7-2015

Room Acoustic Effects on Speech Comprehension of English-as-Second-Language Talkers and Listeners versus Native-English-Speaking Talkers and Listeners

Lily M. Wang
University of Nebraska - Lincoln, lwang4@unl.edu

ROOM ACOUSTIC EFFECTS ON SPEECH COMPREHENSION OF ENGLISH-AS-SECOND-LANGUAGE TALKERS AND LISTENERS VERSUS NATIVE-ENGLISH-SPEAKING TALKERS AND LISTENERS

Lily M. Wang

Durham School of Architectural Engineering and Construction, University of Nebraska – Lincoln, 1110 S. 67th Street, Omaha, NE, 68182, United States
e-mail: LWang4@UNL.edu

Approximately 21% of the children in the United States school system speak a language other than English at home, but are being taught in English at school. English is additionally being used more and more often as a common language in international settings, even though participants at these international events again are not native English speakers. How do adverse room acoustic environments, including higher background noise levels and longer reverberation times, impact English-as-a-Second-Language (ESL) talkers and listeners versus native English-speaking talkers and listeners? This presentation focuses on two recent studies at the University of Nebraska that investigate how assorted room acoustic conditions impact English speech comprehension of ESL persons versus native English-speaking persons. In the first study, the talkers were all native English-speakers, and speech comprehension results are compared between ESL listeners and native English-speaking listeners. In the second study, the talkers were all native Mandarin-speakers, presenting in English. Speech comprehension results are compared between three groups then: native English-speaking listeners, native Mandarin-speaking listeners, and ESL listeners whose native language is not Mandarin. Results indicate that high background noise levels (RC-50 with native English-speaking talkers, and RC-40 with ESL talkers) negatively impact performance of all listening groups, but have a greater detrimental effect on ESL listeners. In terms of reverberation time, listeners with matched accent to the talkers are more capable of coping with longer reverberation, but adverse conditions ($\geq$ 0.8 sec) do produce lower speech comprehension performance by listeners that do not have a matched accent to the talker.

1. Introduction

The classroom acoustics standard that is promoted in the United States, ANSI/ASA S12.60-2010 "Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools", sets acoustic guidelines for unoccupied conditions in classrooms, namely that the reverberation time (RT) in most classrooms be less than 0.6 sec and that the unoccupied background noise level (BNL) be less than 35 dBA [1]. Much of the research basis for this standard, however, comes from speech recognition studies, rather than speech comprehension ones. That is, the investigations often asked adults or children to recognize syllables, words, or simple phrases or sentences in varying signal-to-noise ratio (SNR) conditions; they did not necessarily focus on whether the participants understood or comprehended the information that was presented.

Two recent studies have looked at speech comprehension more specifically. Klatte et al tested combinations of two types of noise (activity noise and babble noise) and two RTs (0.5 and 1.1 sec), and found that performance on a listening comprehension test was more degraded than performance on speech recognition tests under both noise conditions [2]. Valente et al also investigated combinations of two SNR (+7 and +10 dB) and two RTs (0.6 and 1.5 sec) simulated in a lab [3]. Their results implied that the more severe SNR and RT conditions had greater detrimental effect on speech comprehension tasks than speech recognition ones. More research that looks into how a wider variety of room acoustic conditions influence speech comprehension, rather than simply speech recognition, is needed.

Another growing area of research in the speech communication field is studying the impact of negative acoustic conditions on those who do not speak English as a native language. A recent report indicated that 21% of school-age children in the United States do not speak English at home [4], but rather may be considered as students who use English-as-a-Second-Language, or ESL. Previous research has shown that ESL listeners do experience more difficulties under excessive reverberation and noise [5-7]. ESL listeners are more impaired than native English-speaking listeners on recognizing components of speech (vowel/consonant combinations, words, or sentences) under more adverse SNR [8-11]. Many of these studies, though, focused again on speech recognition rather than comprehension performance. Also, most used a limited number of acoustic conditions that were usually more severe than what is commonly found in the built environment.

Another facet that has not been studied as in depth is how speech produced by non-native English-speakers may be comprehended by both native and non-native English-speaking listeners under adverse acoustic conditions. A recent statistic in the United States indicates that foreign-born university faculty members in science, technology, engineering and mathematics represent a range from 19% of faculty in areas like psychology to a large 54% of faculty in areas like engineering [12]. Non-native English-speaking talkers are consequently common in university classrooms. How then do adverse room acoustic environments, including higher background noise levels and longer reverberation times, impact speech comprehension by non-native English-speaking talkers and listeners versus native English-speaking talkers and listeners? This is the primary research question addressed in this paper.

Two studies have recently been run at the University of Nebraska – Lincoln, focused on this research question. The goal has been to quantify speech comprehension performance by both native and non-native English-speaking listeners, when listening to native and non-native English-speaking talkers, under a wide range of realistic building acoustic conditions. What are the detrimental effects of excessive RT or BNL in each of these situations? What is the effect of talker accent on speech comprehension by different groups of listeners? Should room acoustic design guidelines be modified in consideration of these situations?

