The impact of building acoustics on speech comprehension and student achievement

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ABSTRACT

The movement for improved classroom acoustics has primarily been grounded on studies that show how building acoustics (i.e. background noise levels and room reverberation) affect speech intelligibility, as determined by speech recognition tests. What about actual student learning, though? If students do not understand each spoken word in the classroom perfectly, can they still manage to achieve high scholastic success? This presentation will review two recent studies conducted at the University of Nebraska – Lincoln, linking classroom acoustic conditions to student learning outcomes and speech comprehension (rather than simply recognition). In the first, acoustic measurements in two public school districts in the Midwest were correlated to elementary student achievement scores. Results indicate that higher background noise levels, greater than 40 dBA, may lead to unacceptable scholastic performance in language and reading tests. The second study focuses on how room acoustic conditions impact English speech comprehension of native-English-speaking listeners in contrast to English-as-second-language (ESL) listeners, a group which includes 21% of children in the United States K-12 school system. Conclusions are that higher reverberation times and background noise levels do reduce speech comprehension in both groups of listeners, but adverse noise conditions are particularly more detrimental on ESL listeners.

Keywords: Classroom Acoustics, Background Noise, Reverberation, Speech Comprehension
I-INCE Classification of Subjects Number(s): 63.3

1. INTRODUCTION

Classrooms are learning environments, and as such, the built environment of a classroom should allow students to not only hear speech intelligibly but also to comprehend the meaning behind it and learn the material presented. Researchers have investigated the relationship between the acoustical characteristics of classrooms and the ability of English-speaking students with normal-hearing to understand words or phrases in those rooms (1, 2, 3, 4). These studies and earlier work as reviewed in booklets on classroom acoustics produced by the Acoustical Society of America (5, 6) have clearly shown that higher background noise levels (BNL) and longer reverberation times (RT) result in poorer speech intelligibility. The ANSI Standard S12.60 “Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools” (7) gives guidelines for maximum values of BNL (35 dBA) and RT (0.6 sec) based on these speech intelligibility studies.

These room acoustic metrics, however, are only recently being well-correlated to speech comprehension and student learning outcomes. Speech comprehension, as defined in this paper, relates to how well students can comprehend the meaning behind the words, rather than simply being able to repeat the word itself. Shield and Dockrell’s field study (8) showed that environmental noise had a negative impact on the academic performance and attainment among primary school children. Klatte, Lachmann, and Meis (9) investigated language comprehension in a laboratory setting. Their results indicate that listening comprehension is more impaired than speech recognition under the presence of noise. Another recent study by Valente et al (10) also found that speech comprehension scores degraded much more significantly than sentence-recognition scores for both adults and children, due to increased BNL and RT.

In this paper, two recent studies conducted at the University of Nebraska – Lincoln are reviewed.

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One is a field study, in which the acoustics of 125 unoccupied elementary classrooms were surveyed, and those measurements were correlated to student achievement scores of students learning in those rooms. The other is a laboratory study, whose aim was to compare speech comprehension performance of native-English-speaking listeners to non-native-English-speaking listeners under assorted acoustic conditions.

2. PROJECT 1: IN SITU ELEMENTARY STUDENT ACHIEVEMENT

2.1 Methodology

The goal of this project was to measure the BNL and RT of a large number of unoccupied elementary school classrooms and to correlate those results with student achievement scores. Two local school districts were included. In District 1, all 2nd and 4th grade classrooms were measured for a total of 58 classrooms across 14 schools. In District 2, all 3rd and 5th grade classrooms were measured for a total of 67 classrooms across 14 schools. All classrooms had closed floor plan designs and typical room finishes, including acoustical ceiling tile, thin floor carpet, and either gypsum board or concrete masonry unit walls.

The primary source of background noise in these facilities was the mechanical system for heating, cooling and ventilation, so the BNL was logged across 5 minutes in an unoccupied condition while the mechanical system was operating in cooling and heating modes. The RT was measured using balloon pops, due to the large number of classrooms that were surveyed.

