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Effect of Different Types of Noises on Chinese Speech Intelligibility of Children in Elementary School Classrooms

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Summary

For investigating the effect of noise type on Chinese speech intelligibility of children, subjective listening tests were performed with 5 different types of noises (the impact noise, traffic noise, fan noise, Chinese speech-shaped noise and babble noise). The listeners were children in grades 2, 4 and 6 (7–8, 9–10 and 11–12 years old respectively). The experiments were carried out in two classrooms of different reverberation times (RT, 0.8s and 1.3s), under two signal-to-noise ratios (SNR, 0dB and 10dB). The speech intelligibility scores rise with the decreasing of RT and increasing of SNR and grade. The scores vary among different noise type under the same RT, SNR and grade. The impact noise has the highest intelligibility scores among all the noises for the both reverberation conditions, and the speech-shaped and babble noises result in lower scores than other noises. In general, the lower the grade is, the larger the increase of intelligibility score is with the increase of SNR. The largest score improvement occurs for the cases of babble noise. The scores of lower grades are more affected by the noises, especially by the speech-shaped and babble noises in the longer RT.

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1. Introduction

In daily communication among teachers and students in elementary school classrooms, noises will interfere and mask the speech, hampering sound information exchange between children and teachers. Researches showed that excessive noises can degrade the reading ability of children [1]. Furthermore, long-term exposure to excessive interfering noises is detrimental to the development of their memory [2]. Bradley conducted subjective tests of speech intelligibility in an anechoic chamber, by reproducing simulated in-door speech and interfering noises [3]. The results showed that room reverberation and signal-to-noise ratio (SNR) could affect speech intelligibility. The background noises along with reverberation time (RT) can decrease the speech intelligibility in rooms even further.

There could be various types or sources of classroom noises. Hodgson made a noise survey in Columbia university, where he found the activity of teachers and students was the primary sources of noise and equipment the secondary ones [4]. Shield and Dockrell made a comparison of outdoor noises among 142 schools in London [5]. They also compared indoor noises of 16 classrooms among

these schools. Among all types of the noises, they found that the noise of air-conditioners was the most prominent one. In China, during the 1980s, Wang carried out a survey on schools in Shanghai and Nanjing. He found that among all the outdoor noises, the traffic noise was the most prominent one [6]. Shield and Dockrell made an experiment on speech intelligibility of children at the ages of 7 to 11 in classrooms [7]. They found that the negative effect of outdoor noises was larger than indoor noises and the children were easily affected by impact noises. Polich reported that low-frequency noise was easier to degrade speech intelligibility than other noises except the speech-shaped noise [8]. Astolfi made some speech intelligibility tests with 983 students from 3 elementary schools in Italy [9]. She obtained the relationship between the subjective intelligibility scores and several objective parameters including SNR and STI. Lee and Jeon investigated the interference effects of combined noises on speech transmission in a simulated open public space. They pointed out that word intelligibility scores were affected by the temporal characteristics of construction noise due to fluctuations in the background noise level [10].

Chinese has several different aspects from many other foreign languages. For example, it includes tones. When the speech intelligibility in a room is fine for a western language, it may be not for Chinese [11]. Peng explored the

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impacts of three different types of interfering noises on the Chinese speech intelligibility and found that the masking effect of the noise on speech heavily depends on the noise spectrum [12]. He further compared the children's ability of recognizing syllables between low-frequency noise and white noise. The results showed that the ability was lower in the former condition [13]. Zhang also pointed out that the frequency range of the noise had a significant effect on Chinese speech intelligibility [14].

The majority of researches on speech intelligibility of Chinese were specific to adults so far. However, the hearing function of children develops along with their age, and gradually reaches the level of adults until they grow up to 13–15 years old [15]. In this paper, the effects of 5 different types of noises on Chinese speech intelligibility of children from Grade 2, 4 and 6 were explored. The experiments were carried out in two classrooms of different RTs under two SNRs. The tested noises were the impact noise, traffic noise, fan noise, Chinese speech-shaped noise and Chinese babble noise, which were chosen on basis of daily experience. This study was made in Guangzhou city in the south China. In such a subtropical area with very hot and wet climate, nature ventilation by fully opening the windows, as well as mechanical ventilation by use of electric fans, is very important and often needed for the healthy purpose during the daily use of the classrooms. And therefore heavy noise pollution from outside is often inevitable. The seats near the open windows are normally favorable for better ventilation but face the most severe direct outdoor noise, where the building façade works very poor from the view angle of noise insulation, providing very limited attenuation and change in the outdoor noise level and spectrum in the worst situation. The traffic and construction noises are the typically encountered outdoor noises in this area. And the fan noise, as well as noises caused by human talking, is the typical indoor noise.

