EFFECTS OF REVERBERATION AND NOISE ON SPEECH PERCEPTION BY CHILDREN WITH NORMAL AND IMPAIRED HEARING – PRELIMINARY RESULTS

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1 INTRODUCTION

Children need acoustic access to the teacher and to class discussions for academic success[1,2]. Today's classrooms in countries around the world, however, have been shown to be noisy and reverberant environments[3,4,5]. Reverberation time is defined as the time in seconds that it takes for sound in a room to decrease in energy by 60 dB after sudden termination[6]. (Data suggest, however, that everyday classroom noise can impede academic progress[7]. It is known only in general terms that noise can be a far greater obstacle to children with hearing loss compared to peers with typical hearing. Less is known about the detrimental effects of noise combined with reverberation.

Many studies have reported on the effects of noise and/or reverberation on speech perception by children[8]. The only published study to date to measure speech perception by children with and children without hearing loss in several speech-to-noise ratios across several degrees of reverberation has been Finitzo-Hieber and Tillman[9]. The children with hearing loss (mild to moderate; n=12) and without hearing loss (n=12) listened monaurally to speech presented from a speaker in 12 combinations of noise (four levels) and reverberation (three degrees). We will compare the results of that study[9] to the present study in the Results section.

A study of students' speech perception needs to include a realistic classroom acoustic environment. Participants in the Finitzo-Hieber and Tillman study[9] listened monaurally and did not have available the benefits of today's digital hearing aids and cochlear implants. The present study included students with digital aids and cochlear implants, as well as use of their binaural amplification as worn in class. This project is intended to answer several questions:

1. To what extent do students with severe-to-profound hearing loss need reduced classroom noise as compared to students with typical hearing when perceiving speech in noise and reverberation?
2. To what extent do students with severe-to-profound hearing loss need reduced reverberation as compared to students with typical hearing when perceiving speech in noise and reverberation?
3. What minimal limits on noise and reverberation are required for optimal speech perception by children with these hearing abilities?

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2 METHODS

2.1 Participants

Participants were 29 school-aged children. Fifteen children (eight boys, seven girls) had severe-to-profound hearing loss. Four used hearing aids and 11 used cochlear implants. Ages ranged from 8.8 to 16.1 years, with a mean of 12.3 years. Included were children with at least fair auditory-only word perception score in quiet (75% or better). An additional 14 children (seven boys and seven girls) had typical hearing (pure-tone thresholds of ≤15 dB HL, 500-8000 Hz). Ages ranged from 8.8 to 16.5 years, with a mean of 12.7 years. Approval for this study for human subjects protection was obtained from the Smith College Institutional Review Board.

2.2 Design and Test Conditions

The study used an 8 x 3 within-subjects, repeated measures design. The first factor was speech-to-noise ratio (S/N) at 8 levels (in 3-dB steps). The second factor was reverberation time (RT) at three levels (0.3s, 0.6s, and 0.9s). The three degrees of reverberation were counterbalanced to the extent possible with the number of participants in each group.

The test classroom had hard-surfaced walls, ceiling and floor. Room dimensions were 10.06 by 6.64 meters, with a ceiling height of 3.35 meters. A carpet 5.79m by 6.10m covered the approximate center of the room. A kitchen sink, stove, cabinets and refrigerator were located along a portion of the back wall, with an approximate total volume of 2.22 m^3. Located in front of the stove was a 0.94 m^3 floor cabinet ("island") with a 2.25 m^2 counter top.

Speech and background noise were produced from a compact disc (CD) of the BKB-SIN Test Version 1.03[10]. The speech level was controlled by means of a two channel audiometer (Grason Stadler 10) and amplified through a sound field system amplifier (Phonic Ear 210) to a single speaker (Phonic Ear 578-S) placed at the front of the classroom. The position of this "teacher" speaker approximated the head position of a teacher, 0.74m from the front of the room and 1.47m above the floor. Participants sat at a school desk near the center of the room and 3.05m from the speaker. This desk position was chosen to approximate the second row in a classroom. Noise levels were controlled through the audiometer and amplified with a second amplifier (Phonic Ear 210) and four speakers (Phonic Ear 578-S). Each speaker faced a corner of the room at a distance of 0.91m from the corner, and was centered 1.47m above the floor.

