Research Article

Use of an Application to Verify Classroom Acoustic Recommendations for Children Who Are Hard of Hearing in a General Education Setting

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Purpose: Classrooms including children who are hard of hearing (CHH) may be modified to manage noise and reverberation and improve speech perception. Little is known about the acoustic characteristics of contemporary general education classrooms that include CHH compared to classrooms of typical peers. We proposed the following research questions about the acoustic environment of general education classrooms including CHH: (a) How reliable are acoustic measurements collected using an iOS device, application, and external microphone? (b) What proportion of classrooms meet the American National Standards Institute's standards for unoccupied noise levels and reverberation?

Method: A smartphone application was used to measure sound levels, reverberation, and clarity for 164 general education classrooms including CHH. Linear mixed models were used to examine the following: (a) reliability of acoustic measures made using an application and external microphone and (b) predictors of sound levels,

reverberation, and clarity for elementary classrooms including CHH.

Results: Results indicate the application reliably measures classroom acoustics. Classrooms exceeded the American National Standards Institute's recommended noise levels, but met reverberation time guidelines. Grade; heating, ventilation, and air conditioning status; and room volume predicted classroom acoustics.

Conclusions: As a screening tool, the application was shown to be effective in reliably measuring reverberation and classroom noise levels. The high levels of noise in unoccupied classrooms indicate a need for increased use of noise abatement strategies and the use of remote-microphone systems, especially in classrooms where noise levels cannot feasibly be reduced. Using an application may be a cost-effective method for monitoring important acoustic features that impact children's ability to understand speech in the classroom.

Children who are hard of hearing (CHH) face challenges to learning in academic settings. Even with hearing aids, hearing loss limits access to auditory input from teachers, classmates, and electronic media. Poor classroom acoustics—such as high levels of background noise or reverberation—exacerbate these challenges, adding energetic and informational masking to otherwise audible

speech. Classroom noise and reverberation decrease speech understanding and reduce the ability to encode and consolidate information in memory for students with and without hearing loss (Crandell & Smaldino, 2000; Lewis, Valente, & Spalding, 2015; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Poor acoustics in the classroom have been linked to deficits across academic domains, such as mathematics and reading (Shield & Dockrell, 2008). It is important that children have optimal acoustic access to instruction, regardless of hearing ability, to maximize learning opportunities in the classroom.

The American National Standards Institute (ANSI), in conjunction with the Acoustical Society of America, created standards for classroom acoustics. These standards recommend a maximum unoccupied classroom noise level of 35 dBA and maximum reverberation time (RT60) of 0.6 s (12.60-2010/Part 1; ANSI, 2010). ANSI standards were developed to provide an optimal environment for speech

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understanding for children with normal hearing. The recommended values are likely to underestimate the needs of CHH, who require lower noise levels and reverberation times to perform similarly to children with normal hearing on speech perception tasks (Picard & Bradley, 2001; Whitlock & Dodd, 2008). Furthermore, the standards do not include measures that directly relate to speech intelligibility within a classroom. Clarity (C50), a measure of the ratio of early to late reflections, is affected by acoustic characteristics of the classroom and is associated with better speech intelligibility for children (Bradley & Sato, 2008). Reliable, cost-effective, and efficient means to collect acoustic measurements, including those that relate to speech intelligibility, are needed to determine whether classrooms including CHH are meeting recommended values and providing optimal auditory access of speech.

Typically, acoustic measurements of buildings are performed with expensive equipment by trained professionals to uphold a high standard of accuracy and performance. However, school districts are unlikely to have funding for regular acoustic measurements of classrooms by a trained professional. An alternative approach is to use smartphone applications to measure acoustic characteristics of classrooms. The measurements of certain applications are consistent with traditional, more expensive sound-level meters, especially when used with an external microphone (Kardous & Shaw, 2016). Teachers or other service providers within the school could be taught to perform the measurements using such an application on a smartphone device, eliminating the need for a trained professional and expensive equipment. The use of smartphone applications as an inexpensive and easy-to-use alternative to sound-level meters for classroom measurements is clinically relevant. A recent study evaluated noise levels of a small number of classrooms including children who are deaf and hard of hearing using an iOS device and application (Grempp & Easterbrooks, 2018). The classrooms were either classified as general education ($n = 11$) or separate instruction ($n = 27$), where children who are deaf or hard of hearing received instruction in a separate classroom from peers with typical hearing. The authors found that all of the classrooms including children who are deaf and hard of hearing exceeded ANSI-recommended guidelines for unoccupied noise levels (reverberation time was not measured), regardless of type of instruction. An application such as that used in the Grempp and Easterbrooks study would allow educators to monitor noise levels and reverberation without purchasing expensive equipment and performing elaborate measurement techniques. However, the use of applications for acoustic measurements in classrooms has not been widely validated in environments with known acoustic characteristics. Reliable, validated measurements from an application could enable routine monitoring of noise and reverberation, leading to an increased awareness of classroom acoustics and need for/efficacy of classroom modifications.