2. Experiments and methods

Subject testing is conducted for each listening position using Mandarin Chinese test word lists as specified by SJ2467-84 [16] (which followed international standard ANSI S3.2-1969 as a Chinese version). Generally, Chinese speech sounds like a flow of subsequent monosyllabic words, each word composed of a starting consonant and a following vowel. The speech lists used in the tests are made up of word rows and each row contains 5 monosyllabic words of an identical vowel but different consonants, for example (in pinyin), “hao, sao, gao, zao” and “kao”. For each row, a target word was uttered and the listener was asked to mark the word in the row which he believed to have heard. The target word is embedded in a carrier sentence as “the $\times$ row reads —”, where the “ $\times$ ” represents row number and “—” represents the target word. In fact, the key for the listener is to identify the correct consonant, which is normally characterized by middle and high frequency components of sound. All test words embedded in carrier sentence for each list were recorded at the rate of

four words per second and 65 dB sound pressure level by a male speaker using an omnidirectional instrumentation-grade microphone at a distance of 0.5 m from the speaker in an anechoic chamber.

The impact noise was the piling sound recorded at a building construction site. The traffic noise was recorded near a high way at the time with a quite stable and dense traffic flow. There were about 45 cars per minute with an average velocity about 60 km/h. The fan noise was obtained in an empty classroom (in fact the classroom B introduced below) with an electric fan installed there working at its normal condition. A wind capped microphone was put 0.8 meter below the fan, while the reverberation radius of the room being about 1.2 meter. The babble noise is the mixture of talks of 6 pupils including 3 males and 3 females, since the babble noise of 6 talkers may cause most obvious masking effect on Chinese language than other talker numbers according to some previous researches [17, 18]. The Chinese speech-shaped (CSS) noise was obtained by filtering steady white noise using a filter with a long term spectrum of Chinese speech signals. The sampling rate of all these signals is 44.1 kHz. Figure 1 plots the signals together with different relative levels and sampling rate 10 Hz to illustrate their temporal features. The one-third octave band spectra of these noises calibrated with a same A-weighted level (70 dBA here) are shown in Figure 2. It can be seen that the spectra of speech-shaped and babble noises are close to each other on almost all frequency bands, although the temporal patterns of the two noises are far different, the former being steady but the latter fast-fluctuating. By the way, the spectrum of the speech-shaped noise is exactly that of the long term speech signals. In the frequency range above 5000 Hz, the speech-shaped and babble noises have obviously higher level than the other three, namely, the impact, traffic and fan noises. The traffic and fan noises recorded in this test are quite steady noises with minor fluctuations, the spectra of them being very close to each other in the frequency range below 5000 Hz while the level of the traffic noise being lower than that of the fan noise on the bands above 5000 Hz.

Two rectangular classrooms, Room A and B as sketched in Figure 3, were selected from elementary schools for the experiment, whose dimensions are 8.60 m (length) $\times$ 6.15 m (width) $\times$ 3.25 m (height) and 9.35 m $\times$ 7.80 m $\times$ 3.70 m respectively. The classrooms are simply decorated without special acoustical treatment. The floors are paved with ceramic tiles. The brick walls and concrete ceilings are smoothly plastered. During the experiment, the glass windows and wooden doors were closed to prevent outside interference, making the background noise level below 45 dBA. In each classroom, a main sound speaker near to the front wall and a receiver at rear part of the room were located on the longitudinal central room axis, and a pair of assistant sound speakers symmetrically installed at the two corners of the front wall. The main sound speaker was used for providing speech signals while the assistants for the interfering noises. The acoustical parameters measured at the receiver position in each room using impulse

Table I. Objective acoustic parameters at listening positions in two classrooms, for the denoted octave bands.