The student achievement data varied between the two districts. In District 1, the Iowa Test of Basic Skills was administered at the end of the school year providing both math and reading comprehension scores. The data provided to the investigators were average test results reported per grade level per school, rather than per classroom. Additionally, demographic data were provided in terms of average poverty rates per school; these were used to control for the data. In District 2, Terra Nova Tests were administered in November, including math, reading, and language arts topics; then a Nebraska State Accountability Reading Test was administered in March. These results were provided in terms of average test results per classroom. The demographic data provided for control was the percent of students receiving free or reduced-price lunches per classroom.

2.2 Results

Figures 1 and 2 show the measured reverberation times and background noise levels respectively from District 1. Note that all of these classrooms meet the ANSI S12.60 recommendations for RT, but none of them meet the BNL recommendation of 35 dBA. Figures 3 and 4 show the measured RT and BNL respectively from District 2. Again, all of the classrooms meet ANSI S12.60 recommendations for RT, but the majority of them do not meet BNL limits.

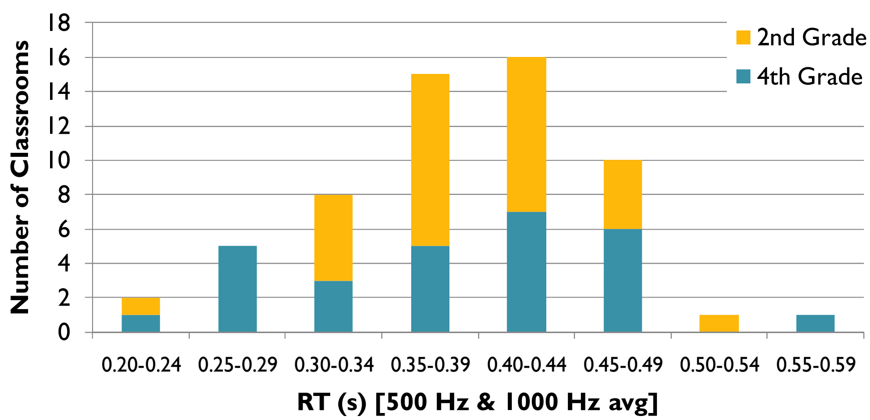

Figure 1 – Measured reverberation times for 2nd and 4th grade classrooms in District 1

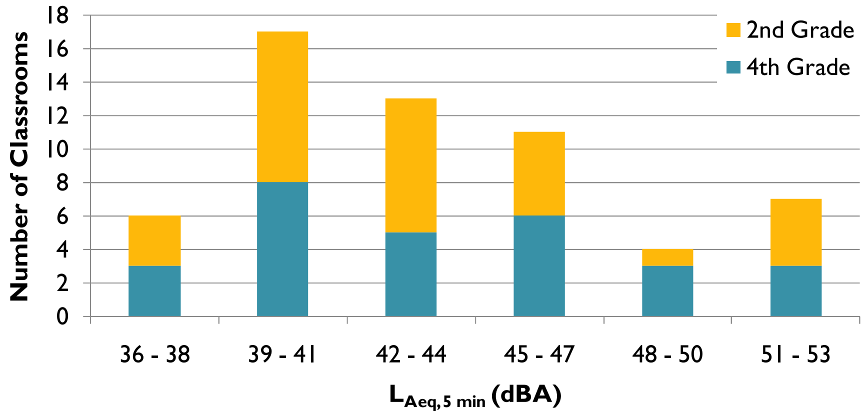

Figure 2 – Measured background noise levels for 2nd and 4th grade classrooms in District 1