2. Subjective Testing

Two studies have been conducted, using similar test procedures but different groups of talkers and listeners. In Study 1, all of the English speech comprehension test materials were produced by native English-speaking talkers (one male and four females) while both native and non-native English-speaking listeners participated. In Study 2, all of the English speech comprehension test materials were produced by non-native English-speaking talkers (one male and one female) whose native language was Mandarin Chinese; the two talkers demonstrated similar degrees of accentedness in their English, based on the commercially available Versant Spoken English Test [13]. Listeners in Study

2 were then grouped as (1) native American English-speaking (NAE), (2) non-native English-speaking but native Chinese-speaking (NNC), or (3) non-native English-speaking and non-native Chinese-speaking (NNO).

2.1 Test Procedure

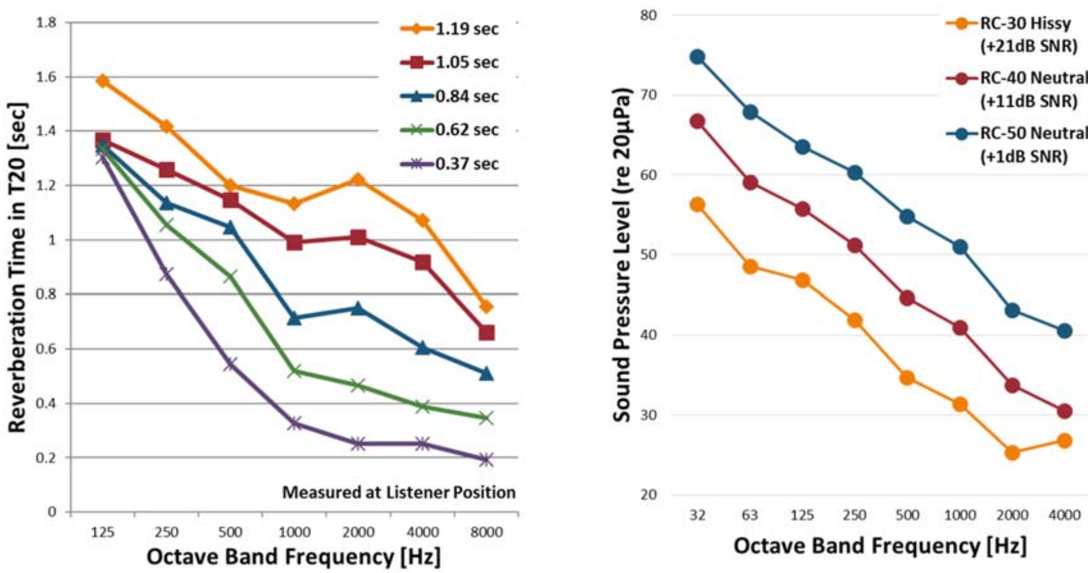
All subjective testing was conducted in the Nebraska Acoustics Testing Chamber at the University of Nebraska. This room is a 25 m^3 acoustically isolated space with a mid-frequency reverberation time of 0.22 sec and a low ambient background noise level of RC-26(H). The background noise stimuli were presented in the chamber primarily through a ceiling-panel loudspeaker located above the listener position and a subwoofer in the front left corner of the room. The reverberation time scenarios were created in ODEON, embedded in the speech comprehension audio material, and presented through two monitor speakers that flank two monitors in front of the listener (Fig. 1). At the listener's position, the playback level was maintained to be 59 dBA (re 20 μPa).

Figure 1. View from listener's position in the Nebraska Acoustics Testing Chamber.

Each participant was tested under 15 different acoustic conditions, created from combinations of five RT scenarios ranging from 0.4 to 1.2 sec at the mid-frequencies, and three BNL conditions of RC-30, 40 and 50 (corresponding to SNR of +21, +11, and +1 dB, respectively). These conditions were selected because they represent conditions in realistic classroom environments.

The RT scenarios were simulated in ODEON using a typical classroom of 260 m^3 by varying the surface materials to achieve the five RT conditions. Appropriate binaural room impulse responses were then generated within ODEON, given the locations of the monitor loudspeakers and listener in the testing chamber; these impulse responses were convolved with the anechoic speech comprehension test materials for presentation to the test subjects. The measured RTs at the listener position for the five RT scenarios are shown in Fig. 2(a). The measured BNLs at the listener position for the three BNL scenarios are shown in Fig. 2(b).