CHH may require classroom modifications that improve speech understanding, such as lowering noise levels and reverberation times, but few data exist to confirm if

contemporary acoustic learning environments of CHH are better than peers who have normal hearing. Questions remain about whether current general education classrooms that include CHH meet ANSI guidelines and provide an acoustic environment conducive to the understanding of speech. The goal of this study was to use an iOS device, application, and external microphone to document acoustic characteristics (unoccupied and occupied sound levels, reverberation time, and clarity of speech) for a large number of general education classrooms in which CHH learn. The following research questions will be addressed:

1. How reliable are the acoustic measurements collected using an iOS device, application, and external microphone?
2. What proportion of classrooms meet ANSI standards for unoccupied noise levels and reverberation?

Method

Acoustics measurements were collected in classrooms that included participants from the Outcomes of School-Age Children who are Hard of Hearing and Complex Listening Skills in Children who are Hard of Hearing research studies. CHH were initially recruited as part of the Outcomes of Children with Hearing Loss research study (see Tomblin et al., 2015, for recruitment details) or through a research participant database at UNC-Chapel Hill, Boys Town National Research Hospital and the University of Iowa. Children included in the studies presented with bilateral, permanent hearing loss, primarily between 25 and 75 dB HL pure-tone average (average of thresholds at 0.5, 1, 2, and 4 kHz). All children had nonverbal cognitive abilities within the average range and spoke English as their primary language. All families signed Institutional Review Board–approved consent forms prior to participation, as well as releases allowing study personnel to request permission from the child's classroom teacher to obtain the acoustic measurements. Participating school districts granted permission for data collection in their classrooms, when requested. The acoustic measurements were completed at local schools by study personnel. The equipment and instructions to complete the measurements were shipped to teachers when schools were located outside of driving distance for the research staff. Teachers then completed the measurements, with the aid of study personnel over the phone, if necessary. For the purpose of examining reliability, all measures were repeated three times within the classrooms when time allowed.

Classrooms

One hundred sixty-four classrooms ($n = 36$ first grade, $n = 69$ third grade, $n = 59$ fourth grade) are included in the data set. One hundred fifty-six had a description of classroom type: 146 (93.6%) classrooms were conventional, four (2.6%) were dual (two adjacent conventional classrooms without a dividing wall), five (3.2%) had an open floor plan,

and one (0.6%) was modular. The remaining eight classrooms are missing a descriptor regarding classroom type. Room volume was reported for 111/164 (67.7%) classrooms. Room volume varied from 4,211 ft³ to 12,066 ft³ ($M = 7,702$ ft³, $SD = 1,369$). If a classroom was represented for multiple students or multiple years, only the earliest measurements of that classroom were included in the data set.

Acoustic Measurements

Measurements were collected using the Studio Six Digital AudioTools application on an iPod Touch 5. A Studio Six Digital iTestMic or iTestMic2 was connected to the iPod Touch via the lightning port or via an adaptor. The microphone and application were calibrated according to the instructions provided by AudioTools (<http://www.studiosixdigital.com/support/audiotools-user-guide/audiotools-manual-rev-72.pdf>). One calibration procedure involved connecting a piston phone to the microphone and adapting the application's dB values to match the output of the piston phone. Another procedure involved playing a reference tone via a calibrated source in sound field (e.g., audiometer and loudspeaker in sound field within a sound-treated audiometric test booth) and adapting the dB in the application to match the level obtained using a sound-level meter. Measurements completed using applications and external microphones in this manner have been shown to be ± 1 dB compared to those performed with a sound-level meter (Kardous & Shaw, 2016). Prior to data collection, device noise floor measurements were performed using the Real Time Analyzer function within the AudioTools application in an anechoic chamber. The average device noise floor value over six repetitions was 28.9 dBA ($SD = 1.2$).

