Poor Listening Conditions Impair Memory for Intelligible Lectures: Implications for Acoustic Classroom Standards

Robert Ljung, Patrik Sörqvist, Anders Kjellberg and Anne-Marie Green
Laboratory of Applied Psychology, Centre for Built Environment
University of Gävle, Gävle, Sweden
Robert.ljung@hig.se

This paper reports two experiments on the effects of degraded speech signals on memory for spoken lectures. Experiment 1 showed that broadband noise impairs university students' memory for a spoken lecture, even though the participants heard what was said. Experiment 2 showed that reverberation has detrimental effects to school adolescents' memory for spoken lectures, similar to broadband noise. The results suggest that poor listening conditions (resulting from background noise and/or long reverberation time) impair memory and learning, even if the conditions allow the listeners to hear what is said. Since the goal for students and pupils attending to lectures is to remember the lecture rather than just hearing what is said, the results presented here indicate that standards for acceptable signal-to-noise ratios and reverberation times in buildings designed for learning should consider the distinction between speech intelligibility and memory. Standards should be based on memory criteria instead of intelligibility criteria.

Keywords: broadband noise, reverberation time, signal-to-noise ratio, classrooms, acoustic standards, memory

1. INTRODUCTION

Acoustic standards for classrooms are based on intelligibility criteria [1-3]. The American National Standards Institute states that "Normal adults typically require 0 dB signal-to noise ratios for high speech intelligibility when listening to simple and familiar speech material for short periods of time"[4]. An underlying assumption is that if speech is identified correctly, there are no detrimental effects of noise and reverberation. Still, to hear what the teacher says is only a necessary condition for understanding and remembering the lecture, but perhaps not a sufficient condition. Kjellberg [5] argued that poor listening conditions may impair memory for spoken materials even when it is possible to hear what is said. This hypothesis was tested by Kjellberg, Ljung and Hallman [6] by presenting to-be-recalled spoken word lists with and without a background noise (signal-to-noise ratio 4 and 27 dB respectively). Participants were asked to repeat aloud each word immediately after its presentation. This repetition procedure made it possible to ensure complete intelligibility. After list presentation, the participants were asked to recall all words presented in the list. The results revealed that a broadband noise during presentation impairs memory, even when the words are correctly identified. Ljung and Kjellberg [7] later conceptually replicated these results, using the same procedure, but comparing memory for word lists spoken with a long reverberation time with memory for word lists spoken with a short reverberation time. They found that memory is impaired by a long reverberation time, even though the words are intelligible, just as with a small signal-to-noise (S/N) ratio. These results are consistent with several other studies showing that noise impairs memory for intelligible word lists [8-11]. We therefore argue that the acoustic standards for classrooms should be based on a memory criterion instead of intelligibility criteria.

A good memory of a spoken message seems to require a better S/N ratio than 0 dB, even though high speech intelligibility may be achieved at this ratio. Relatively good S/N ratios may therefore be detrimental to memory and learning in schools. However, studies looking into the effects of noise on memory for intelligible speech have almost exclusively been restricted to memory for word lists. Recall of spoken word lists is a task rarely encountered outside the laboratory, and it is therefore too rash to base acoustic standards for classrooms on these studies. Students and school children are challenged with the task of understanding and remembering spoken lectures rather than word lists, and background noise and reverberation may well interfere with memory for spoken lectures in ways that differ from memory for a word list.

Memory for spoken lectures can be said to consist of traces from many different levels of processing: perceptual processing, analysis of the words, phrases, sentences and the meaning of the message. Traces from any of these activities may be retained in memory [12] and poor listening conditions may interfere with any of these levels of processing. For instance, noise might impair perception and memory of single words, but still not affect the listener's memory of larger parts of the lecture. Another factor to be considered when moving from memory of word lists to memory of lectures is the context which may promote intelligibility for spoken lectures, whereas this is not possible for lists of unrelated words presented with no context. This may make understanding and memory of the lecture less sensitive to the effects of noise.

