuning pegs, bridge, bow and strings (see Figure 1). The tip of the hardwood neck is often elaborately carved into shapes such as a bat or dragon's head. At the base of the neck there is a resonator made from python skin stretched over a hollow wooden box on one side and with a sound hole left on the other. The Erhu is played by a sitting performer with the belly on his left leg. The left hand fingers press the strings while the right hand draws the bow. As opposed to Western bowed string instruments, the bow hair of the Erhu is never separated from the strings; it passes between them instead.

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2. Measuring procedure

The measurements were taken in the reverberation chamber of South China University of Technology, which has a volume of 200 m^3. The length, width and height were 7.3, 6.8 and 4.5 m, respectively. Along two adjacent walls, some cylinder diffusers were laid out and other diffusers were hung under the ceiling.

When measuring, four microphones were placed in a circle around the performer at a distance of 2 m. The height of the microphones above the floor was 1.5 m. The performer was located at the center of the chamber. The performer was positioned with the face pointing between two microphones.

The test instruments included a Nor118 sound level meter with Nor1225 microphone; a BK 2260 sound investigator with BK4189 microphones, and a two-channel BK PULSE 3560C with two BK4189 microphones.

Four channels were used to record the microphone signals simultaneously, and the mean sound power level was obtained by averaging. When measuring the sound power of a sound source which contains significant discrete frequency components like a musical instrument, the number of source positions is recommended to be more than one. However, according to the suggestions of Meyer and Angster [3], based on their measuring work on the sound power of the violin, a change in source position causes only little effect on the measuring results. For lower frequencies, the standard deviation increased only 0.2 dB with a single source location and for higher frequencies (above 800 Hz) only 0.1 dB. Therefore, in our measurements the sound source position was not changed.

In contrast to a stable source, the sound power of a musical instrument has a dynamic range which not only depends on the type of the instrument, but also on the performing technique as well as the performer's interpretation of the dynamic markings. Considering that there are differences among musical instruments and among musicians, we invited two professional players with 21 and 45 years experience, respectively, to perform on their own instruments. One of the Erhu was 28 years old and the other had only been used for two years. Before measuring, the tuning was adjusted so that the pitch of the note a^1 (A4) note was 440 Hz.

The full playing register and the normal register of the Erhu are d^1 (D4 = 293.7 Hz)–e^4 (E7 = 2637 Hz) and d^1 (D4)–e^3 (E6 = 1318 Hz), respectively. For convenient comparison with Western orchestral instruments, the scientific pitch notation is given in parenthesis. Besides the normal register, single tones were chosen for recording so that the characteristics of the instrument could be more realistically displayed and the measurement results could be used for practical loudness evaluation in a hall. From the normal register three representative single notes, d^1, d^2 and d^3, and a special Chinese music scale consisting of 5 notes over two octaves, were selected for the sound power measurements. The music scale played was d^1 e^1 #f^1 a^1 b^1 d^2 e^2 #f^2 a^2 b^2 d^3.

In each measurement round, a famous folk song "Molihua" (Jasmine flower) was first performed. The recording time was set to be 20 s. Then, the music scale was played with a recording period of 8 s. During this period, the scale could be repeatedly played with a speed of about 2–3 notes per second. Finally, the three notes d^1, d^2 and d^3, which are representative notes for the low, medium and high registers, respectively, were played. In this case, 4 s was allotted for each tone. The players were asked to perform in a continuous style. This means that they could use

Figure 1. The Erhu.

both up- and down-bows to play the notes. The song, music scale and the three single notes were all played at four dynamic markings; pianissimo, mezzo-piano, forte and fortissimo (*pp, mp, f, ff*). Here *pp* means playing clearly and as gently as possible, *mp* means playing normally and smoothly, *f* means playing powerfully and *ff* means playing as intensely as possible yet still keeping the pitch correctly. Since the acoustic environment of a reverberation room is different from a usual performing environment, the players were asked to do some exercises before formal testing so that they could acquaint themselves with the reverberant space.

For each case, the sound pressure level in 1/3 octave bands were recorded and analyzed. By taking an average across the four microphone positions, the sound power levels of each 1/3 octave band were obtained by equation (1) in accordance with ISO 3741.

$$L_{Wn} = L_p - 10\log\frac{T}{T_0} + 10\log\frac{V}{V_0} + 10\log\left(1+\frac{S\lambda}{8V}\right) + 10\log\frac{B}{1000} - 14, \quad (1)$$

where L_{Wn} is the sound power level of *n*th 1/3 octave frequency band [dB], $n = 1\ldots21$, T is the reverberation time of the test chamber [s], $T_0 = 1$ s, V is the volume of the test chamber [m^3], $V_0 = 1$ m^3, S is the total surface area of the test chamber [m^2], λ the wavelength of center frequency of 1/3 octave frequency band [m], B is the atmospheric pressure [mbar], L_p the mean sound pressure level of 1/3 octave band [dB].

$$L_p = 10\log\left(\frac{1}{N}\sum_{i=1}^{N}10^{0.1L_{pi}}\right), \quad (2)$$

where L_{pi} is the sound pressure level in 1/3 octave band at each microphone position [dB], N is the number of microphone positions, here $N = 4$.