Participants were asked to conduct two simultaneous tasks during the testing: (1) speech comprehension tasks and (2) an Adaptive Pursuit Rotor (APR) task. A dual task paradigm was selected to avoid a ceiling effect in the speech comprehension scores, whereby the subjects could get all answers correct although at greater effort under certain conditions. The speech comprehension tasks were adapted from the Test of English for International Communication (TOEIC). Fifteen equivalently difficult sets of speech comprehension tasks were developed. Each set consisted of four different question types that took approximately 15 minutes in total to complete: (a) matching the correct verbal statement to a photo on the screen; (b) matching the correct verbal reply to a verbal question; (c) listening to an oral conversation between two talkers and then selecting correct verbal replies to verbal questions on the conversation; and (d) listening to an oral presentation by one talker and then selecting correct verbal replies to verbal questions on the speech. During one 45-minute testing session, the participants would be exposed to one consistent background noise level and three different RT conditions, via three sets of speech comprehension tasks. Each test subject participated in six different 45-minute testing sessions, to include all 15 acoustic conditions as well as three practice cases. Accuracy in the speech comprehension tasks was quantified by the percentage of questions answered correctly within each 15 minute test.



(a) (b)

Figure 2. (a) Measured reverberation times (mid-frequency averages shown in legend) and (b) measured background noise levels (RC and signal-to-noise ratio values shown in legend) across octave bands at the listener position for the five RT and three BNL conditions.

The APR task involved tracing a dot around a circle, as presented on a screen below the monitor with the speech comprehension tasks (see Fig. 1). The speed of the dot would vary adaptively so that the participant maintained being on-target 80% of the time. The average speed in rotations per minute (rpm) was quantified for each 15 minute speech comprehension task.

2.2 Participants

All test subjects in both studies participated in individual orientation sessions that involved a hearing screen to ensure that subjects had lower hearing thresholds than 25 dB HL from 125 Hz to 8000 Hz for both ears. During the orientation, subjects were also screened on their English proficiency using three different tests: the Woodcock-Johnson III NU Tests of Cognitive Abilities for (a) listening span and (b) oral comprehension, and (c) a Bilingual Verbal Abilities Test (BVAT). Each subject's results from the three tests were used to create a composite 'standardized English proficiency score', which separated the non-native and native-English speakers quite well. Figure 3 shows the range of this standardized score across the participants for Study 1. No subjects participated in both Study 1 and Study 2.

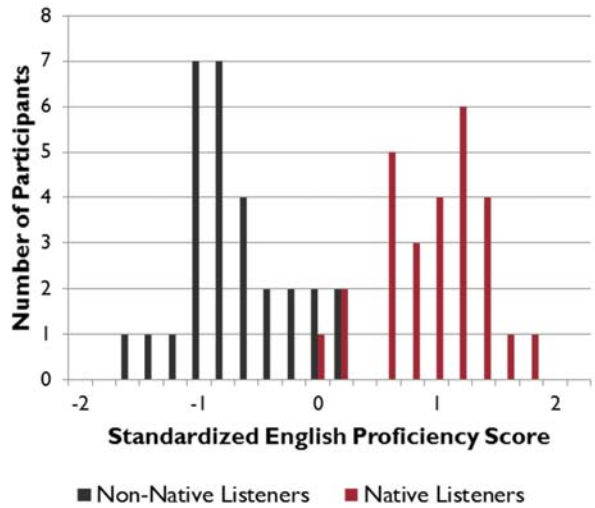


Figure 3. Number and range of standardized English proficiency scores for the native and non-native English-speaking listeners in Study 1.

There were 26 native English-speaking participants and 29 non-native English-speaking participants in Study 1. In Study 2, there were 20 native English-speaking participants, 19 in the NNC category whose native language was Mandarin Chinese, and 20 in the NNO category with other native languages besides Chinese or English.

3. Study 1 Results

A mixed-design analysis of covariance (ANCOVA) was used to statistically analyse the results from Study 1. The independent variables were the RT and BNL conditions, both of which were within-subject as all participants were tested under all acoustic conditions. English proficiency, though, was a between-subject independent variable as it varied across participants. Finally, the dependent variable was taken to be the speech comprehension score in rationalized arc-sine units or RAU [14].

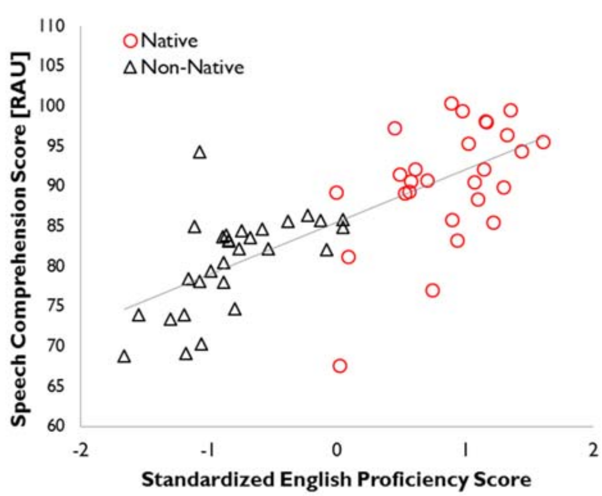


Figure 4. Speech comprehension scores in RAU from Study 1, averaged across 15 acoustic conditions, as a function of English proficiency level for both native and non-native English-speaking listeners.