In a pioneering study, Rabbitt [13] showed that poor listening conditions (+5 dB S/N) impair memory of spoken prose. He let the participants listen to prose passages and answer questions about the contents afterwards. One group of participants listened to the prose passage without noise in the background (No noise group). Another group listened to the passage without noise during the first half and with noise during the second half (Noise group). Rabbitt found that the Noise group scored lower on questions concerning the first half of the prose passage (which was heard without noise in both groups) as well as the second half. Rabbitt's interpretation of the results was that the degraded speech in the second half in the Noise group impaired any additional processing of the first half of the lecture. However, the between-groups design used by Rabbitt is open to other interpretations. One possible interpretation of his results is that the participants in the Noise group had a lower memory capacity in general, or poorer speech perception abilities, and therefore received a low score. This explanation is consistent with the finding that the Noise group received a lower score for the part of the prose passage that was heard without noise. Another problem with Rabbitt's design is that he tested the participants in groups of 11 to 22. Obviously, listening conditions may have varied with group size and this effect differed between the two groups (e.g., if the speech was presented in loudspeakers and not with earphones; the description of the method is not clear on this point). Hence, there are reasons to doubt that the difference between the two groups was caused by noise.

2. EXPERIMENT 1

In Experiment 1, we aimed to replicate Rabbitt's [13] results by testing the effects of broadband noise on memory for a spoken lecture, while controlling for the participants' ability to hear what is said during the lecture and using a within-subjects design.

2.1 METHOD

2.1.1 Participants

28 university students 19-35 years old were paid to participate in the experiment. All participants were native speakers of Swedish and reported normal hearing ability.

2.1.2 Materials

Spoken lectures and noise. The spoken lectures (eight minutes long) were studio recorded and taken from two reading comprehension tests previously used in the national university aptitude test. The participants listened to one lecture with recorded broadband background noise and another lecture without the background noise. One lecture concerned inductivism and scientific methods, and the other lecture was about acting. After listening to the lecture, the participants were given eight open-ended questions about the content of the lecture. In the noise condition, a broadband noise was presented simultaneously with the spoken lecture giving a S/N ratio of + 5dB(A), which was expected to make it difficult but possible to hear everything that was said during the lecture. In the control condition, the S/N ratio was +29 dB(A). The lectures and the noise were presented in two loudspeakers placed 1.5 m in front of the participant.

Hearing test. The hearing tests consisted of two lists of ten sentences each presented with and without the broadband noise. All sentences had the same structure (e.g. *Sean took eighteen old balls*, *Anna held three beautiful rings*), and were constructed so as to carry no redundant information (i.e., the context gave few cues to what word would follow). The participants immediately repeated each sentence aloud. The five first sentences in each list were considered as training, and only the results from the five last sentences were used to measure the hearing ability. The sentences were taken from a standardized hearing test [14].

2.1.3 Procedure and design

The experiment was conducted in a sound-attenuated climate chamber, with the participants seated at a desk in the middle of the room. All participants were tested individually. They began by performing the hearing test followed by the two tests of memory for spoken lectures, one presented with broadband noise and one presented without broadband noise. A within-subject design was used and the order between background noise and control condition was counterbalanced (i.e., half of the participants began with the background noise condition and half with the control condition), as well as the order of the two different spoken lectures.

2.2 RESULTS

The participants' memory performance was worse when the lecture was heard in the noise condition (M = 2.68, SD = 1.64) than in the control condition (M = 3.45, SD = 1.76), as shown in Figure 1. A 2 (Noise condition: +5dB S/N ratio vs. +29dB S/N ratio) $\times$ 2 (Condition order: +5dB S/N ratio first vs. +29dB S/N ratio first) analysis of variance, with Noise condition as a within-subject variable and Condition order as a between-subject variable, revealed a significant difference between the two background conditions, $F(1, 26) = 6.71$, $MSE = 1.23$, $p < .05$, $\eta^2 = .20$, observed power = .70, but no significant main effect of condition order and no interaction between these two variables. An additional analysis including only participants with no errors in the hearing test (n = 16) showed consistent