Room		125	250	500	1k	2k	4k	8k	Mean
A	RT/s	1.09	1.12	0.86	0.80	0.79	0.75	0.57	0.83
	EDT/s	1.22	0.84	0.94	0.94	0.77	0.68	0.58	0.94
	C_{50} /dB	-6.25	1.95	-0.07	-0.90	2.29	2.38	5.38	0.93
	C_{80} /dB	0.91	4.23	3.23	2.43	5.98	6.69	9.30	4.58
B	RT/s	1.81	1.58	1.34	1.25	1.21	1.12	0.89	1.30
	EDT/s	1.73	1.30	1.26	1.32	1.17	1.20	0.88	1.29
	C_{50} /dB	-10.07	-3.11	-2.09	-1.57	-1.00	-0.49	4.02	-1.29
	C_{80} /dB	-6.91	-0.35	1.17	1.21	2.32	3.74	4.31	2.11

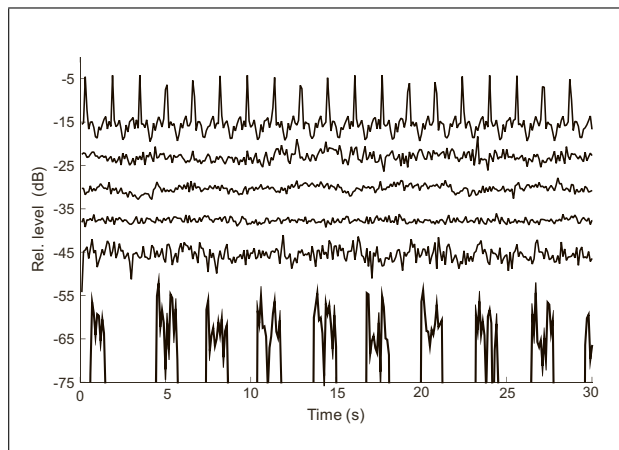


Figure 1. Relative overall level pattern vs time sampled every 0.1 s of the noises, namely the Impact, Traffic, Fan, CSS and Babble noise ordered from top to bottom.

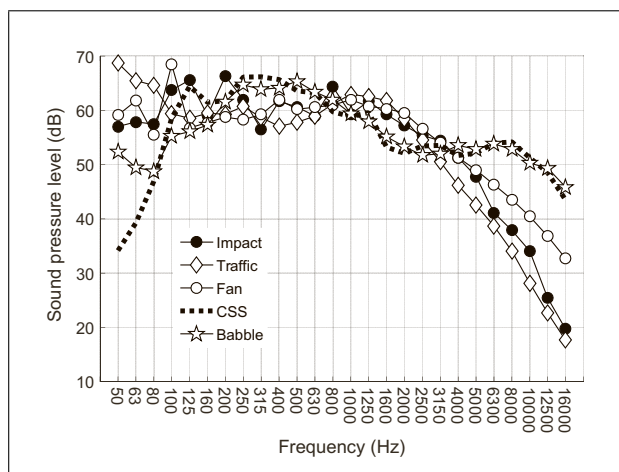


Figure 2. Spectrum shapes of the noises with same A-weighted level.

response technique, including $RT(T_{30})$, EDT, C_{50} and C_{80} , are listed in Table I. The mean values of RT and EDT were calculated from 500 Hz and 1 kHz octave bands, and those of C_{50} and C_{80} from 500 Hz–4 kHz octave bands. Represented by their RT values of 0.83 s and 1.30 s, Room A and B have significantly different reverberation conditions. By the way, the RT value near 0.8 s were suggested by Houtgast *et al.*, as the optimal for resisting the noise in-

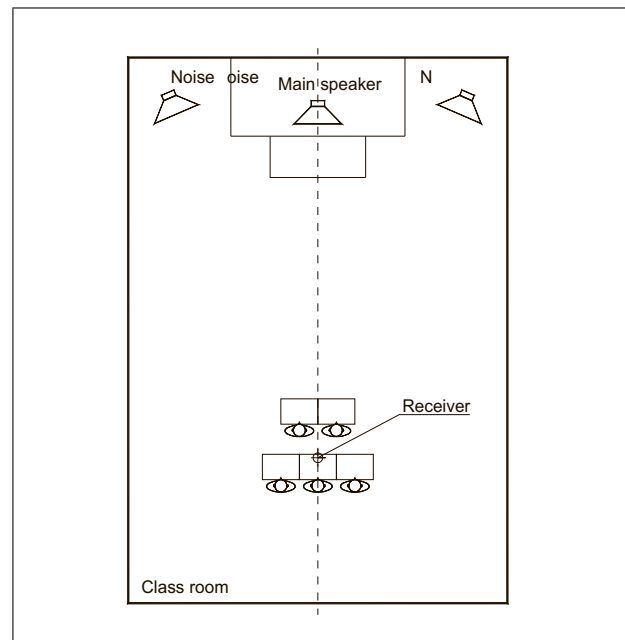


Figure 3. Schematic drawing of listening setup.

terference in speech communication in rooms [19], and the value near 1.3 s is normally regarded as the upper limit for speech dominated drama in Chinese theater design standard [20].

