PAN
ARCHIVES OF ACOUSTICS
Vol. **43**, No. 1, pp. 123–128 (2018)

DOI: 10.24425/118087

The Effects of the Noise and Reverberation on the Working Memory Span of Children

Peng JIANXIN, Jiang PENG

School of Physics and Optoelectronics
South China University of Technology
Guangzhou 510640, China; e-mail: phjxpeng@163.com

(*received May 20, 2017; accepted September 1, 2017*)

Three different reverberation time (RT) conditions were obtained by room acoustical simulation. The working memory span of grades 3 (8 to 9 years old) and 6 children (11 to 12 years old) was tested under these reverberation conditions with different signal-to-noise ratio (SNR) by headphone reproduction in a quiet classroom. The working memory span scores (WMSSs) were obtained under the different RTs and SNRs conditions. The results demonstrated that children's age, RT and SNR had significant effect on children's WMSSs. With the increase of SNR and the decrease of RT, the WMSSs increased gradually. Under the same SNR and RT condition, the children's WMSSs were increased with the increase of their age. Multiple linear regression analysis shows that children's WMSSs are related to age, RT and SNR, and the correlation coefficient is 0.99.

Keywords: reverberation time; signal-to-noise ratio; working memory span; children.

1. Introduction

Working memory span (WMS) is a measure of the capacity of individual working memory units, and reflects the storage capacity and processing efficiency of working memory (Conway *et al.*, 2005). Working memory is of great significance in advanced cognitive activities such as verbal comprehension, problem solving, reasoning and learning. Baddeley and Hitch (1974) proposed a multi-component working memory model through experimental investigation. They thought that while working memory originates from short-term memory, it is not equivalent to short-term memory.

The classroom is an important place where children acquire knowledge. They not only listen to what teachers say in the given moment, but also need later to remember what was said. The effect of excessive noise and reverberation do not only restrict children's hearing of the words that are spoken but also interfere with the working of their memory in the classroom (Klatte *et al.*, 2002; Dawna *et al.*, 2014). If the critical effect of noise and reverberation is that word identification requires a larger part of the available working memory resources, it can be argued that people with a low working memory capacity are especially vulnerable to conditions of noise and reverberation. Kjellberg (2008) measured the subject's reading breadth in experiments where noise affected vocabulary memory, finding that WMS (reading span) was significantly correlated with the vocabulary memory score. The higher the WMS of subjects under conditions of noise, the higher their score in terms of memory vocabulary (Pichora-Fuller *et al.*, 1995; Surprenant, 1999; Sorqvist *et al.*, 2014; Sullivan *et al.*, 2015; Marrone *et al.*, 2015). The working memory model presented by Baddeley (2003) confirmed the important role of WMS in verbal understanding and memory. Ljung *et al.* (2013) further investigated the WMS of 35 undergraduates under four signal-to-noise ratios (SNRs). The results showed that the memory performance of the high WMS group was not affected by an increase in noise, but that the memory performance of the low WMS group increased with a linear increase of noise.

Ljung and Kjellberg (2009) explored the effects of reverberation time (RT) on WMS using the adult memory span test. Their results indicate that a long RT impaired memory with relation to speech information. Compared with short RT conditions, the number of words remembered by the adults in the study under long RT conditions was small, and the error rate was also high. Beaman and Holt (2007) presented visual stimuli in memory tasks and indicated that a long reverberation can reduce the effect of "unrelated sound effects" by attenuating noise and its variability. However, their results do not have practical significance since they performed the test under a 5 s RT condition. This is compounded by the fact that Perham (2007) conducted a similar study with RTs of 0.7 s and 0.9 s, and did not reach the same conclusions. Klatte *et al.* (2011) explored the effects of reverberation on short-term memory under different types of noise conditions, finding that both pink noise and indoor noise affected subjects' memory score, and that memory scores within a quiet environment were much higher than those under conditions of non-correlated speech noise in the same room with a long reverberation time.

Although some of the above studies have investigated the effects of reverberation and noise on WMS under fixed SNR, the effects of variable SNR and variable RT on children's working memory are rarely reported. In the current study, room impulse responses with different RTs were obtained using acoustic modeling method in a rectangular classroom. The WMS of children of different ages was evaluated under different RT and SNR conditions. In light of this argument, the aim of the current paper is to explore the effects of noise and reverberation on the WMS of children of different ages.