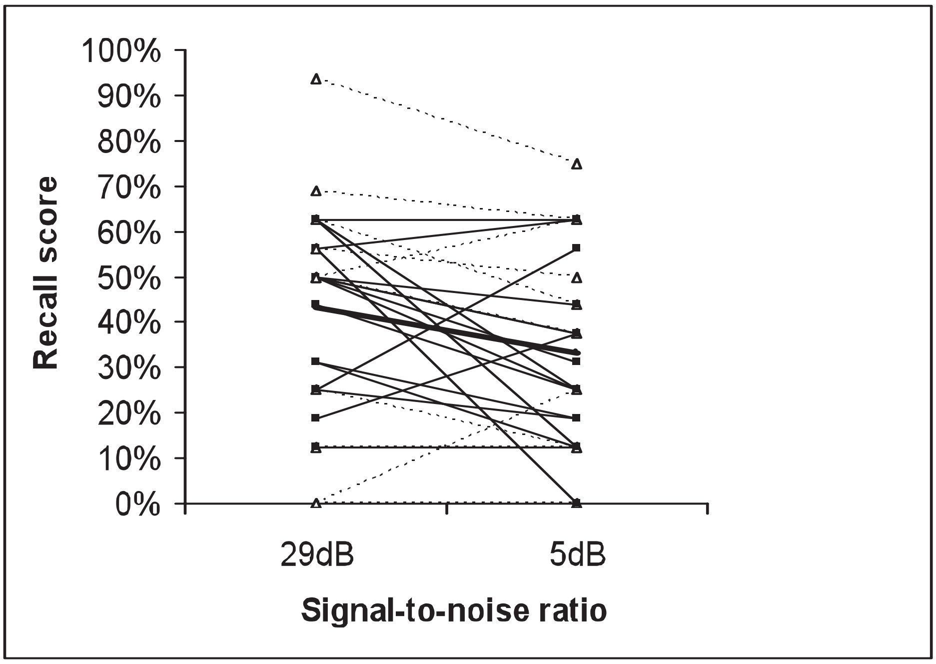

Figure 1. Each participant's recall score (in percent of total score possible) for lectures spoken with a +29 dB versus a +5 dB signal-to-noise ratio in Experiment 1. Dotted lines with triangle-marks represent participants who had at least one error on the listening test, whereas unbroken lines with square-marks represent participants who had no error on the listening test. The thick line with circle-marks represents the two condition means.

results. These results suggest that a background noise impairs memory for spoken lectures.

2.3 DISCUSSION

The results from Experiment 1 are consistent with previous investigations [6, 9, 13] and indicate that background noise in classrooms may be detrimental to listeners' memory for lectures even when they are able to hear what is said, at least for university students.

Another factor that influences the transmission of speech from a speaker to a listener is reverberation. The reverberation time is the time it takes for a sound signal to drop 60 dB from its initial dB level [15]. Typically recommended values for classrooms are in the range of 0.3-0.8 s [3, 4, 16], but it is not unusual to find a reverberation time of as much as 1.3 s in classrooms [17, 18]. The effects of reverberation on the speech signal resemble those of a broadband noise. Based on the results obtained in Experiment 1, we assumed that a long reverberation time is detrimental to memory for a spoken lecture, even when the listener is able to hear what is said.

3. EXPERIMENT 2

The memory of spoken information presented with varying reverberation time has, to our knowledge, only been dealt with in one previous study [7] where the to-be-remembered material was word lists. The purpose of Experiment 2 was to conceptually replicate the effect found in Experiment 1, but testing the effect of reverberation time instead of broadband noise on memory for spoken lectures. Another aim of the experiment was to test the effect in more ecologically valid conditions. Two steps were taken towards reaching a higher ecological validity in Experiment 2. First, the spoken lectures were recorded in two ordinary classrooms; one with a long reverberation time and one with a short reverberation time. Second, school adolescents (rather than university students) were recruited as participants and tested in a group setting.

3.1 METHOD

3.1.1 Participants

A total of 20 adolescents from an upper secondary school class in Sweden served as participants in exchange for a cinema ticket. One reported a hearing impairment and was therefore removed before the analyses. The remaining 19 participants (17 females and 2 males) were about 17 years old and reported normal hearing and Swedish as their native tongue.