The speech signals were reproduced through the loudspeaker JBL-LSR6325P, with human directivity, at the middle of the rostrum in the classrooms, 1.5 m high. The SPL of speech signals were tuned as 70 dBA at the receiver. The interfering noises were reproduced through a pair of loudspeakers 1.5 m high at the front corners of each classroom symmetrically. Two SNRs, 0 and 10 dB, were used for the test. The percentile sound levels L_{10} , L_{50} and L_{90} of the noises and a typical speech signal (with the silent intervals excluded) are listed in Table II for SNR of 0 dB.

The listeners were 60 children from three grades, grade 2 (7–8 years old), 4 (9–10 years old) and 6 (11–12 years old), who all speak Chinese well and have no known hearing problems. For every listening condition, 5 children from the same grade took the test with each child finishing 2 different lists, and the score was decided by the mean value of them.

Table II. Percentile sound levels of the noises and speech signals at L_{eq} 70 dBA.

	L_{90}	L_{50}	L_{10}
Impact	65	69	75
Traffic	69	70	71
Fan	69	70	71
CSS	70	70	70
Babble	68	70	71
Speech	61	67	74

3. Results and discussions

The speech intelligibility scores of 60 combinations of two RTs, two SNRs, five types of noises and three grades are shown in Figure 4.

Multi-factor analysis of variance shows that the factors of RT, SNR, Age and Noise type all have significant effect on the scores ($P < 0.001$). The F values of the single factors exhibit a descendent order $SNR > RT > Noise\ type > Age$, implying the important influence of SNR. Table III gives the results of the Multi-factor analysis of variance, where the factors with significant effect are marked with mark *. In general, the scores appear to be positively related to SNR and age but negatively related to RT.

At the level $SNR = 10\text{ dB}$, the scores of all the types of noises are nearly over 90% for $RT = 0.83\text{ s}$ and 80% for $RT = 1.30\text{ s}$. The score differences between the grades are narrow for the fan, speech-shaped and babble noises. For those 3 noises, generally higher grades get higher scores, or in other words the younger pupils are less able to resist the noise interference. For the impact and traffic noises, the score differences between grades are even smaller. The largest score difference between the types of noise is less than about 7% in the conditions of $RT = 0.83\text{ s}$, and expands to about 12% when RT becomes longer to 1.30 s. When SNR drops to 0 dB, along with the decreasing of the score for every type of the noise and each grade, the score differences between the grades and types of noise obviously become larger, and the trend of score declining is more obvious.

For each grade, the scores in impact noise are the highest among all the noises under the two reverberation conditions. An important reason might be the temporal property of the impact noise. The dynamic range of the impact noise in time domain is very large. During about every 1.6 s, there is a strong impact sound of only 0.08 s, whose sound pressure level is 11.4 dB higher than that in the rest time range. That means, for example, when the overall SNR was 0 dB, in only 1/20 of the time were the listeners affected by an actual SNR of -9.4 dB and in the rest time they had an actual SNR of 2 dB. Moreover, children appears to be able to take advantage of listening in the gaps of impact noise, where its level is low, to overcome some linguistic confusions[21]. In addition, some other research showed that the shorter the time in which