2. Experimental method

2.1. Simulation of room impulse responses

In this paper, a classroom of $8.4 \times 7.7 \times 3.9$ m^3 was used as the model, and acoustical simulation software (ODEON) was used to obtain different test conditions for RT. The classroom model is shown in Fig. 1. In the model, the walls was plastered brickwork and ceiling was plastered concrete for condition A (see Table 1). There were two glass windows in each sidewall and two wooden doors in one sidewall. The floors were covered with ceramic tiles and the student's area had wooden desks and chairs. The sound source "S" is located in the middle of the podium, 1.0 m away from the blackboard; the listening position "R1" is 4.6 m away from the sound source. The three room impulse responses with different RTs (0.51 s, 0.80 s, 1.18 s, which corresponds to conditions C, B and A in Table 1, respectively) in the 500–1000 Hz octave band were obtained by changing the sound-absorbing material arrangement of the walls and ceilings in the classroom. The objective acoustical parameters such as the early decay time (EDT), RT, and the definition (D50) of the 500–4000 Hz octave band which were calculated from the simulated room impulse response, are shown in Table 1.

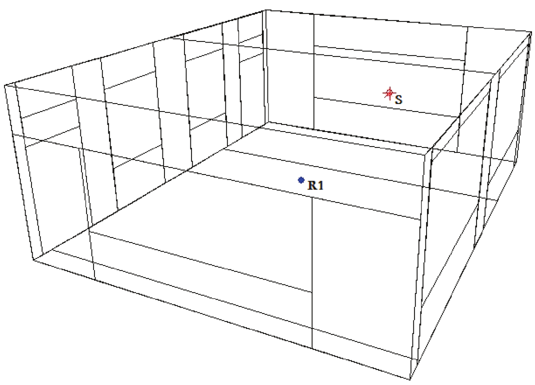

Fig. 1. The classroom model and the sound sources and listening positions in the model.

Table 1. Objective acoustical parameters for three room impulse responses.

Conditions	EDT [s]	RT [s]	D_{50}
A	1.19	1.18	0.54
B	0.69	0.80	0.69
C	0.36	0.51	0.86

2.2. Subjects

Third and sixth grade children were randomly selected from a primary school in Guangzhou City for the study. Third grade children were eight to nine years old, and sixth grade children were 11 to 12 years old. 90 children were selected for each grade, totalling 180 for the study. All students who participated in the test were able to understand and speak standard Mandarin Chinese and no hearing problems were reported by them and their parents.

2.3. Working memory span test

A measure of working memory span was used to evaluate children's working memory span through test programming, edited by one of the current authors using psychological and behavioral experiment software, E-Prime (Turner, Engle, 1989; Unsworth *et al.*, 2005). To obtain test speech and noise signals, two-syllable words signals recorded in the anechoic chamber and speech-shaped noise based on the average speech spectrum of all test words were convoluted with the room impulse response of 0.51 s, 0.80 s and 1.18 s RT respectively, and then mixed with the varying SNR (3 dB(A), 9 dB(A) and 15 dB(A)) using Cool Edit Pro software. The test speech and noise signals were then reproduced through Sennheiser HD-580 headphones in a $8.60 \times 6.15 \times 3.25$ m^3 empty classroom where the background noise level was less than 40 dB(A) during the test. A total of nine (three different RT and three different SNR) conditions were tested.

Considering the limited literacy and reading comprehension levels of younger children (aged eight to nine years), all test words are selected from primary Chinese textbooks in the lower grades and were also ones used frequently in daily life, to avoid the effect of unfamiliar and complex words on children's test results. The addition and subtraction operations of two integers within 10 were used in the test. The number of additions and subtractions for each test was halved, and their right and wrong were also halved. Each arithmetic question was followed by a double syllable word. The test was performed in the order of two arithmetic expressions and two double syllable words in each line, to six arithmetic expressions and six double syllable words. A total of six groups in which there were three lines with the same number of test questions (arithmetic expressions and double syllable words) were presented. Prior to the test, an additional two lines (one line with two arithmetic expressions and two double syllable words, and the other with three arithmetic expressions and three double syllable words), were used as the children's exercise. All tests included a total of 60 ($(2+3+4+5+6)\times 3 = 60$) items.

The test was controlled using E-Prime software and the test items were presented on computer screens. First, an arithmetic expression (for example: $4-2=2$?) was presented on the screen, the child then being asked to determine whether the expression was correct or incorrect by selecting a computer key. The test item would remain on the screen until the computer detected the child's response. Once the latter was detected, the computer automatically recorded the subject's judgment, and then the accompanying double syllable word (such as 'classmates') was reproduced through the headphones. After three seconds, the computer automatically presented the next arithmetic expression and double syllable word. When all the test items (arithmetic expressions and double syllable words) were completely presented in a line, the test program prompted the subject on the computer screen as follows: 'please write down the words that you just heard.' Then, the subject wrote down the words that s/he heard in order on the form recording working memory span. The presentation time of the prompt was set to 'infinity' by the software and triggered by the computer key, meaning that the subjects could decide independently whether or not to begin the next test. The purpose of this was to give the subjects sufficient time to remember and record the test words and to avoid to affect the recalling of the words correctly because of time constraints. When a group test was completed, an arithmetic expression and a double syllable word were added to each line in next group, and the next group test started. According to each child's response to the experiment and recording speed, the average time spent doing the exercises was between 18 to 25 minutes. The scene of the on-site experiment is shown in Fig. 2.