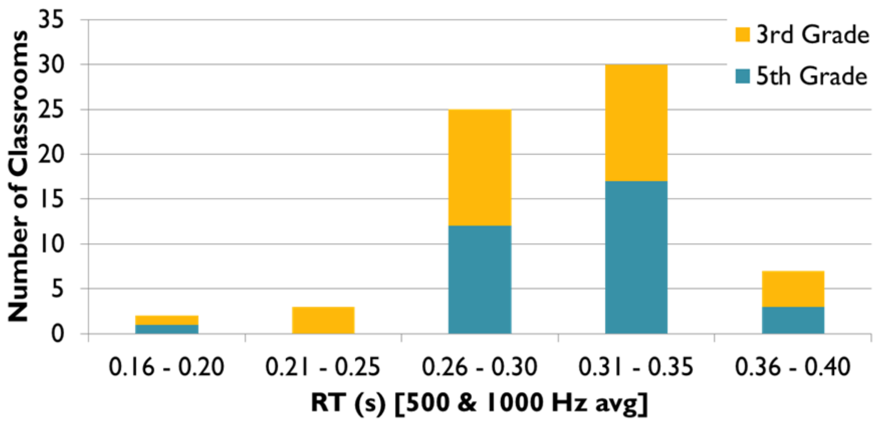

Figure 3 – Measured reverberation times for 3rd and 5th grade classrooms in District 2

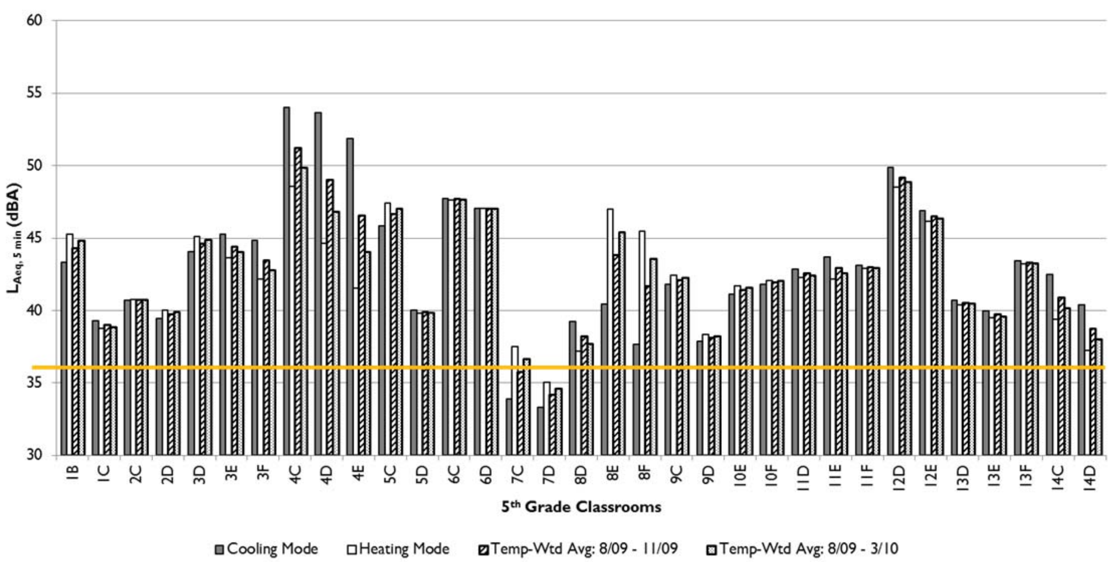

Figure 4 – Measured background noise levels for 3rd and 5th grade classrooms in District 2

These measured RT and BNL data were statistically compared to the gathered student achievement scores, using correlations and analysis of variance (ANOVA), controlling for poverty rates. For District 1, results show no significant relationships between RT and math or reading comprehension scores, nor any significant relationships between BNL and math scores. However, there is a significant negative relationship between BNL and reading comprehension scores ($p<0.05$), as plotted in Figure 5.