All acoustic measurements were made with a Larson Davis System 824 (Type 1) meter. The microphone for all measurements was placed at the estimated center of a participant's head when seated at the desk (1.02m high, 3.05m from the teacher speaker). Measurements for speech and babble noise levels were made using speech spectrum noise recorded on the CD. The speech and the babble noise had been recorded on the CD for their frequent peaks to match the level of the speech spectrum noise on the VU meter[11]. The speech level was 60 dBA in the 0.6s RT condition. This speaker output level was not readjusted for the other two reverberant conditions, resulting in speech levels of 58 dBA in 0.3s RT and 61 dBA in 0.9s RT. This speech level was not audible to two participants with hearing loss and, hence, had to be raised by 6 dB for them. Noise levels decreased by 4 dB from 0.6s to 0.3s RT, and increased by 1 dB from 0.6s to 0.9s RT. Noise levels were adjusted by means of the audiometer, and this procedure will be discussed later. Amplifier tone settings were spectrally analyzed and adjusted to comparable outputs.

2.3 Procedure

The dependent variable was the number of correctly-perceived key words in sentences from the BKB-SIN Test[10]. Sentences were used because they may more accurately estimate the effects of reverberation than lists of single words. This may be due to the potential for both backward and forward masking. Words, even when spoken in carrier phrases, may be subject only to forward masking[12]. Sentences may also more accurately represent the form of spoken communication in a classroom. The BKB-SIN Test[10] sentences were in lists of eight, containing a total of 25 key words per list. Each list had been paired with another list on the CD.

Each list pair was established to have perceptual equivalency with the other list pairs in the test[10]. In this study, three list pairs were presented within each reverberant condition. This resulted in a total of six lists per condition containing at total of 150 key words.

A total of nine list pairs, therefore, were presented to each participant across the three reverberant conditions. These nine list pairs were drawn from a pool of 15 in the BKB-SIN Test (List Pairs 4-18)[10]. The order of list pairs was assigned randomly across the three conditions, and without repetition for any one participant. A modification was made to the length of some lists. The BKB-SIN Test[10], in its commercial version has 10 sentences in each of list pairs 1-8. (The remaining lists in the test, numbers 9-18, have eight sentences each.) Sentences 9 and 10 of each list were dropped from each of these lists in order to equalize the number of sentences across all lists. This change likely had little-to-no effect on the test scores. Sentences 9 and 10 of each list in the BKB-SIN[10] were recorded to be presented under the poorest S/Ns. These last two sentences, therefore, would likely not heard by participants with hearing loss. Deleting them, therefore, would likely have no effect on final scores[13]. In regard to participants with typical hearing, as described later, the test was modified for this study so that removing the last two sentences would have the same negligible effect described above.

The BKB-SIN test[10], across eight sentences, has a fixed range of +21 dB S/N to 0 dB S/N (i.e., 3-dB descending steps in S/N per sentence). However, in this study, using the fixed range of +21 dB to 0 dB S/N would not have permitted most participants with hearing loss to reach their optimal performance and not have allowed participants with typical hearing to reach their most challenging S/Ns. Hence, the 21-dB range of the BKB-SIN test[10] was treated as a moveable “bracket”. For participants with poor speech-in-noise perception abilities, the first sentence in a list would be presented in +27 dB S/N (rather than 21 dB S/N). After seven 3-dB declines in S/N, the eighth sentence would present at +6 dB S/N. For a participant with good abilities to perceive speech in noise, the range bracket could begin at a poorer S/N. Following this procedure, participants typically perceived correctly the first two sentences, began to show errors with the next four sentences as the S/Ns declined further, and could recognize few words in the last two sentences. These adaptations of the 21-dB “bracket” to each participant 1) helped yield performance-intensity functions for each participant regardless of hearing ability and 2) limited durations of inaudibility that can discourage a child and decrease test reliability.