Fig. 2. The test on-site.

Subjects correctly recalled a word in the correct position for 1 point, with the percentage of the total number of words recalled in the correct order and the total number of test words subsequently taken as their working memory span score (WMSS). Under each test condition, the WMSS was the mean of the WMSSs of 10 subjects under this condition.

3. Results

Figure 3 shows the children's WMSSs across the two grades under three different SNR and three different RT conditions. It can be seen that the higher the SNR, the higher the children's WMSSs under the same RT and age conditions. The children's WMSSs increased with the decrease of RTs under the same SNR condition. The higher the children's age, the higher the WMSSs under the same RT and SNR condition. The results of analysis of variance show that RT, SNR, and

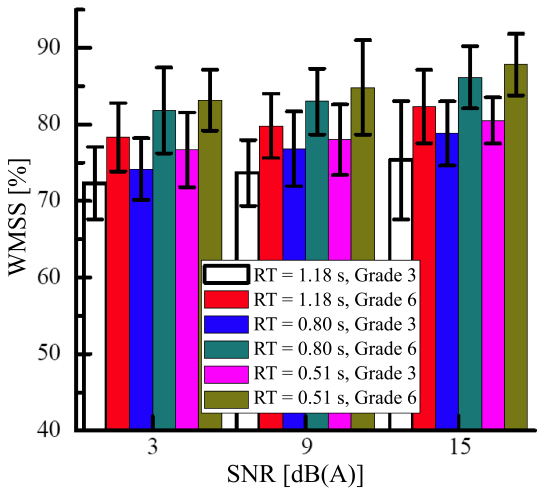

Fig. 3. WMSSs under different grade, SNR and RT conditions.

children's age have significant effects on WMSS, but no interaction effect was found significant for RT, SNR, and children's age.

To further analyze the effects of different SNRs and RTs on children's WMSSs, the WMSSs under different SNR and RT conditions were tested using pairwise comparisons. While significant differences emerged between the WMSSs of children under 3 dB(A) and 15 dB(A) of SNR, there was no significant difference found between the WMSSs of children under 9 dB(A), 3 dB(A), or 15 dB(A) SNR. There were significant differences between the WMSSs of children with 0.51 s and 1.18 s of RTs, but no statistical significance in the difference between the WMSSs of children between 0.51 s and 0.80 s, and between 0.80 s and 1.18 s of RT. These results indicate that RT should be reduced as far as possible and that the interference of various ambient noise should be avoided in classrooms, as the classroom is an important learning place for children. It is also indicated here that a higher SNR would benefit children's memory performance during the class, with the implication that the children would better remember what the teachers taught and that the learning effect would thus be improved.

Table 2 presents differences in the children's WMSSs across the two grades. There was a minor difference found in the WMSSs between grades three and six under different SNR and RT conditions, and no significant difference ($F(2,\ 8) = 1.754$, $p = 0.251$) found for these conditions. The range of the differences in scores was between 6.0% and 7.66%, and the mean difference was 6.78% with standard deviation 0.20. On average, the WMSS for sixth grade children was 6.78% higher than that of third grade children.

Table 2. Differences in WMSS between third and sixth grade.

SNR [dB(A)]	WMSS difference [%]		
	$T_{30} = 0.51$ s	$T_{30} = 0.80$ s	$T_{30} = 1.18$ s
3	7.00	6.16	6.00
9	7.34	6.17	7.66
15	7.33	6.83	6.50

A multiple regression model was used to fit the children's WMSSs and the fitting equation was shown in Eq. (1).

$$\text{WMSS} = 57.28 + 2.26\text{AGE} - 6.07\text{RT} + 0.41\text{SNR}. \quad (1)$$

The "AGE" represents the age of children in Eq. (1). The correlation coefficient was 0.99 and standard deviation was 0.7%. The AGE, RTs and SNRs (significance level $p < 0.001$) were the main influencing factors of these children's WMSSs. There was a positive linear relationship found between children's age, SNRs and children's WMSSs, while there was a negative linear relationship between RT and children's WMSSs. The children's working memory span increased by 2.26% for each additional age year. For each 0.1 s increase of RT, the children's WMSS decreased by 0.61%; for each 1 dB increase in SNR, the children's WMSS increased by 0.41%. The average age of the children in sixth grade was three years older than that of third grade children. When the RT and SNR were fixed, the Eq. (1) showed that sixth grade children's average WMSS was 6.78% higher than that of third grade children. From this, it can be seen that the predicted values are consistent with the results of the analysis in Table 2.