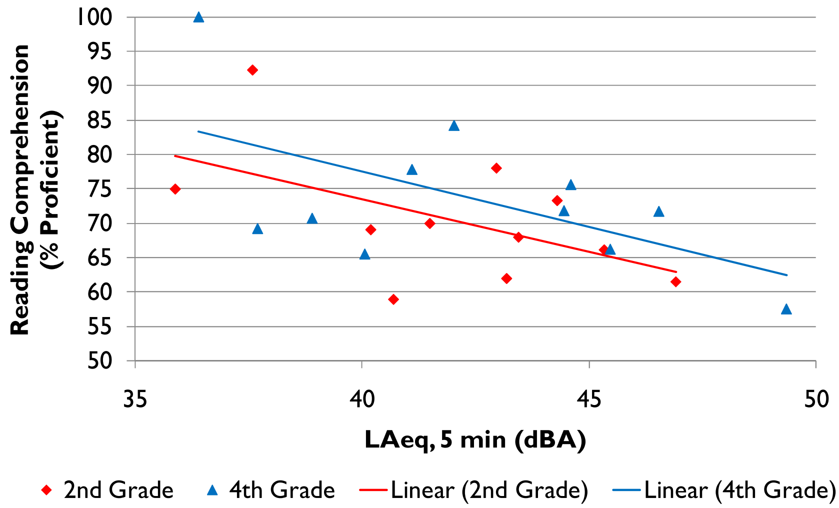

Figure 5 – Measured BNL versus reading comprehension scores given in percent proficient from District 1.

Results were similar for District 2, as shown in Figure 6. The data show no significant relationships between RT and achievement scores, nor any significant relationships between BNL and 3rd grade achievement scores. However, there is a significant negative relationship between BNL and 5th grade language and reading scores ($p<0.05$).

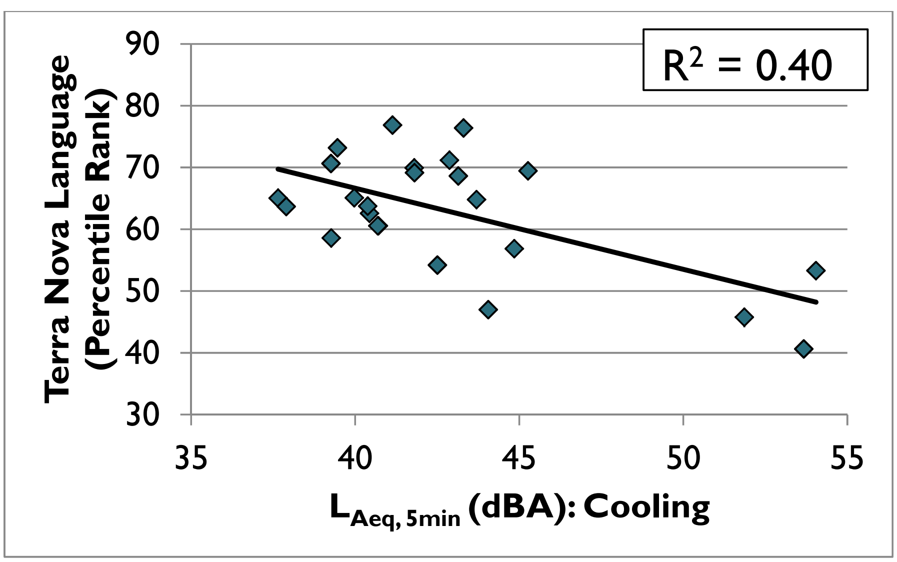

Figure 6 – Measured BNL under cooling mode versus Terra Nova language scores given in percentile rank.

2.3 Summary

All measured RT values in this survey of elementary school classrooms were within limits specified in ANSI S12.60-2010, and consequently those are not found to have negative relationships with student achievement. However, most of the measured BNLs were above ANSI S12.60-2010 guidelines, and significant negative relationships between those unoccupied BNL and language/reading scores were found. Projecting from the data, an unoccupied BNL of less than 41 dBA is required to meet minimum reading comprehension performance, according to goals set by the states in these two districts.

3. PROJECT 2: SPEECH COMPREHENSION – NON-NATIVE VERSUS NATIVE ENGLISH-SPEAKING LISTENERS

3.1 Methodology

This project measured speech comprehension in a controlled laboratory under a number of acoustic conditions, with a focus on determining if non-native English-speaking listeners experience more difficulty comprehending speech under adverse acoustic conditions than native English-speaking listeners. English-as-a-second-language (ESL) learners make up a significant proportion (21%) of the school age children in the United States, and a number of previous studies have indicated that ESL listeners do perform worse on speech intelligibility of word or phrases under adverse reverberation and noise conditions (11, 12, 13). The goal here was to expand the findings by testing not simply recognition of word/phrases, but comprehension of the meaning behind words and phrases.