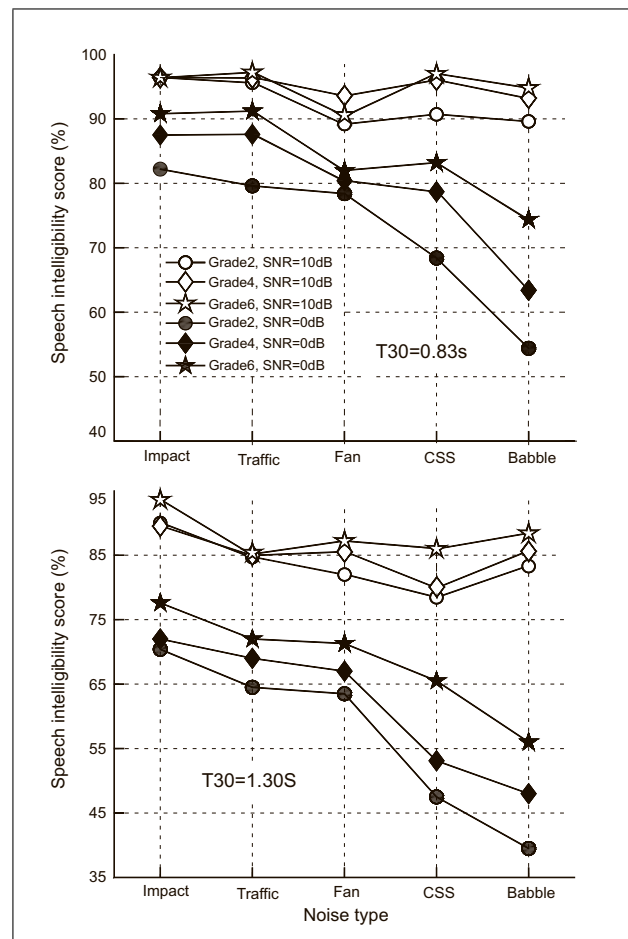


Figure 4. Intelligibility scores under different T30, SNR, grades and types of noise.

Table III. ANOVA of the factors RT, SNR, Noise type and Age. Dof: Degree of freedom.

factor	Dof	F	P
RT	1	550.464	<0.001*
SNR	1	1317.464	<0.001*
Age	2	68.116	<0.001*
Noise type	4	90.720	<0.001*
RT×SNR	1	54.162	<0.001*
RT×Noise type	4	7.984	<0.001*
SNR×Age	2	18.595	<0.001*
SNR×Noise type	4	51.945	<0.001*
Age×Noise type	8	3.477	0.001*
RT×Age	2	1.881	0.153
RT×SNR×Age	2	0.246	0.782
RT×SNR×Noise type	4	0.294	0.882
RT×Age×Noise type	8	0.791	0.611
SNR×Age×Noise type	8	1.103	0.360
RT×SNR×Age×Noise type	8	0.202	0.990

the masking noise level surpasses speech, the weaker the noise's masking effect [10]. As a result, high scores were achieved since a high actual SNR was kept for a long time in cases of impact noise.

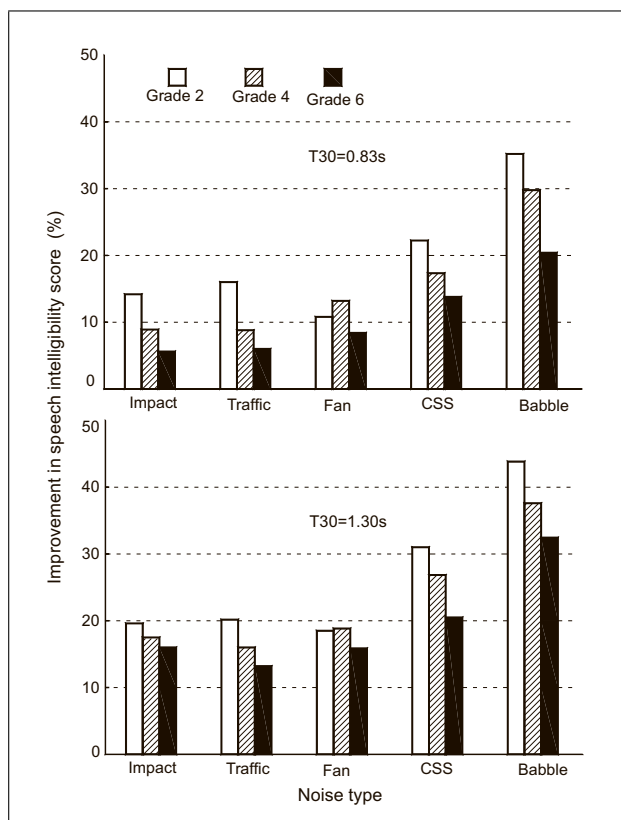


Figure 5. Score improvements as SNR increasing from 0 to 10 dBA.