Results show a statistically significant main effect of English proficiency [$F(1,54) = 67.37$, $\eta_p^2 = 0.55$, $p < 0.001$]; the greater a subject's English proficiency, the better they scored on the speech comprehension tasks (Fig. 4). There is also a significant main effect for BNL [$F(2,108) = 36.26$, $\eta_p^2 = 0.39$, $p < 0.001$]. As shown in Fig. 5, planned comparisons indicate that in comparison to the lowest condition (RC-30), significant performance degradation is observed at the RC-50 condition ($d = 1.18$, $p < 0.001$) but not in RC-40.

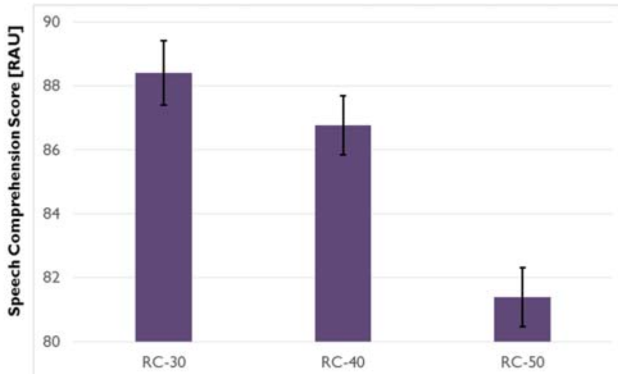


Figure 5. Marginal means of speech comprehension performance in Study 1, averaged across all RT scenarios for each BNL condition. Error bars indicate one standard error.

A significant main effect is also found for RT, but at a much lower effect size [$F(4,216) = 3.73$, $\eta_p^2 = 0.05$, $p = 0.006$]. The planned comparisons against the lowest RT condition of 0.4 sec show that significant performance degradation is observed at the 0.8 sec ($d = 0.38$, $p = 0.007$) and 1.2 sec ($d = 0.42$, $p = 0.003$) conditions, but not in the 0.6 sec or 1.0 sec conditions (Fig. 6).

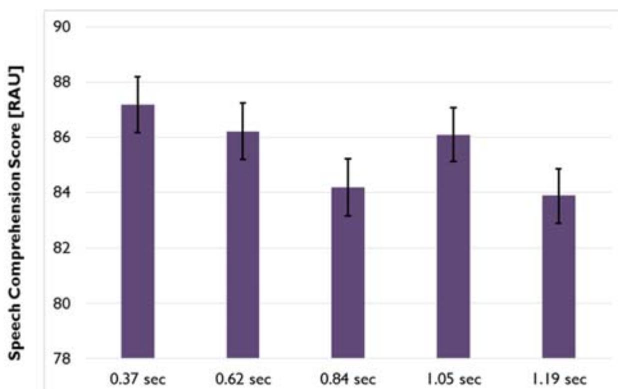


Figure 6. Marginal means of speech comprehension performance in Study 1, averaged across all BNL scenarios for each RT condition. Error bars indicate one standard error.

Finally there is a significant interaction between BNL and English proficiency level [$F(2, 108) = 5.72$, $\eta_p^2 = 0.08$, $p = 0.004$]. Figure 7 highlights this interaction; participants with lower English proficiency level do significantly worse on the speech comprehension task with increasing BNL, specifically from RC-30 to RC-50 ($p < 0.004$).

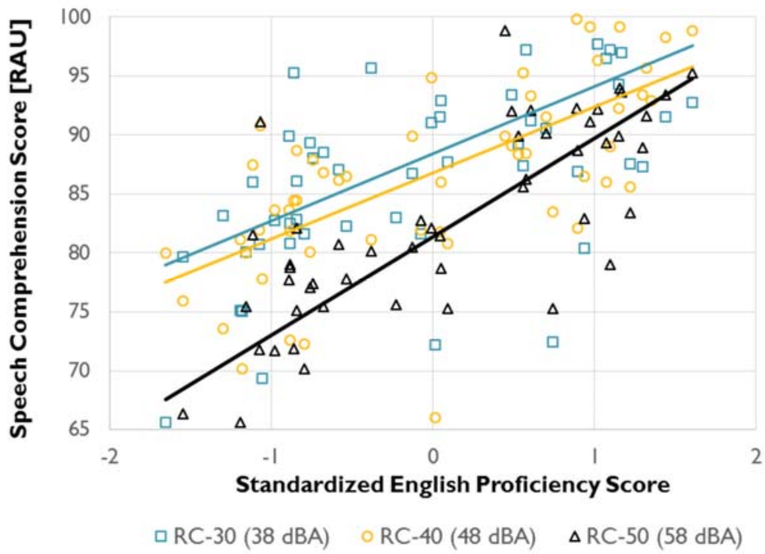


Figure 7. Relation of speech comprehension performance and standardized English proficiency level under the three BNL conditions in Study 1.