After obtaining the sound power of each 1/3 octave band, the total sound power level L_W was calculated from

$$L_W = 10\log\left(\sum_{n=1}^{21}10^{0.1L_{wn}}\right), \quad (3)$$

where L_{wn} is the sound power level of *n*th 1/3 octave band from 100 to 10 000 Hz, the number of bands being 21. Finally, the mean sound power level and dynamic range for the two instruments when performing the melody, music scale and single notes were calculated.

3. Results and analysis

3.1. Linear sound power levels and dynamic range

Generally, the measurements of repeated recordings showed quite a high reproducibility, which indicates that the players were qualified for their task and the recording conditions satisfactory.

Table I. Mean sound power levels and dynamic ranges for two Erhus when single notes, a music scale and a folk song are performed (dB).

		pp	*mp*	*f*	*ff*	Dyn. range
Notes	d^1	66.5	75.8	84.2	88.3	21.8
	d^2	66.1	76.9	85.3	89.2	23.1
	d^3	60.0	68.1	73.0	76.2	16.2
Music scale		75.5	80.5	90.1	92.7	17.2
Song		75.5	80.9	86.8	90.8	15.3

Table I shows the mean sound power levels and dynamic ranges for both Erhus sounding single notes, the music scale and the melody, respectively. The mean sound power levels cover a span of 60–93 dB. The lowest average level was observed for d^3 at *pp* level and the highest for the melody at *ff*. The dynamic range varied from 15 dB for the melody to 23 dB for the single note d^2.

There were no obvious differences between the dynamic ranges of the two Erhus in the low and middle register. However, Erhu A showed a much higher dynamic range of 20 dB for the d^3 note, while for Erhu B the value was only 12 dB. At this pitch, the highest sound power levels of both instruments were very similar, 76 dB. However, the minimum levels were not, 55 dB for Erhu A and 65 dB for Erhu B. This means that the particular combination of Erhu A and its player could perform at a much softer level.

3.2. 1/3 octave bands sound power levels

The sound power levels of each 1/3 octave band of Erhu A and Erhu B when the music scale is played are shown in Figure 2. From the figure some aspects of the general character of the Erhu as well as of the individual character of the two instruments can be seen. The sound radiation shows two main peaks in the ranges 500–800 Hz and 1600–2000 Hz. In the lower frequency bands (<500 Hz) and higher bands (above 2000 Hz), the sound power levels drop quickly. It can also be seen that the total sound power of the Erhu is contributed mainly by the bands between 500 and 2000 Hz. This applies to both instruments. The curves also show characteristics revealing the individual characters of each instrument. For example, the sound power of Erhu A in the higher frequency region at *pp* and *mp* levels falls off more quickly than that of Erhu B. This may indicate a special timbral character of the instrument.

Figure 2 shows that the envelope of the sound power spectrum of the Erhu is independent of dynamic level. Almost the same sound power spectrum can be seen at *pp* and *ff* playing, except for the obvious vertical shift in level. This is an important observation and suggests that the timbre of Erhu is largely independent of performing dynamics. Meyer and Angster [3] came to a similar conclusion in their sound power measurements of violins, also measuring in 1/3 octave bands.

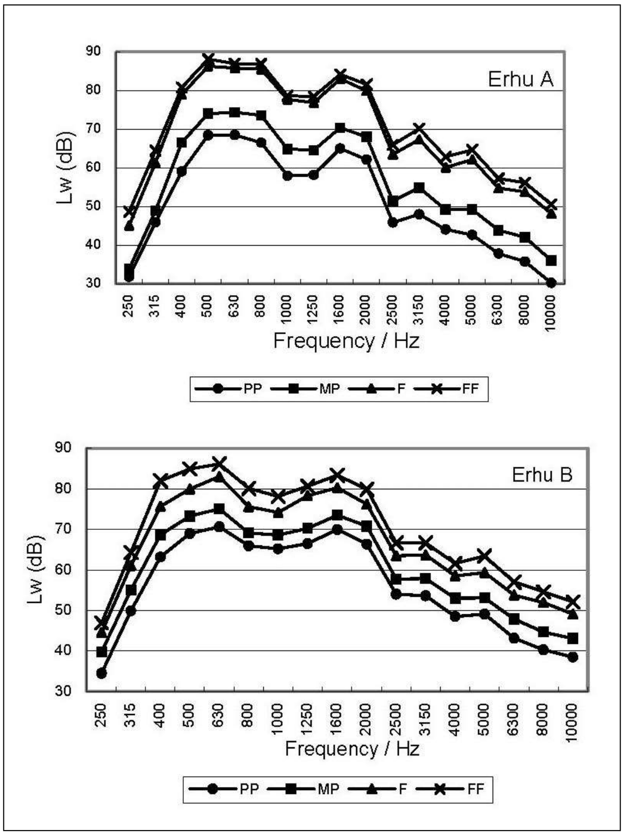

Figure 2. Sound power levels in 1/3 octave bands for Erhu A and B for a music scale performed at four dynamic levels (*pp, mp, f, ff*).