Degrees of 0.3s, 0.6s and 0.9s RT were attained in the classroom by adding/removing acoustic pads (each was 0.91m by 0.61m). Reverberation measurements followed procedures recommended in ASTM C423-02a[1], Appendix X2[14]. These procedures were modified, first, with reverberation measured at only one location - the position of the participant’s head - and not at the four positions. Second, RT measurement at 160 Hz was substituted for 125 Hz due to floor noise at 125 Hz. RTs were averaged across 500, 1000 and 2000 Hz[1]. RT 0.3s was attained by hanging 34 acoustic panels on the walls just below ceiling height, by placing eight panels near floor level, and by laying eight panels on the floor, for a total of 50 panels. RT 0.6s was attained by hanging 12 panels on the walls, just below ceiling height. Panels were evenly distributed throughout the room in a pattern replicated for each participant. For RT 0.9s, no panels were in the room. Of the 50 panels used, 45 were 5.0 cm thick and five were 2.5 cm thick, with manufacturer’s noise reduction coefficients of 1.25 and 1.15, respectively[15].

2.4 Statistical Methods

We fit a random intercept regression model[16] with SNR-50 as the outcome. The repeated measures model controlled for age (linear), RT (2 df, 0.3s reference group), hearing status (impaired reference group) and RT*hearing interaction. This model can be thought of as an analogous to a repeated measures analysis of variance, with a more flexible model for repeated measurements. The Stata version 9.1 xtmixed procedure was used for estimation.

3 RESULTS

3.1 SNR-50

The 15 students with severe-to-profound hearing loss (SP), ages 8.8 to 16.1 years (M=12.3) demonstrated SNR-50 values with a range of 11.5 to 16.6 dB. The 14 students with typical hearing (TH), ages 8.8 to 16.5 years (M=12.7) had SNR-50 values between -3.5 and -1.5 dB.

There was a significant association between mean SNR-50 scores for RT (df=2, $p<0.0001$), hearing status ($p<0.0001$), and the interaction between RT and hearing status (df=2, $p<0.0001$), while controlling for age. Age was not a significant predictor of SNR-50 scores ($p=0.22$). The model-based estimates in dB (and standard error) for SNR-50 for a 12-year-old participant are provided in Table 1.

There was a significant difference between each of the following comparison groups (all p-values <0.002): TH in 0.3s RT and TH in 0.9s RT; SP in 0.3s RT and SP in 0.6s RT; SP in 0.3s RT and SP in 0.9s RT; SP in 0.6s RT and SP in 0.9s RT. The comparison between TH in 0.3s RT and TH in 0.6s RT was borderline significant ($p=0.0546$), as was the comparison between TH in 0.6s RT and TH in 0.9s RT ($p=0.0582$). The developers of the BKB-SIN Test[10] previously established critical differences of 1.9-2.0 dB with a 95% confidence interval for this age group and number of list pairs (three) used in each condition as in present study. The SNR-50 scores increase as a function of RT, but that increase was larger for the SP group compared to the TH group. Averaged across the SNR-50 in three RTs, the SP group required a S/N that was 16.2 dB higher than the TH group. In comparison to data by Finitzo-Hieber and Tillman[9], a calculation of SNR-50s for the group with mild to moderate hearing loss suggested they needed roughly a +5 dB higher S/N than children with typical hearing. This difference in higher S/Ns between the two studies may have been due to the difference in hearing loss between the respective groups.

Table 1. - Model-based mean estimates in dB (and standard error) for SNR-50 for a 12-year-old participant in the group with severe-to-profound hearing loss (SP) and in the group with typical hearing (TH).

	0.3s RT	0.6s RT	0.9s RT
SP	11.5	13.0	16.6
TH	-3.5	-2.5	-1.5

(For each estimated mean, the standard error was 0.8.)