4. Discussions

To investigate the effects of RT and SNR on children's WMS, a memory span task was used to evaluate the working of visual and auditory sequence memory with the interference of noise and reverberation. The test results reflected the children's input and processing ability with regard to visual and auditory information. The research paradigm used visual and auditory dual tasks instead of a short-term memory span task. The working memory span tasks in the current study focus on the continuity of memory storing, processing and extraction. For the test, noise and reverberation acted as the stimulating interference. Subjects could realize memory-oriented tasks through the internal retelling of the test words when they conducted the working memory task. As such, the results in the current study arguably accurately reflect children's memory level (Tao, 2015).

The study by Klatte *et al.* (2013) showed that noise and reverberation have a significant impact on children's auditory and non-auditory tasks, as well as on cognitive performance, especially with young children. Listening to speech under conditions of noise and reverberation requires more cognitive resources, and places higher demands on top-down driven processing to restore the distorted sensory signal and to complete the memory task (Larsby *et al.*, 2005). When the allocation of cognitive resources is greater than subjects' WMS, the auditory information that can be further processed by the subjects is impaired (Just, Carpenter, 1992). Although WMS undergoes rapid development in third grade children, The WMS of third grade children cannot go beyond their physiological threshold in terms of their age, and still have poor immunity to interference. However, the development of WMS in sixth grade children is close to that of adults, meaning that these children can obtain a higher WMSS under shorter RT and higher SNR conditions. By employing a WMS test with college students, Ljung *et al.* (2013) found that SNR had no significant effect on subjects' high working memory scores, and that it did have a significant effect on subjects' low working memory. During the high WMS test, the subject can easily encode, retell and retrieve the test items using sufficient resources in the free recall experiment. However, Ljung *et al.* (2013) also hypothesized that the impact of SNR on children may be more serious. The results from the current study confirm Ljung *et al.* speculation, to some extent.

Although the word materials used in this study were unrelated and presented to the subjects in a pseudo-random manner using E-Prime software, the memory strategies for third grade and sixth grade children were found to differ significantly under reverberation and noise conditions. After the test, the subjects were asked how to remember the test words under the conditions of noise interference and reverberation. The survey showed that, firstly, third grade children mostly used the mental mechanical retelling procedure to complement their memory of the test words. Obviously, third grade children's memory recall method is easily affected by unrelated stimuli interference. However, sixth grade children employed the process of using a sentence to link the unrelated words in order to complete their memory tasks. For example, for the test series 'music, workers, bread, east, center, success', third grade children generally recited these in their mind in a mechanical manner. In contrast, sixth grade children used a different strategy to link the test words, doing so, for example, as full sentences: 'music worker's bread in the center of the East can be successful'; this then helped them to remember the test words. This indicates that older children are better able to process and store the target tasks using the conversion and extraction strategy mechanism of the central execution system. Secondly, third grade children were found to be significantly weaker than sixth grade children in terms of their ability to focus their attention and avoid distraction, and to allocate and control attentional resources (Turner, Engle, 1989). Third, children's WMS relates to their education level and development of cognitive performance (Shang, 2003). The development of working memory in children is limited to a certain degree of physiological maturity and education level.

5. Conclusions

The WMSSs of third and sixth grade children were obtained under different SNR and RT conditions, and the influence of noise and reverberation on the children's WMS was investigated. The results show that the children's age, RT and SNR had significant effects on the WMSSs. With the increase of SNR, the WMSS gradually increased. There was a significant difference in children's WMSSs when the SNR was between 3 and 15 dB(A). The difference in scores was not significant under the 9 dB(A) and 3 dB(A) of SNR, and 9 dB(A) and 15 dB(A) of SNR. Under the same age and SNR conditions, the children's WMSSs increased with the decrease of RT. There was found to be a significant difference in the WMS of children under 0.51 s and 1.18 s conditions, and no significant difference in scores when the RT was 0.51 s and 0.80 s, and 0.80 s and 1.18 s. Under the same SNR and RT conditions, children's WMSSs increased with age. The correlation coefficient of children's working memory span with children's age, RT and SNR was 0.99, and the standard deviation was 0.7%.