3.1.2 Materials

Contents of lectures. Two lectures were constructed. One lecture was about a fictitious culture called the "Timads" and the other was about a fictitious culture called the "Lobiks". The purpose of using fictitious cultures was to make sure that previous knowledge did not influence task performance. Each lecture consisted of 10 short paragraphs about different topics (e.g., religion, geography, history) and included two phases; one listening phase and one recall phase. In the first phase, the participants listened to the 10 paragraphs. In the second phase of the lecture task, 20 questions (2 for each paragraph) were presented in sequential order on a computer screen. The questions concerned facts explicitly stated in the lecture (e.g., "What did people wear in their afterlife?"). Answers were never longer than a single sentence (e.g., "In bird feathers") and scored as correct if they contained a specific keyword (e.g., "feathers") or described the accurate meaning of the keywords (e.g., "Bird suits"). The participants answered the questions by typing them on the computer keyboard and were given as much time as they needed to answer the questions. After each lecture, the participants scored their ability to hear the lecture on a 7-point scale. This made it possible to compare self-reported hearing of the two lectures.

Auditory recording of lectures. The two lectures were spoken in male voice at normal speed in an anechoic room and recorded. To get ecological school recordings, the lectures were played from a loudspeaker in two ordinary classrooms (one with long reverberation time and one with short) and recorded binaurally. These binaural recordings were presented to the participants through headphones. The classrooms were about the same size (length 10 m, width 6 m, height 3 m) and were furnished with desks. The loudspeaker was placed 1 m in front of the blackboard in the centre of the classroom at a height of 1.5 m, and an acoustical head was placed as a seated student at a desk in the back of the room, about 6 m in front of the loudspeaker. The classroom with short reverberation time had various absorbing panels on the walls and the ceiling. The reverberation time was 0.3 s in all octave bands from 125 Hz to 4 kHz. The classroom with long reverberation time had some absorbing panels, but the walls and the ceiling was mostly painted concrete, and the reverberation time was 1.84 s at 125 Hz, 1.46 s at 250 Hz, 0.94 s at 500 Hz, 0.77 s at 1 kHz, 0.78 s at 2 kHz and 0.68 s at 4 kHz.

3.1.3 Design and procedure

The computers, with headphones attached, were rigged in an ordinary upper secondary school classroom. The participants entered the classroom and sat down at their computers, which were selected without the influence of the experimenter. The participants were given a short oral statement of the purpose of the experiment (i.e., that the experiment was about memory for stories) and thereafter performed the two lecture tasks. Since the participants completed the lecture tasks at different paces, additional filler tasks followed after the last lecture. The purpose with these tasks was to engage the participants in a meaningful activity so as not to disturb the other participants still working on the lecture tasks. The participants did not interact during the experiment proper. After the experiment, the participants were debriefed and thanked. Experiment 2 had a within-subject design, and the order between the two reverberation-conditions was counterbalanced between participants (i.e., half began in the long reverberation time condition and half in the short reverberation time condition), as well as the order of the two different spoken lectures.

3.2 RESULTS AND DISCUSSION

The participants' memory performance was worse when the lecture was heard with a long reverberation time (M = 2.16, SD = 1.57) than in the short reverberation time condition (M = 4.00, SD = 2.03), as shown in Figure 2. A 2 (Reverberation condition: long vs. short reverberation time) $\times$ 2 (Condition order: long reverberation time first vs. short reverberation time first) analysis of variance, with Reverberation condition as a within-subject variable and Condition order as a between-subject variable, revealed a significant difference between the two reverberation conditions, $F(1, 17) = 16.60$, $MSE = 2.12$, $p < .001$, $\eta^2 = .49$, observed power = .97, but no main effect of condition order and no interaction between these two variables.