A within-subjects test design was used wherein all subjects were exposed to 15 different acoustic conditions, consisting of five RT scenarios (ranging from 0.4 to 1.2 sec) and three BNL conditions (RC 30, 40 and 50). All testing was conducted in the Nebraska Acoustics Testing Chamber, with a volume of 25 m^3 and a mid-frequency reverberation time of 0.22 sec. The background noise conditions were played back via a ceiling panel loudspeaker and corner subwoofer, while the RT conditions were embedded in the audio through convolving dry speech material with auralizations created in ODEON.

Participants were asked to perform two simultaneous competing tasks, one being the speech comprehension task presented on a large monitor and the other being an adaptive pursuit rotor (APR) task presented on an adjacent smaller monitor. The APR task involves tracing a dot on a circle whose speed changes adaptively so that the participant maintains being on-target 80% of the time. The motivation for using the dual task scheme was to avoid having participants reach the ceiling of 100% on the speech comprehension tests, and to match more realistic learning scenarios where multiple tasks are often involved.

A number of speech comprehension tests have been developed at the University of Nebraska – Lincoln. These include four different types of tasks: matching photographs with aural descriptions; providing reasonable responses to questions, both presented aurally; listening to a conversation and answering aural questions about the material; and listening to a single talker and answering aural questions about the material. One sequence of all four tasks takes 15 minutes to complete; fifteen different but equivalently difficult test sequences were used in this investigation, randomly assigned to acoustic conditions for each participant.

A total of 56 persons (27 native English-speakers and 29 non-native English-speakers) were recruited to participate. All of these persons were found to have normal hearing levels, less than 25 dB HL from 125 Hz to 8000 Hz.

3.2 Results

Statistical ANOVA analyses indicate that there is a significant main effect of both background noise level ($p<0.001$; Figure 7) and reverberation time ($p=0.006$; Figure 8) on the speech comprehension results. Specifically, post-hoc tests indicate that RC-50 is significantly different from the other two BNL conditions, and that the highest RT tested (1.19 sec) is significantly different from most of the other RT conditions. Additionally there is a significant interaction between background noise level and English proficiency. Figure 9 shows that those with lower English proficiency (i.e. non-native English-speaking listeners) perform worse in the louder BNL conditions than those with higher English proficiency (i.e. native English-speaking listeners).

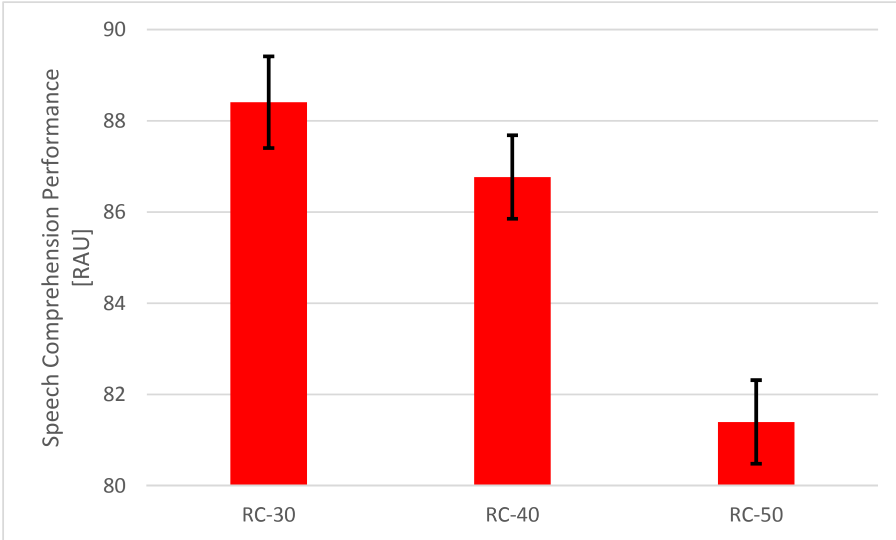

Figure 7 – Background noise level conditions versus the speech comprehension performance, given in rationalized arcsine units (RAU). Error bars show one standard deviation.