Acknowledgments

This work is supported by National Natural Science Foundation of China (Grant No. 11674104, 11374106). The very helpful cooperation of the teachers, children and school administrations has made this work possible.

References

1. Baddeley A. (2003), *Working memory and language: An overview*, Journal of Communication Disorders, **36**, 189–208.
2. Baddeley A.D., Hitch G. (1974), *Working memory*, Psychology of Learning and Motivation, **8**, 47–89.
3. Beaman C.P., Holt N.J. (2007), *Reverberant auditory environments: the effects of multiple echoes on distraction by 'irrelevant' speech*, Applied Cognitive Psychology, **21**, 1077–1090.
4. Conway A.R.A., Kane M.J., Bunting M.F., Hambrick D.Z., Wilhelm O., Engle R.W. (2005) *Working memory span tasks: A methodological review and user's guide*, Psychonomic Bulletin and Review, **12**, 5, 769–786.
5. Dawna E.L., Crystal M.M., Daniel L.V., Nicholas A.S. (2014), *Children's Understanding of Instructions Presented in Noise and Reverberation*, American Journal of Audiology, **23**, 326–336.
6. Just M.A., Carpenter P.A. (1992), *A capacity theory of comprehension: individual differences in working memory*, Psychological Review, **99**, 122–129.
7. Kjellberg A., Ljung R., Hallman D. (2008), *Recall of words heard in noise*, Applied Cognitive Psychology, **22**, 1088–1098.
8. Klatte M., Bergström K., Lachmann T. (2013), *Does noise affect learning? A short review on noise effects on cognitive performance in children*, Frontiers in Psychology, **4**, 578–589.
9. Klatte M., Lachmann T., Meis M. (2011), *Effects of noise and reverberation on verbal short-term memory in young adults in a classroom-like setting*, The 9th Biennial Conference on Environmental Psychology, Eindhoven. Available: http://proceedings.envpsych2011.eu/files/orals.html.
10. Klatte M., Meis M., Janott C., Hilge C., Schick A. (2002), *The effects of the soundfield system*

on cognitive performance of elementary school children, Proceedings Forum Acousticum, Sevilla, SS-NOI-04.

11. Larsby B., Hällgren M., Lyxell B., Arlinger S. (2005), *Cognitive performance and perceived effort in speech processing tasks: effects of different noise backgrounds in normal-hearing and hearing-impaired*, International Journal of Audiology, **44**, 131–143.

12. Ljung R., Israelsson K., Hygge S. (2013), *Speech intelligibility and recall of spoken material heard at different signal-to-noise ratios and the role played by working memory capacity*, Applied Cognitive Psychology, **27**, 198–203.

13. Ljung R., Kjellberg A. (2009), *Long reverberation time decreases recall of spoken information*, Building Acoustics, **16**, 301–311.

14. Marrone N., Alt M., DeDe G., Olson S., Shehorn J. (2015), *Effects of steady-state noise on verbal working memory in young adults*, Journal of Speech, Language, and Hearing Research, **58**, 1793–1804.

15. Perham N., Banbury S., Jones D.M. (2007), *Do realistic reverberation levels reduce auditory distraction?*, Applied Cognitive Psychology, **21**, 839–847.

16. Pichora-Fuller M.K., Schneider B.A., Daneman M. (1995), *How young and old adults listen to and remember speech in noise*, The Journal of the Acoustical Society of America, **97**, 1, 593–608.

17. Shang B. (2003), *Contemporary child development psychology*, pp. 296–310, Shanghai: Shanghai Education Press.

18. Sorqvist P., Hurtig A., Ljung R., Ronnberg J. (2014), *High second-language proficiency protects against the effects of reverberation on listening comprehension*, Scandinavian Journal of Psychology, **55**, 91–96.

19. Sullivan J.R., Carrano C., Osman H. (2015), *Working memory and speech recognition performance in noise: implications for classroom accommodations*, Communication Disorders, Deaf Studies and Hearing Aids, **3**, 136–141.

20. Surprenant A.M. (1999), *The effect of noise on memory for spoken syllables*, International Journal of Psychology, **34**, 328–333.

21. Tao H. (2015), *Effects of noise types and noise sensitivity on working memory and noise annoyance of college students*, Disseration, Beijing Forestry University, Beijing.

22. Turner M.L., Engle R.W. (1989),*Is working memory capacity task dependent?*, Journal of Memory and Language, **28**, 127–154.

23. Unsworth N., Heitz R.P., Schrock J.C., Engle R.W. (2005), *An automated version of the operation span task*, Behavior Research Methods, **37**, 498–505.