The Study 1 results indicate that higher levels of background noise and reverberation negatively affect speech comprehension performance, although the negative effect is stronger for BNL (η_p^2= 0.39) than for RT (η_p^2= 0.05). Non-native English-speaking listeners generally scored 10 RAU (or approximately 10%) below native English-speaking listeners on the speech comprehension tests, but their performance degraded much more significantly at the highest BNL tested. Additional insight comes from running similar ANCOVA models separately for the native and non-native English-speaking listener groups. As summarized in Table 1, both BNL and RT were detrimental for non-native English-speaking listeners with similar effect sizes for the main effects. However, while native English-speaking listeners were negatively impacted by higher BNL, they were not influenced by longer RTs. Native English-speaking listeners appear to be able to compensate for the higher RTs used in this study investigating speech comprehension.

Table 1. Effect size comparisons of the significant main effects and interactions from the ANVOCA analyses of speech comprehension performance in Study 1 between native and non-native English-speaking listener groups.

	Native Listeners (N=26)		**Non-Native Listeners (N=29)**	
	p-value	**η_p^2**	**p-value**	**η_p^2**
English Proficiency Level	0.006	0.28	0.001	0.39
BNL	0.053	0.12	0.005	0.20
RT	0.62	0.03	0.007	0.18
RT x English Proficiency Level	0.68	0.02	0.01	0.12

4. Study 2 Results

Study 2 involved non-native English-speaking talkers presenting in English. Results from the ANCOVA model show that there were statistically significant main effects for English proficiency level (Fig. 8) [$F(1, 57) = 20.49$, $\eta_p^2 = 0.25$, $p < 0.001$], BNL [$F(2, 114) = 122.85$, $\eta_p^2 = 0.67$, $p < 0.001$], and RT [$F(4, 228) = 6.12$, $\eta_p^2 = 0.09$, $p < 0.001$]. Planned comparisons are used to identify the level of performance degradation with the lowest condition as the reference level. For BNL (Fig. 9), listeners performed significantly better in the RC-30 condition than either of the other two conditions: RC-40 (d = 31, p = 0.022) and RC-50 (d = 1.8, p < 0.001). For RT (Fig. 10), listeners performed significantly better in the 0.4 sec scenario as compared to the three highest RT conditions tested: 0.8 sec (d = 0.32, p = 0.02), 1.0 sec (d = 0.42, p = 0.002), and 1.20 sec (d = 0.45, p = 0.001).

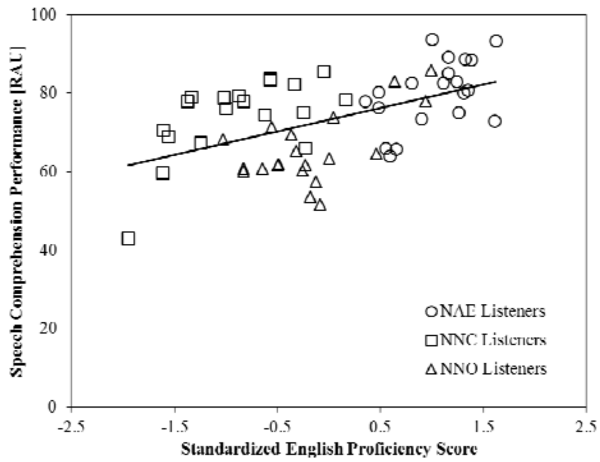


Figure 8. Speech comprehension scores in RAU from Study 2, averaged across 15 acoustic conditions, as a function of English proficiency level for all listener groups (NAE = native American English speaking; NNC = native Mandarin Chinese speaking; NNO = other native language speaking).

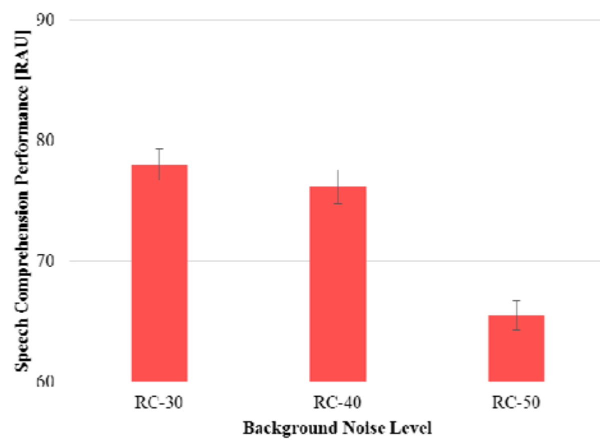


Figure 9. Marginal means of speech comprehension performance in Study 2, averaged across all RT scenarios for each BNL condition. Error bars indicate one standard error.

Additional insight comes from analysing the results through grouping each of the three listener sets, rather than using English proficiency as an independent variable. As plotted in Fig. 11, results show that the NAE listener group scored significantly higher on speech comprehension tasks than the NNC and NNO listener groups together (d = 1.04, p < 0.001), and the NNC listener group scored significantly higher than the NNO group (d = 0.89, p = 0.006). These results suggest that non-native English-speaking listeners still perform worse than native English-speaking listeners on foreign-accented speech comprehension under assorted acoustic conditions. However, those who share the same native language with the non-native talkers appear to benefit from the matched accent and are able to understand the accented English speech better than other non-native English-speaking listeners.