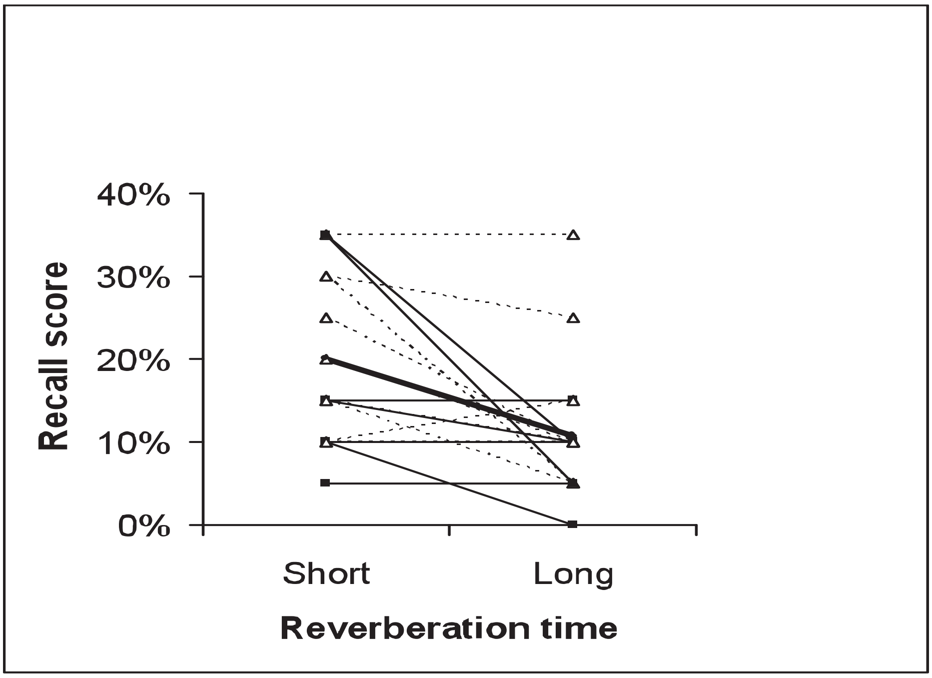

Figure 2. Each participant's recall score (in percent of total score possible) for lectures spoken with a short (0.3 sec) versus long (≈ 1.0 sec) reverberation time in Experiment 2. Dotted lines with triangle-marks represent participants who reported that they heard the lecture with short reverberation time better, whereas unbroken lines with square-marks represent participants who had reported that they heard the lecture with long reverberation time at least as good as the other lecture. The thick line with circle-marks represents the two condition means.

These results suggest that a long reverberation time impairs memory for spoken lectures. The participants' mean rating of how well they heard the lecture was 4.95 (SD = 1.75) in the short reverberation time condition and 4.68 (SD = 1.89) in the long reverberation time condition. These two means did not differ significantly, as shown by a paired t-test, $t(18) < 1$. An additional analysis was carried out based only on the participants who rated their hearing of the lecture spoken with long reverberation time equal to or better than their hearing of the lecture spoken with short reverberation time (n = 8). The results from this analysis were entirely consistent with the results from the analysis above. Taken together, the results from Experiment 2 indicate that a long reverberation time disrupts memory for lectures, even when the participants are able to hear the lectures equally well as lectures spoken with a short reverberation time.

4. GENERAL DISCUSSION

Taken together, these two studies show that background noise and long reverberation time are detrimental to memory of spoken lectures, even when people are able to hear what is said. Experiment 1 found that a S/N ratio of +5 dB, which is higher than the 0 dB needed for high speech intelligibility [4], impaired memory for a spoken lecture compared with a S/N ratio of + 29 dB. Experiment 2 found similar results for long reverberation time compared with short. These results are consistent with previous investigations into the effects of noise on memory for spoken word lists [6, 8-11] and for spoken prose [13] and lead us to argue that acoustic standards for rooms meant for learning (e.g., upper secondary school classrooms) should be more stringent than previously suggested.

With few exceptions, studies on the effects of noise on learning have tested memory for written materials [19-22]. Little has been done concerning effects of noise on memory for speech, and to our knowledge, the present paper is the first to report effects of reverberation on memory for spoken lectures. We suggest two directions for future investigations. The effects of reverberation and background noise could be combined to test for interactions. Also, the effects of different levels of S/N ratios (and reverberation times) on memory should be compared to investigate the function between decreased S/N ratio (and reverberation time) and decreased memory performance.

In conclusion, hearing what is said is a necessary but not a sufficient condition for people to remember what is said. Today's standards for acceptable signal-to-noise ratios and reverberation times in buildings designed for learning do not consider this discrepancy between intelligibility and memory. The standards are solely based on a hearing criterion [1-4]. Since the goal is to remember the lecture rather than solely hear it, the results presented here and elsewhere [6, 9, 10, 13] suggest that acoustic standards should be based on memory criteria instead.