When the SNR is 0dB, the scores of speech-shaped and babble noises are lower than that of the other three noises. From Figure 2 it can be seen that when the A-weighted sound pressure levels are the same, the speech-shaped and babble noises have extremely similar frequency spectra (which is also similar to that of speech signals). At high frequency (>3 kHz), the sound pressure level of the speech-shaped and babble noises are obviously higher than the other three noises, leading to a more effective shelter to speech signals [12]. Carhart pointed out that the babble noise with over four voices could cause more masking than that of steady-state noise, although the informational masking was found in his study to reach its maximum at three-voice-babble and thereafter decrease [22], which reflected the complex effects of the combination of energetic and informational masking. The other noises cause almost only energetic masking. And although the impact noise is not a steady one, it has the lowest L_{90} and L_{50} values among all the noises, as shown in Table II, and therefore causes less masking relatively. These factors could result in that the babble noise were lowest for SNR = 0 dB conditions.

For each grade, as SNR increasing from 0 to 10 dB, the scores increase for all the types of noise and the two reverberations with various amounts (Figure 5). The largest improvements of the scores occur for the cases of babble noise. Generally, for each type of noise under each reverberation condition, the lower the grade the larger the increase of intelligibility score, with only one exception

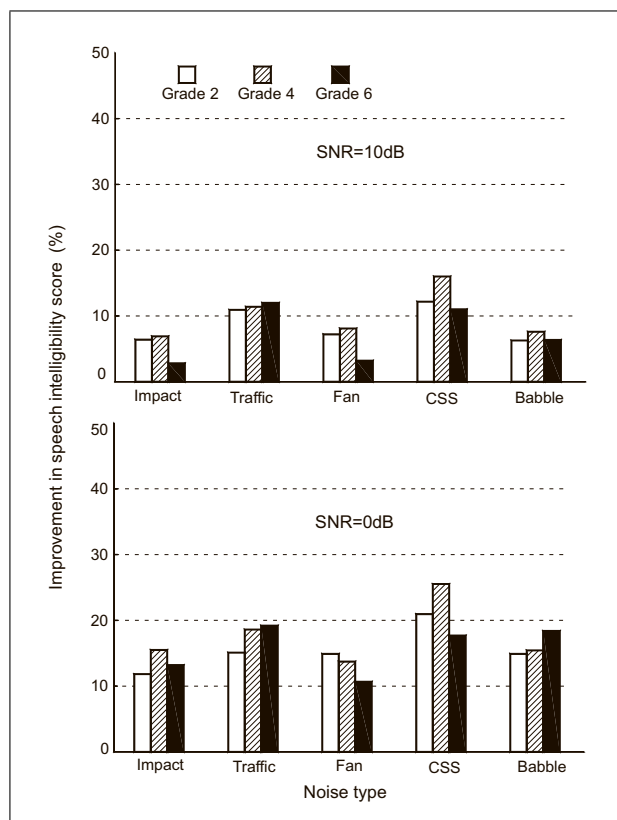


Figure 6. Score improvements as RT decreasing from 1.30 s to 0.83 s.

that the increase of grade 2 is a little smaller than grade 4 for the fan noise. It is easier to understand if noticing that the scores of higher grades are already larger than those of lower grades, leaving less room for further improvements. Another observation is that the improvements for the speech-shaped noise and babble noises are comparatively larger than the other noises under each reverberation condition. In other words, the scores of lower grades are more affected by the noises, especially by the CSS and babble noises in the longer reverberation condition.

Score improvements as RT decreasing from 1.30 s to 0.83 s are shown in Figure 6. There are no obvious systematic trends in Figure 6, except the improvements are generally a little larger in cases of SNR = 0 dB than 10 dB. Firstly, the score increases in the cases of speech-shaped noise and babble noises are not comparatively larger. It means that the effects of the two factors, SNR and RT, on the masking performance of the speech-shaped and babble noises are different. Secondly, for different noises, the increases of scores do not show systematic trend among the grades. So if we ask which measure, enhancing SNR or dropping RT, is more effective for improving speech intelligibility for children in classrooms, the answer is it depends on the levels of the two factors. However, at the like SNR and RT levels studied here, increasing SNR should be the first concern for that purpose, shown by the experiment results.