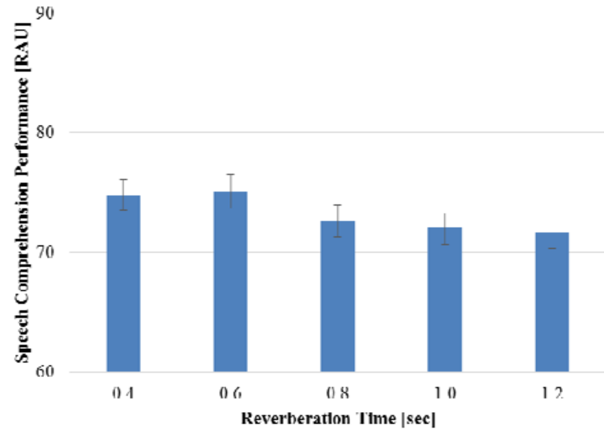


Figure 10. Marginal means of speech comprehension performance in Study 2, averaged across all BNL scenarios for each RT condition. Error bars indicate one standard error.

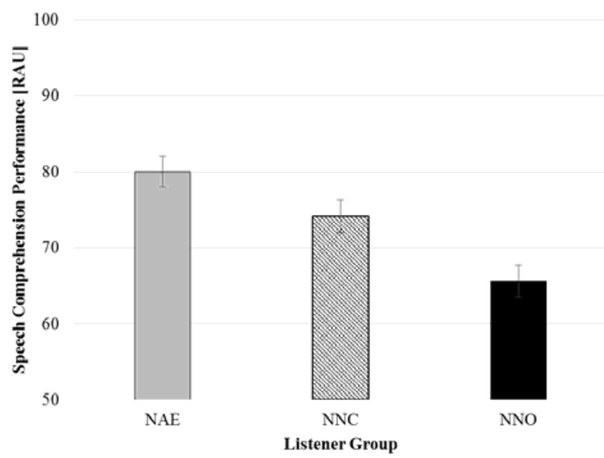


Figure 11. Marginal means of speech comprehension performance in Study 2 across the three listener groups. Error bars indicate one standard error.

5. Combined Analysis

Combining the results from both Study 1 and Study 2 allows more in-depth investigation of the effect of talker accent on speech comprehension by the different listener groups under assorted acoustic conditions. A mixed-design analysis of variance (ANOVA) was used with RT and BNL as within-subject independent variables, and with talker accent (American English or Mandarin Chinese) and listener group (NAE, NNC, or NNO) as between-subject independent variables. English proficiency level was not controlled for comparisons among listener groups at this point.

Statistically significant main effects were found for talker accent [$F(1, 108) = 48.62$, $\eta_p^2 = 0.30$, $p < 0.001$], listener group [$F(1, 108) = 26.12$, $\eta_p^2 = 0.31$, $p < 0.001$], BNL [$F(2, 216) = 146.38$, $\eta_p^2 = 0.57$, $p < 0.001$], and RT [$F(4, 432) = 8.42$, $\eta_p^2 = 0.06$, $p < 0.001$]. For talker accent, post hoc analysis was performed to compare listeners' comprehension performance of speech produced by native English-speaking versus native Mandarin Chinese-speaking talkers. It was found that listeners performed worse in comprehending English speech with Mandarin Chinese accent ($d = 0.65$, $p < 0.001$).

Two-way interactions were also found to be statistically significant for BNL x talker accent [$F(2, 216) = 7.82$, $\eta_p^2 = 0.06$, $p = 0.001$] and BNL x listener group [$F(4, 216) = 2.55$, $\eta_p^2 = 0.03$, $p = 0.04$]. Figure 12 plots the interaction between BNL and talker accent; planned comparisons show that the performance deficit of comprehending Chinese-accented speech was significantly greater under the RC-50 than the RC-30 condition ($p = 0.001$). Figure 13 graphs the other two-way interaction between BNL and listener group; planned comparisons indicate that speech comprehension performance decrease between the RC-30 and RC-50 BNL conditions significantly differed across listener groups ($p = 0.019$). More specifically, as BNL increased from RC-30 to RC-50, NAE listeners experienced significantly less performance degradation than NNC and NNO listeners together ($p = 0.001$).

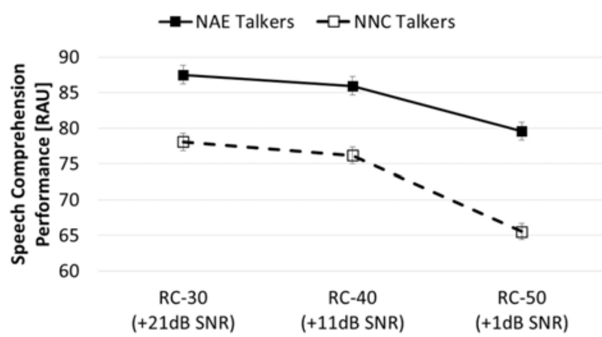


Figure 12. Two-way interaction effect between BNL and talker accent on speech comprehension performance over the combined Studies 1 and 2. Error bars indicate one standard error.