3.2 Performance-Intensity Comparisons

The mean scores for each S/N tested within each of the three reverberant conditions are plotted for the two groups in Figure 1. These six performance intensity curves suggest the minimal optimal listening conditions for students with and without hearing loss. For sake of comparison to these more-challenging conditions, most of the SP participants (12/15) were tested with a single BKB-SIN Test[10] list pair presented at 60 dB SPL in quiet in a sound-resistant booth. They obtained a mean speech-perception score of 89% correct.

Figure 1 suggests that, *in the steepest portion of the gradients*, a 3-dB improvement in S/N helps improve speech perception by 16 percentage points for SP group and 21 percentage points for TH group. The lesser benefit for the SP group may be due to an overall narrower range of performance altogether, compared to the TH group. In comparison, data from Finitzo-Hieber and Tillman[9] suggest an approximate improvement of 9 percentage points per 3-dB improvement in S/N for both groups. The difference in benefit between the two groups in the present study, yet a similarity in performance between groups in the previous study, may be due to the fact that there was greater hearing difference between the groups in the present study as compared to the smaller differences between the two groups in the latter study. The difference between the two studies in the effects of changes of 3 dB S/N (16 and 21 points vs. 9 points) on speech perception scores requires further investigation.

Next, the effect of changes in RT on scores was calculated. This required first calculating the change in scores with change in RT for each of the eight S/Ns. For example, for +12 dB S/N, a change in score was calculated for each participant within a group as RT changed from 0.6s to 0.3s. This score was averaged across all participants by group. The same was done for scores at +9 dB S/N, and so forth. All the score changes at each S/N were averaged together to calculate the overall mean change in scores from 0.6s to 0.3s RT. The same was then done for change from 0.9s to 0.6s RT. The same calculations were also made for the S/Ns and RTs in the Finitzo-Hieber and Tillman study[9].

The data (also used to create Figure 1) indicated that, for the group with hearing loss, a decrease for RT 0.9s to 0.6s (averaged across S/Ns) yielded improvements in scores of 11 percentage points. A further decrease, from 0.6s to 0.3s, improved scores by another five points. For the group with typical hearing, these improvements from RT 0.9s to 0.6s and 0.6s to 0.3s yielded improvements in scores of seven and two percentage points, respectively. In comparison, calculations based on data from Finitzo-Hieber and Tillman[9] suggest that, for the group with hearing loss, from RT 1.1s to 0.4s scores improved by 16 percentage points and from RT 0.4s to 0.0s, by another 10 points. For the group with typical hearing, the improvements were 16 and 7 percentage points, respectively. In order to account for the differences in RT values between the two studies, these improvements in scores were then divided by the amount of change in RT in each calculation above. For example, if an improvement in score of 36 percentage points accompanied a change in RT from 0.9s to 0.3s, this was calculated as 36/0.6, or 6 points improvement per decrease of 0.1s in RT. Results from the present study indicated a gain in 2.7 percentage points for every 0.1s decrease in RT for the SP group. By comparison, the data from Finitzo-Hieber and Tillman[9] indicated a gain of 2.4 percentage points for the group with hearing loss. The TH group in the present study demonstrated a gain of 1.5 percentage points for each decrease of 0.1s RT, while the comparative group in Finitzo-Hieber and Tillman study[9] demonstrated an improvement of 2.1 percentage points. The differences in results between the two studies, though not greatly different, need further investigation. To compare the effects of RT on respective groups within the present study, the gains of the TH group were divided by the gains of SP group (i.e., 1.5/2.7). This calculation suggests that the SP group demonstrated a 56% greater gain in scores for each reduction in RT as compared to the TH group.

The data in Figure 1 also suggest that scores for the SP group began to decline rapidly from approximately +15 to +18 dB S/N. Scores for the TH group, however, remained at near-optimal levels to approximately 0 dB S/N, and then fell steeply with further increases in noise level.