For the purposes of our study, we analyzed reverberation time several different ways using the information provided within the AudioTools results file: RT60, T30Mid, and T30 at 1 kHz. RT60 is commonly used when referring to reverberation and is understood to be the amount of time it takes for an initial impulse sound to decay by 60 dB. T30 represents the amount of time it takes for the initial impulse sound to decay 30 dB—averaging the measurements either at the 500-Hz and 1000-Hz octave bands (T30Mid) or at the 1000-Hz octave band (T30 at 1 kHz). Measurements of T30 are often extrapolated to represent RT60 in conditions where a decay of 60 dB is not feasible (e.g., in situations where the noise floor masks the later reflections of the impulse sound). The research staff took steps to ensure that the device setup produced valid measurements of reverberation time in comparison to sound samples with known reverberation characteristics. A series of recorded impulse responses (IRs) with known reverberation times (RT60 = 0.24, 0.53, 0.93, 1.64 s) were played through a loudspeaker in a sound-treated test booth. The responses were recorded using the IR module of the AudioTools application. Three repetitions of each known reverberation time were measured. The results from the AudioTools application indicated that the noise floor was too high to effectively calculate RT60; thus, measures of T30 were

used to examine reliability. The mean differences between the four known RT60s and the AudioTools estimates of RT60 based on T30Mid and T30 at 1 kHz were less than 0.03 s, indicating good validity of the reverberation measurements. Within the classroom measurements, estimates of T30 Mid and T30 at 1 kHz were highly correlated within measurements ($r = .86$, $p < .001$). Due to a larger number of observations of T30 at 1 kHz than T30 Mid, T30 at 1 kHz was used to represent reverberation in the statistical analyses.

Background noise levels were captured using the Real Time Analyzer function within the AudioTools application. Average sound level was reported using dBA weighting with 1/3 octave (25–20000 Hz) bins, flat weighting, and 0.5-s decay. A level of 35 dBA, per ANSI guidelines, was used as criteria for appropriate unoccupied sound levels in the classroom. Reverberation time (T30 Mid) and clarity (C50) were calculated from a recording of a handclap and at least a 5-s decay interval using the IR function within the AudioTools application. The noise floor within the classrooms was too high to calculate RT60; thus, an extrapolation to a decay of 60 dB was obtained from the T30Mid measurement. A value of 0.6 s or less was used as acceptably meeting guidelines for reverberation.

Occupied noise levels were obtained when the students were doing quiet desk work or reading in the classroom. Occupied measurements were attempted as close to the students' desk locations as possible without interfering with their work. Unoccupied noise levels and reverberation were measured when the students were absent from the classroom. Unoccupied measurements were performed at the students' desks. Due to time or constraints with the classroom schedule, research staff was sometimes unable to capture three repetitions of all occupied and unoccupied measurements. Similarly, some of the teachers who performed the measurements did not record three repetitions. For this reason, there are varying numbers of each measurement, as listed in the results below.

Examiners or teachers documented whether heating, ventilation, and air conditioning (HVAC) was on or off during each measurement. HVAC status was missing for 35 classrooms; these classrooms' HVAC statuses were categorized as unknown.

Analysis

Statistical analyses were performed using the R software program (Version 3.1.1, R Core Team, 2014). Linear mixed models (lme4 package, Bates et al., 2015) were used to assess contributions of measurement repetition, HVAC status, and room volume on each dependent variable (unoccupied or occupied noise levels, reverberation, clarity). Parent involvement may influence teacher perception of student communication difficulty in the classroom and, thus, teacher responsiveness to improving access to instruction for CHH (Rekkedal, 2015). Compared to teachers who are less aware of the impact of hearing loss on learning, teachers who are more aware may be more likely to modify their classrooms

to improve the acoustic learning environment for CHH. Although we did not measure parent involvement or teacher responsiveness, we included individual random intercepts for each student as a conservative effort to account for potential effects of these parent- and teacher-related factors on each student's classroom acoustics. Room volume was normalized around the median value and converted to z scores to avoid issues with scaling. The ggplot2 (Wickham, 2016) package was used to create plots of the data. Prior to analysis, the distribution of residuals for each statistical model was visually inspected to ensure that assumptions of normality were met.