The standard deviations (SD) of the speech intelligibility scores are separately displayed in Figure 7 to show the

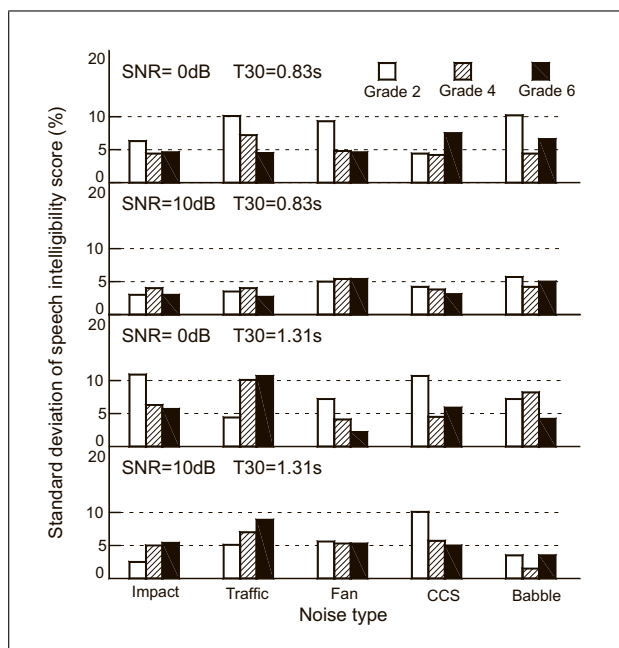


Figure 7. Standard deviation of intelligibility score.

scattering of the data (Figure 4 has already contained too many data, which might seem messed up if the SD bars were added on). The SD values of all the 60 cases are below 11%; most of them below the level of 5%. As expected, the SD values in a poorer listening condition generally are a little larger. For example, we compare the condition of $RT = 0.83$ s and $SNR = 0$ dB with that of $RT = 0.83$ s and $SNR = 10$ dB. In the latter condition nearly all the SD values are below the level of 5% while the SD values of some cases in the former condition reach the level of about 10%. The scores of Grade 2, namely the youngest children who have the most number of cases whose SD values reach 10% level, show a larger scattering than the other two grades. There is an interesting detail observed that the SD values of Grade 2 and babble noise are larger in the cases of the short reverberation time 0.83 s than in the longer $RT = 1.30$ s. The reason might be that in short RT, the content of the babble is more aurally discernible and therefore more distractive masking, especially for the youngest children to overcome.

On the speech intelligibility of Children in noise, most former researches were made under some single noise condition, for example, babble [15], speech shaped noise [23] or natural background noise in classroom [24, 25]. Because the listening conditions are quite different, it is difficult to make comparison among those researches. Lee and Jeon evaluated speech intelligibility scores by adults under traffic (stationary) and construction (impulsive) noise exposures in an open public space [10]. Due to the differences in factors of age, reverberation condition, language and noise property, it is difficult to directly compare their scores with that of this paper. However, the trends are similar that the scores rise with increasing SNR. Perhaps a comparable case is the research of Astolfi, et, al. They studied the Italy speech intelligibility of Children

under four noises (babble, impact, traffic and fan noises). However, they did not give detailed reverberation times and signal-to-noise ratios but only the relations between the speech intelligibility scores and STI values. Generally speaking, more scientific and systematic comparison perhaps could be made in future with more accumulated researches.

It is also noted that the SPL of speech signals were fixed in 70 dBA at the receiver. Teacher's voice level raised due to the heavy noise environment and the facade attenuation was not considered in the present study.

4. Conclusion

In order to explore the influence of various interfering noises on Chinese speech intelligibility of children, subjective listening test was made in two classrooms of significantly different RTs (0.83 s and 1.30 s) at two different SNRs (0 dB and 10 dB). Five types of interfering noises were used, which were the impact, traffic, fan, Chinese speech shaped and babble noises. The subjects were children from grade 2, 4 and 6 (7–8, 9–10 and 11–12 years old respectively).

The experiment results show that generally the scores appear to be positively related to SNR and age but negatively related to RT. The masking effect of speech shaped and babble noises is higher than the other three types of noises, especially in cases of longer reverberation. And with the longer RT, the score improvements are larger when SNR increases from 0 dB to 10 dB. The cases of babble noise have the largest improvements and cases of speech shaped noise the second largest. According to the experiment results, at the like levels of RT and SNR, increasing SNR might be more effective to help improve speech intelligibility than decreasing RT.

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