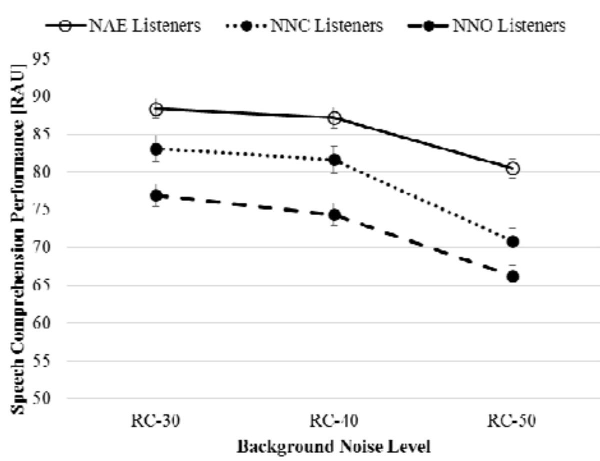


Figure 13. Two-way interaction effect between BNL and listener group on speech comprehension performance over the combined Studies 1 and 2. Error bars indicate one standard error.

The only significant interaction involving RT was a three-way interaction of RT x talker accent x listener [$F(8, 432) = 2.38$, $\eta_p^2 = 0.02$, $p = 0.016$]. As Fig. 14 displays, NAE listeners experienced a greater performance deficit from 0.4 sec to 0.8 sec RT when listening to the non-native English-speaking talkers, as compared to NNC listeners with matched foreign accent. It appears that the NNC listeners are able to suppress the negative impact of excessive RT in this case, much as the NAE listeners did in Study 1.

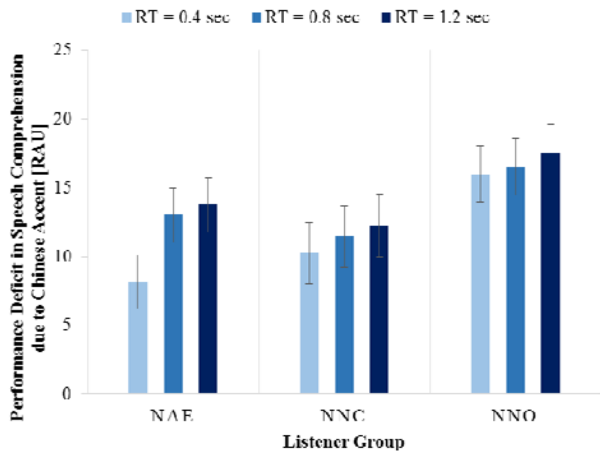


Figure 14. Three-way interaction effect shown as speech comprehension performance deficits due to talker having a Chinese accent, with listener group (NAE vs. NNC vs. NNO) and reverberation time (0.4 vs. 0.8 vs. 1.2 sec). Error bars indicate one standard error.

Finally, Table 2 presents a summary of results from adding English proficiency level to test mixed-design ANCOVA models for each listener group. The data further support that listeners with matched foreign accent to the talkers do not evidence the negative impact of longer reverberation times that other listener groups do.

Table 2. Effect size comparisons of the significant main effects and interactions on speech comprehension performance among the three listener groups in the combined Studies 1 and 2. N1 is the number of listeners in Study 1, while N2 is the number of listeners in Study 2. Bolded values indicate statistically significant results.

	NAE Listeners (N1 = 26, N2 = 20)		**NNC Listeners (N1 = 10, N2 = 19)**		**NNO Listeners (N1 = 19, N2 = 20)**	
	p-value	**η_p^2**	**p-value**	**η_p^2**	**p-value**	**η_p^2**
English Proficiency Level	**<0.001**	**0.27**	**0.002**	**0.33**	**<0.001**	**0.46**
Talker Accent (NAE vs. NNC)	**<0.001**	**0.36**	≥0.056	0.13	**<0.001**	**0.68**
BNL	**0.004**	**0.12**	**<0.001**	**0.37**	**<0.001**	**0.44**
RT	≥0.38	0.02	≥0.18	0.06	**0.001**	**0.12**
BNL x Talker Accent	**<0.001**	**0.2**	≥0.51	0.03	0.068	0.07

6. Conclusions

This paper presents the results of two studies conducted at the University of Nebraska – Lincoln on how reverberation time and background noise conditions in rooms can impact performance by ESL and native English-speaking listeners on comprehension of speech by ESL and native English-speaking talkers. Study 1 utilized native English-speaking talkers, while Study 2 had non-native English-speaking talkers presenting in English, who spoke Mandarin Chinese as their native language. Results clearly indicate that higher background noise levels degrade performance by all listening groups, in comparison to the lowest BNL condition. More specifically, in Study 1 with native

English-speaking talkers, speech comprehension performance at RC-50 (or +1 dB SNR) was significantly lower than at RC-30 (or +21 dB SNR). With ESL talkers in Study 2, the speech comprehension performance at RC-40 (or +11 dB SNR) was also significantly lower from RC-30; talkers with foreign accent are more difficult to comprehend at higher background noise levels. Conclusions may also be drawn that listeners with matched accent to the talkers are more capable of coping with longer reverberation times (≥ 0.8 sec), supporting the interlanguage benefit of matched accent, as first described by Bent and Bradlow [15]. It appears that background noise level effects on speech comprehension performance is more dependent on the talker's accent (all groups do worse for non-native English-speaking talkers at higher BNL), while reverberation time effects on speech comprehension performance is more dependent on the listener (those with matched accent to the talker do not experience negative impact of higher RT).

