music motifs selected are solos played with the corresponding instrument. The subjects are from three groups: 9 audio technicians aged from 28 to 52 years old; 15 students that major in audio engineering aged from 19 to 21 years old; and 10 graduate students aged from 22 to 24 years old without special audio engineering experience and listening training. All subjects are with normal listening physiology.

The psychometric method used in the test is the constant-stimulus-method. The stimulus was played to the subjects in a random order. To avoid the complication caused by stereo and binaural listening, the music motifs were played to the subjects in monophonic style with headphone. The JND measured this way can be understood as the intrinsic JND of the subjects.

The JND was measured at the reverberation time of 1, 2, 3, and 4 seconds. Table 2 shows the standard stimulus and test stimulus used in this work. A digital reverberation processor was used to add reverberation to the anechoic music motifs. The frequency response of the reverberation processor was adjusted to flat for all test reverberation settings. For each comparison pair consisted of a standard stimulus and a test stimulus, the subject was asked to only answer which one is perceived more reverberant.

Table 2. Standard stimulus and test stimulus

Standard Stimulus(s.)	Test Stimulus (s.)										
1.0	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
2.0	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0
3.0	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5
4.0	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0

The confidence of test was investigated with the comparison of the consistence between the two repeated tests. The consistence of more than 60% was supposed to be acceptable. Among all subjects, 8 audio technicians passed the confidence test, 12 audio engineering students passed the confidence test, and 10 common students passed the confidence test.

The probability of the test stimulus that more reverberant than the standard stimulus was calculated. The test stimulus which is just more reverberant than the standard stimulus with the probability of 75% is labeled as the up limit of JND. On the other hand, the stimulus which is just more reverberant than the standard stimulus with the probability of 25% is labeled as the down limit of JND. The absolute reverberation JND is chosen as the middle point between the up and down JND limit.

Table 3 is the test result. The reverberation JND of the audio engineering students group is given for the three different music motifs played with different instruments. For comparison, the JND of the audio technicians group for Music A is listed in the table. The JND of the common students group for Music A and B is also given. Figure 1 shows the JND of Music A for the three different subject groups. Figure 2 shows the JND of the audio engineering student group for the three different music motifs.

Test 3. Measured reverberation JND for different subjects and different music motifs

Subjects	Instruments	JND at Different Standard Stimulus				Average
		1.0s	2.0s	3.0s	4.0s	
Audio Technicians	Music A	34.5%	22.5%	23.3%	26.3%	26.7%
Common Students	Music B	33.0%	25.8%	25.2%	27.8%	28.0%
	Music A	39.0%	22.5%	25.2%	21.2%	27.0%
Audio Engineering Students	Music A	32.0%	25.3%	26.2%	26.1%	27.4%
	Music C	27.0%	28.5%	26.8%	25.1%	26.9%
	Music B	31.5%	27.8%	26.3%	24.3%	27.5%

The reverberation JND of three groups at the reverberation time from 1 to 4 seconds with three different music motifs is from 21.2% to 39.0%. This is much higher than the JND measured by previous studies as showed in Table 1.

The systematic difference of JND is observed between different subject groups. This reveals that JND may be affected by the experience and professional training of the subjects. For the same subject group, there is slight JND difference for different music motifs. The group of students major in audio engineering has no special preference on instrumental music motifs used in this test. For this group, the JND difference due to the different instruments and different music motifs is insignificant. It may assume that JND measured in this work is basically physiological parameter, not affected by the content of the music and timbre of the instrument.

The factors that may cause bias in the test include: music motifs, subjects, reverberation processing method and psychometric method etc. Based on the observation of the test result, it is not difficult to find that music motifs and subjects affect the test result in a different way. The test materials used by other researchers [1][2][3] are different from that we used in

this work, as showed in Table 1. Only in Ref.[3], the music motif was used.

In Ref.[1] and Ref.[2], the constant-stimulus method was used and the JND measured is 75% JND. The test materials in these two tests were not music motifs. The JND measured in these two tests is smaller than JND measured in this work. In Ref.[3], the minimum-variation method was used to get the JND of operational definition. In the test of this work, the subjects were asked to make only two judgements, therefore, the JND measured in this work is not the JND of operational definition. It is the 75% JND. In order to compare the test result in this work with JND of operational definition measured by other researchers, a supplement test was carried out to measure the JND of operational definition with the same audio engineering students group and the same music motif A. The psychometric methodology is the minimum-variation method. The subjects were asked to make three judgements on the test stimulus when they listened to the standard stimulus and test stimulus: more reverberant, less reverberant, and equal reverberant. In the test, the up bound of the equal area is defined as the stimulus that is more reverberant than the standard stimulus with probability of 50%. The down limit is defined as the stimulus that is less reverberant than the standard stimulus with probability of 50%. Among 15 subjects, 7 subjects passed the confidence test. The measured JND of operational definition is listed in Table 4. For comparison, the probability in the two-judgements-method that corresponding to the same JND is also listed in the table. From Table 4, it can be seen that the JND of operational definition is the same as the 63.7%—70%(average 67%) JND measured with constant-stimulus-method. Even though, the 67% JND measured with constant-stimulus-method is 13%--17%. This is still higher than the result listed in Table 1.

In Ref.[1], [2], [3], the JND were measured at the reverberation time below 1s. In this work, the JND were measured at the reverberation time of more than 1s because the application consideration is above 1s. But, even at 1 sec. the JND measured in the work of this paper is much higher than that by other studies. The reliability of the test in this paper is confirmed by a series of supplement test[4]. Without the problem on the reliability of the tests, a question is raised: why the JND of reverberation measured in the work of this paper is so much higher than it is used to be cited.