REFERENCES

1. Karabiber, Z., & Vallet, M., Classroom acoustics policies – An overview, *Acta Acustica (Stuttgart)*, 2003, 89, 12.

2. Shield, B. M., & Dockrell, J. E., The effects of noise on children at school: A review, *Building Acoustics*, 2003, 10, 97-116.

3. Smaldino, J. J., & Crandell, C. C., Speech perception in classroom, *Volta Review*, 2000, 101(5), 15-21.

4. American National Standards Institute., *Acoustical performance criteria, design requirements, and guidelines for schools*, 2002, (Standard S12.60-2002).

5. Kjellberg, A., Effects of reverberation time on the cognitive load in speech communication: Theoretical considerations, *Noise & Health*, 2004, 7, 11-21.

6. Kjellberg, A., Ljung, R., & Hallman, D., Recall of words heard in noise, *Applied Cognitive Psychology*, 2008, 22, 1088-1098.

7. Ljung, R. & Kjellberg, A., Long reverberation time decreases recall of spoken information. *Building Acoustics* (in press)

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

9. Rabbitt, P., Recognition memory for words correctly heard in noise, *Psychonomic Science*, 1966, 6, 383-384.

10. Rabbitt, P., Mild hearing loss can cause apparent memory failures which increase with age and reduce with IQ. *Acta Otolaryngologica*, 1991, 479, 167-176.

11. Surprenant, A., Effects of noise on identification and serial recall of nonsense syllables in older and younger adults, *Aging, Neuropsychology, & Cognition*, 2007, 14, 126-143.

12. Kintsch, W, & Bates, E., Recognition memory for statements from a classroom lecture, *Journal of Experimental Psychology: Human Learning and Memory*, 1977, 3, 150-159.

13. Rabbitt, P., Channel-capacity, intelligibility and immediate memory, *Quarterly Journal of Experimental Psychology*, 1968, 20, 241-248.

14. Hagerman, B., Sentences for testing speech intelligibility in noise, *Scandinavian Audiology*, 1982, 11, 79-87.

15. Rossing, T. D., *The science of sound*, Reading Mass, 1990, Addison-Wesley.

16. Finitzo-Hieber, T. & Tillman, T., Room acoustics effects on monosyllabic word discrimination ability for normal-hearing and hearing-impaired children, *Journal of Speech & Hearing Research*, 1978, 21, 440-458.

17. Bradley, J. S., Speech intelligibility in classrooms, *Journal of the Acoustical Society of America*, 1986, 80, 846-854.

18. Crandell, C. C. & Smaldino, J. J., An update of classroom acoustics for children with hearing impairment, *Volta Review*, 1994, 96, 291-306.

19. Beaman, C. P., Auditory distraction from low-Intensity noise: a review of the consequences for learning and workplace environments, *Applied Cognitive Psychology*, 2005, 19, 1041-1064.

20. Evans, G.W., & Lepore, S. J., Nonauditory effects of noise on children: A critical review, *Children's Environments*, 1993, 10, 31-51.

21. Hygge, S., Classroom experiments on the effects of different noise sources and sound levels on long-term recall and recognition in children, *Applied Cognitive Psychology*, 2003, 17, 895-914.

22. Hygge, S., Boman, E., & Enmarker, I., The effects of road traffic noise and meaningful irrelevant speech on different memory systems, *Scandinavian Journal of Psychology*, 2003, 44, 13-21.

OVER 10% OF CHILDREN FALSELY IDENTIFIED AS HAVING NOISE INDUCED HEARING LOSS

New research from University of Minnesota hearing scientists shows that fewer than 20 percent of teenagers in the United States have a hearing loss as a result of exposure to loud sounds. The research, to be published in the Journal of Speech, Language, and Hearing Research, points out that the small hearing losses that audiologist are trying to identify with conventional hearing tests are subject to measurement error and that as many as 10 percent or more of children are falsely identified as having a noise induced hearing loss using these methods.