Because modern learning environments are likely to include non-native English-speakers as talkers and listeners, the post hoc analyses from the investigations described herein can be used to support appropriate design guidelines for BNL and RT in classrooms. The two studies together find that the cut-off above which speech comprehension performance degrades is between the RC-30 and RC-40 background noise conditions (~38 dBA or +21 SNR, and ~48 dBA or +11 SNR), and between reverberation times of 0.6 sec and 0.8 sec. Interestingly, these guidelines align with those already suggested in the ANSI S12.60 standard.

ACKNOWLEDGEMENTS

The author gratefully acknowledges former graduate student, Dr. Zhao 'Ellen' Peng, who conducted the work presented in this paper as part of her doctoral dissertation at the University of Nebraska – Lincoln [16]. The research was funded by grants from the Paul S. Veneklasen Research Foundation and a Research Seed Grant from the UNL Durham School of Architectural Engineering and Construction.

REFERENCES

1 American National Standard Institute, *ANSI/ASA S12.60 Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools*, (2010).

2 Klatte, M., Lachmann, T., and Meis, M. Effects of noise and reverberation on speech perception and listening comprehension of children and adults in a classroom-like setting, *Noise & Health,* **12**, 270–282, (2010).

3 Valente, D. L., Plevinsky, H. M., Franco, J. M., Heinrichs-Graham, E. C., and Lewis, D. E. Experimental investigation of the effects of the acoustical conditions in a simulated classroom on speech recognition and learning in children, *Journal of the Acoustical Society of America,* **131**, 232-246, (2012).

4 Aud, S., Hussar, W., Planty, M., Snyder, T., Bianco, K., Fox, M., Frohlich, L., Kemp, J., and Drake, L. *The Condition of Education 2010 (NCES 2010-028)*, US Department of Education, Institute of Education Sciences, Washington, DC, (2010).

5 Takayanagi, S., Dirks, D. D., and Moshfegh, A. Lexical and talker effects on word recognition among native and non-native listeners with normal and impaired hearing, *Journal of Speech, Language and Hearing Research*, **45**, 585-597, (2002).

6 Rogers, C. L., and Lopez, A. S. Perception of silent-center syllables by native and non-native English speakers, *Journal of the Acoustical Society of America,* **124**, 1278-1293, (2008).

7 Shi, L. F. Normal-hearing English-as-a-second-language listeners' recognition of English words in competing signals, *International Journal of Audiology*, **48**, 260-270, (2009).

8 Bradlow, A. R., and Bent, T. The clear speech effect for non-native listeners, *Journal of the Acoustical Society of America,* **112**, 272-284, (2002).

9 Cutler, A., Weber, A., Smits, R., and Cooper, N. Patterns of English phoneme confusions by native and non-native listeners, *Journal of the Acoustical Society of America*, **116**, 3668-3678, (2004).

10 Rogers, C. L., Lister, J. J., Febo, D. M., Besing, J. M., and Abrams, H. B. Effects of bilingualism, noise, and reverberation on speech perception by listeners with normal hearing, *Applied Psycholinguistics,* **27**, 465-485, (2006).

11 Bent, T., Kewley-Port, D., and Ferguson, S. H. Across-talker effects on non-native listeners' vowel perception in noise, *Journal of the Acoustical Society of America,* **128**, 3142-3151 (2010).

12 National Science Board, *Science and Engineering Indicators 2012,* Arlington VA: National Science Foundation (NSB 12-01), (2012).

13 Downey, R., Farhady, H., Present-Thomas, R., Suzuki, M., and Van Moere, A. Evaluation of the usefulness of the Versant for English test: a response, *Language Assessment Quarterly,* **5**, 160-167, (2008).

14 Sherbecoe, R. L., and Studebaker, G. A. Supplementary formulas and tables for calculating and interconverting speech recognition scores in transformed arcsine units, *International Journal of Audiology,* **43**, 442-448, (2004).

15 Bent, T., and Bradlow, A. R. The interlanguage speech intelligibility benefit, *Journal of the Acoustical Society of America*, **114**, 1600-1610, (2003).

16 Peng, Z., *Designing Acoustics for Linguistically Diverse Classrooms: Effects of Background Noise, Reverberation and Talker Foreign Accent on Speech Comprehension by Native and Non-Native English-Speaking Listeners*, Doctor of Philosophy Dissertation, Architectural Engineering Program, University of Nebraska - Lincoln, (2014).