Some participants (n=15) were asked informally for their subjective preferences among the three reverberant conditions. Three of the SP group and four of the TH group preferred condition 0.3s RT. Two of the SP group and two of the TH group preferred condition 0.6s RT. None of the SP group and four of the TH group preferred the condition 0.9s RT. These responses appear to reflect trends among SNR-50 scores for each group (Table 1).

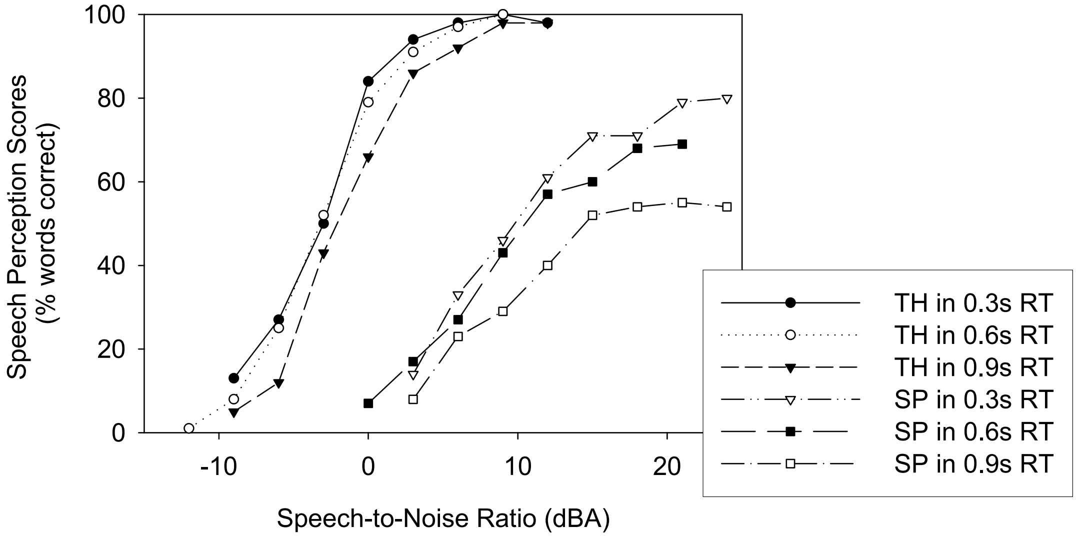

Figure 1. - Plots of mean scores for speech perception for participants with severe-to-profound hearing loss (SP) and with typical hearing (TH) by reverberation time (RT).

4 DISCUSSION

1. *To what extent do students with severe-to-profound hearing loss need reduced classroom noise as compared to students with typical hearing when perceiving speech in noise and reverberation?* Students with severe-to-profound hearing loss needed significantly reduced noise as compared to students with typical hearing. These necessary improvements, based on the present study, exceed 15 dB in terms of speech-to-noise ratios.

2. *To what extent do students with severe-to-profound hearing loss need reduced reverberation as compared to students with typical hearing when perceiving speech in noise and reverberation?* The reduction of reverberation substantially improved speech-perception scores for students with severe-to-profound hearing loss more than for those with typical hearing. In the current study, the improvement in speech perception ability with decreasing reverberation time was approximately 50% greater for students with severe-to-profound hearing loss as compared to the students with typical hearing.

3. *What minimal limits on noise and reverberation are required for optimal speech perception by children with these hearing abilities?* Students with severe-to-profound hearing loss, when in a listening environment with low reverberation time and noise, demonstrated, on average, very good speech perception ability. As expected, they had difficulty with increases in noise and reverberation time. The minimal optimal level for noise was approximately 15 to 20 dB S/N higher than the students with typical hearing. Students with severe-to-profound hearing loss never reached their optimal scores in the test environment, suggesting that the minimal optimal reverberation time may be below 0.3s. The minimal optimal level for noise for student with typical hearing was approximately +3 dB S/N. Speech perception by the group with typical hearing improved significantly in reduced reverberation only when the reductions were large.

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