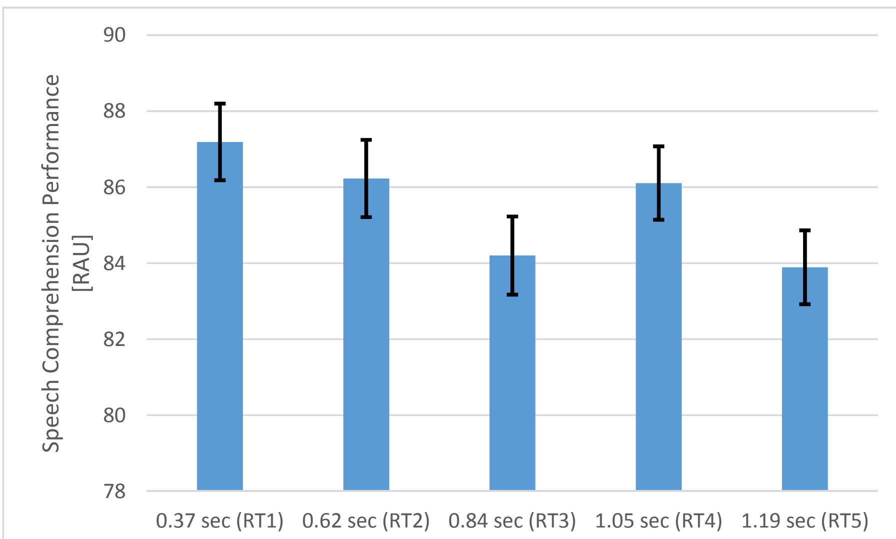

Figure 8 – Reverberation time conditions versus the speech comprehension performance, given in rationalized arcsine units (RAU). Error bars show one standard deviation.

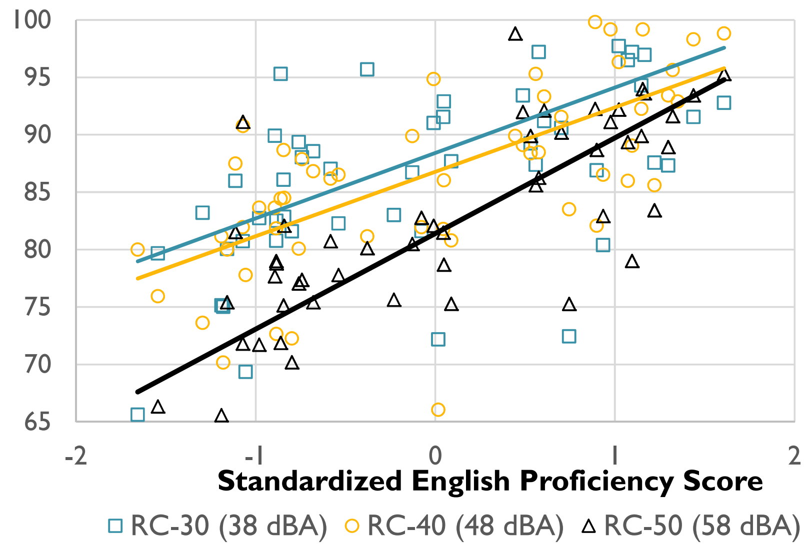

Figure 9 – Standardized English proficiency score versus speech comprehension score.

3.3 Summary

This study confirmed that adverse acoustic conditions result in lower speech comprehension performance. Specifically, the highest RT condition tested (1.2 sec) reduced speech comprehension scores to 83% while the highest BNL condition tested (RC 50) reduced scores to 81%. The negative effect appears stronger for BNL, as its effect size is considerably larger than found for RT. Results also indicate that higher BNLs are more detrimental for listeners with lower English proficiency.

4. CONCLUSIONS

The projects presented here provide evidence that higher levels of BNL are detrimental to student achievement and speech comprehension, particularly for younger children and for those with lower proficiency in the language of presentation. More complete presentation and discussion of these investigations may be found in publications by Ronsse and Wang (14, 15) and Peng's doctoral thesis from the University of Nebraska – Lincoln.

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