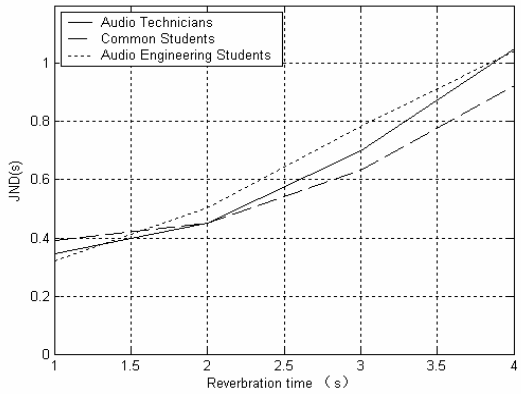

Figure 1. JND for different subjects

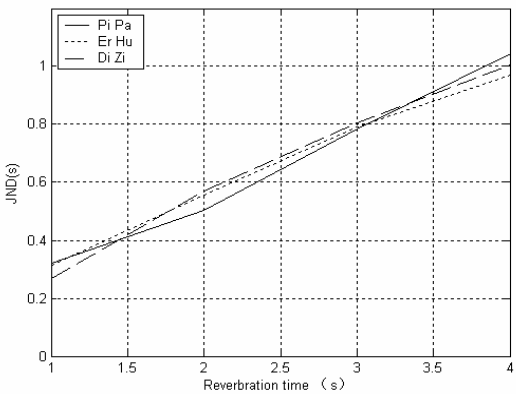

Figure 2. JND of different music

Table 4. JND measured with operational definition and comparison to the result with two judgements method

Standard stimulus	Operational JND with minimum-variation method	Corresponding probability at the equivalent JND in two judgements test with constant-stimulus method
1s	0.18s	70.0%
2s	0.26s	65.6%
3s	0.37s	65.8%
4s	0.57s	63.7%

IV. TEST ON JND OF NOISE LENGTH

To search the answer to the question raised above, and study the true meaning of the result by Seraphim, a test was arranged to measure the JND of the length of white noise with the length from 0.3 to 8 seconds. The noise level was kept constant within a rectangular window. The test procedure is basically the same as that in Seraphim's test except the clue to judge the length of noise. In Seraphim's test, the subjects judged the length of noise based on the duration of the noise before it decayed into the background noise level. While in this test, the subjects judged the length of noise directly from the duration of the noise itself.

Table 5 lists the JND of white noise length for male and female students respectively. The JND for all students is also given. There is no significant difference between male JND

and female JND. It can be seen that all data are below 10%, and very close to the data of Seraphim's test. Although the clue to judge the duration of the noise is different from the clue used in the work of this paper, but JND of 'reverberation' measured by Seraphim is nearly the same as the JND of noise length measured in this paper. Therefore, the data given by Seraphim should not be cited as the JND of reverberation. In fact, it is the same as the JND of noise length.

The result of a psychological test may be affected by the environmental conditions and factors. Since Seraphim's test was conducted decades ago with a different environmental condition as the test in this paper, a test was designed in this paper to check whether the environmental conditions affect the test result significantly. Table 6 and Table 7 are the JND measured at 2 seconds with the continuous stimulus and synchronal visual stimulus respectively. The visual stimulus was produced using a projector. The continuous visual stimulus is the pure color on the screen lasting in the whole duration of the test. The synchronal visual stimulus is the same as the continuous visual stimulus, but the projector switch was synchronized with the test sound. When the noise was turned off, the screen was black. The subjects were asked to stared at the screen during the test. From Table 6 and Table 7, it can be seen that although visual stimulus affects the JND of male and female subjects somewhat differently, it does not change the JND significantly. Therefore, the test environment does not make important sense to the test reliability.

Table 5. JND of white noise length

standard stimulus	0.3	0.5	1	2	4	8
all	7.58%	8.54%	7.59%	6.09%	8.11%	5.96%
male	7.49%	8.14%	7.62%	6.13%	8.13%	5.66%
female	7.62%	8.84%	7.57%	6.25%	8.10%	6.05%

Table 6. JND of white noise with length of 2 seconds and continuous visual stimulus

visual stimulus	no	red	green	blue	yellow
male	6.13%	6.16%	6.02%	5.67%	6.24%
female	6.25%	5.92%	5.21%	5.21%	5.09%

Table 7. JND of white noise with length of 2 seconds and synchronal visual stimulus

visual stimulus	no	red	green	blue	yellow
male	6.13%	6.28%	6.06%	6.28%	7.71%
female	6.25%	5.72%	5.53%	5.81%	5.83%

V. CONCLUSIONS

Based on the a series of test, it found that JND of reverberation perception has been misunderstood for a long time. The reverberation perception of human should be experienced through the listening of sound (speech, music, etc.) in an enclosed space with a definite reverberation time. The JND of reverberation time given by Seraphim is not the JND of reverberation perception. Actually, it is the same as the JND of the length of white noise.

The JND of reverberation perception measured for Chinese subjects with Chinese music motifs in the work of this paper is around 26% on the average. It is much higher than that it is used to be cited as 5% to 10%. The reliability investigation verifies the result of this paper. But, whether different race and music culture may affect the perception of reverberation that based on listening of music has not been known. Further test study is needed to explore this issue.

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