The sound power levels in 1/3 octave bands of both Erhus at *f* level for the three single notes are shown in Figure 3. The frequencies of the fundamental of d^1, d^2 and d^3 are 293.7, 587.3 and 1174 Hz and are located in the 1/3 octave bands at 315, 630 and 1250 Hz, respectively. There are three peaks in the sound power level curve of the d^1 note in the 1/3 octave bands 315, 630 and 1250–2000 Hz, indicating its overtone frequencies. For the d^2 note, two peaks appear in the 1/3 octave bands at 630 and 1250–2000 Hz, and for d^3 note only one peak appears in the band at 1250 Hz.

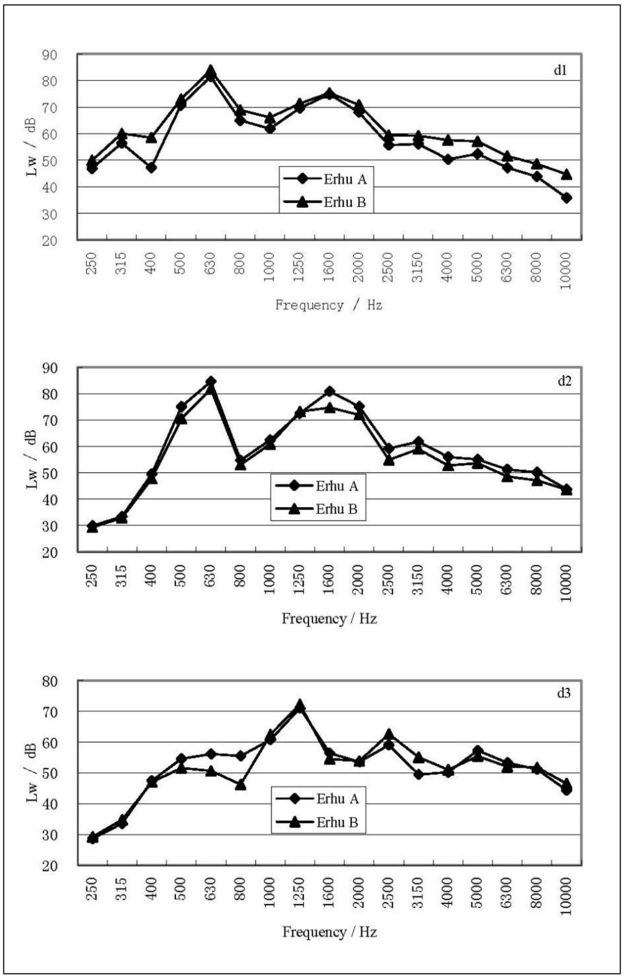

Figure 3. Sound power levels in 1/3 octave bands of Erhu A and B when three single notes (d^1 d^2 d^3) are performed at forte level.

4. Discussion and conclusions

In this study, the sound power level of Erhu has been thoroughly determined for the first time. The dynamic range and sound power levels in 1/3 octave bands at four prescribed dynamic markings (*pp, mp, f, ff*) were also obtained. These data are valuable as guidance or reference for loudness evaluation in concert halls, for sound insulation practice, as well as for sound recording and broadcasting and loudspeaker system design.

The sound radiation measurements also reveal some characteristics of the instrument. It was shown that there are no obvious differences between the dynamic ranges of the two Erhus in the low and middle register. Besides, the envelope of the sound power spectrum of the Erhu seems to be independent of the dynamic level. There are two peaks appearing around the 1/3 octave bands in the ranges 500–800 Hz and 1600–2000 Hz, respectively. The sound power of the Erhu is radiated mainly from the 500–2000 Hz bands. This means that the most sonorous playing region for Erhu is in the low and middle register. Compared with the low and middle frequency range, the sound power level in the high frequency region is reduced by about 10–13 dB. The timbre of the Erhu in the low register is full and not so bright. In the middle register, the timbre becomes soft, mellow and bright, and in the higher register the timbre is perceived as tenuous and tight. In the highest register, which rarely is used, it sounds quite sharp and feeble.

The reproducibility of the musicians' performances is decisive for the usefulness of the results. During a recording session, musicians can usually not immediately reach their best possible performance for a task marked by *pp* dynamics. Usually, when repeating the measurement a lower value of the *pp* level could be expected. In contrast, when playing at *f* level, the reproducibility is much higher. Considering that the forte level in a concert hall has a high correlation with the subjective sensation of spatial impression and source broadening, we suggest that the forte sound power level of performing a scale should be chosen as the most representative value of the sound power of an instrument. In the case of Erhu, the mean forte sound power level when playing a music scale can reach 90 dB. This value is very close to that of the violin, reaching 89 dB [3].

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