Results

Classroom Noise Levels

Figure 1 displays unoccupied classroom sound levels, with respect to the ANSI standard of 35 dBA, and occupied classroom sound levels, which have no recommended guidelines. Four hundred thirteen measurements of unoccupied sound levels ($M = 43.6$ dBA, $SD = 8.2$) were taken, including up to three repetitions done for reliability within each classroom (one repetition = 158, two repetitions = 131, and three repetitions = 124). A linear mixed model with a random intercept for participant was conducted with repetition, grade (first, third, fourth), and HVAC status (on, off,

unknown) as predictors of unoccupied sound level. The effect of repetition on unoccupied sound level was significant, $F(1, 309) = 7.63$, $p = .006$, with later repetitions having lower sound levels (-0.8 dB) than earlier repetitions. There was also a significant relationship between unoccupied sound levels and HVAC status, $F(1, 384) = 25.26$, $p < .001$. Unoccupied sound levels were 4.9 dB higher when HVAC was on ($p < .001$) and 6.6 dB higher when HVAC status was unknown ($p < .001$) compared to when HVAC was off. Grade contributed significantly to unoccupied sound levels, $F(2, 412) = 10.76$, $p < .001$. The only significant difference between grades was fourth grade had lower sound levels (-2.1 dB, $p = .01$) than first grade. Based on the first repetition of unoccupied sound levels, only 12.7% (20 out of 158) of classrooms had unoccupied sound levels less than 35 dBA. The classrooms with HVAC off were more likely to meet classroom acoustics standards ($n = 13/41$, 31.7%) compared to HVAC on ($n = 2/83$, 2.4%) or HVAC status unknown ($n = 5/34$, 14.7%).

Four hundred fourteen measurements of occupied sound levels ($M = 54.7$ dBA, $SD = 8.5$) were taken, including up to three repetitions done for reliability (one repetition = 157, two repetitions = 133, and three repetitions = 124). A linear mixed model with a random intercept for participant was conducted with repetition, grade (first, third, fourth), and HVAC status (on, off, unknown) as predictors of the occupied sound levels. The effects of repetition,

Figure 1. Unoccupied and occupied ambient noise levels (left and right panels, respectively) by repetition. Solid lines inside the boxes represent the median values. The dashed line indicates the American National Standards Institute's recommended noise level (35 dBA) for unoccupied classrooms.

$F(1, 341) = 0.55, p = .45$, grade, $F(2, 341) = 0.15, p = .69$, and HVAC status, $F(2, 367) = 2.84, p = .06$, were not significant.

Reverberation

Estimates of reverberation time were based on T30 at 1 kHz. Three hundred ninety-one measurements of T30 at 1 kHz were taken ($M = 0.34$ s, $SD = .24$), including up to three repetitions done for reliability (one repetition = 148, two repetitions = 125, and three repetitions = 118). A linear mixed model with a random intercept for participant was conducted with repetition, grade (first, third, fourth), HVAC status (on, off, unknown), and volume (ft^3) as predictors of reverberation. Because not all classrooms had reported measurements of volume, only 266 measurements of T30 at 1 kHz were used in the linear mixed model analysis. Figure 2 displays the range of T30 at 1 kHz values as a function of repetition in comparison with the ANSI guideline of 0.6 s. Grade was the only significant predictor of reverberation time, $F(2, 208) = 7.1, p < .001$. The only significant difference between grades was T30 at 1 kHz was 0.45 s longer (poorer) for fourth grade than first grade ($p < .5$). Repetition, $F(2, 195) = 0.62, p = .54$, HVAC status, $F(2, 160) = 0.0162, p = .90$, and volume, $F(1, 122) = 0.36, p = .54$, were not related to T30 at 1 kHz. Based on the first repetition of all T30 at 1 kHz measurements, 95.9%

(142 out of 148) of classrooms were lower than the recommended ANSI guideline of 0.6 s.

Clarity

Three hundred ninety measurements of clarity (C50) were taken, including up to three measurements done for reliability (one measurement = 146, two measurements = 126, and three measurements = 118). A linear mixed model with a random intercept for participant was conducted with repetition, grade (first, third, fourth), HVAC status (on, off, unknown), and volume (ft^3) as predictors of clarity (C50). Similar to the linear mixed model analysis for reverberation, fewer observations were included in the analysis for clarity due to missing reports of room volume. Two hundred sixty-five total measurements of clarity (C50) were used for the analysis ($M = 16.3$ dB, $SD = 5.6$). Volume, $F(1, 121) = 1331, p < .001$, and HVAC status, $F(2, 160) = 8.45, p = .002$, were the only significant predictors of C50. C50 increased with greater room volume. Increased C50 with greater volume indicates that the ratio of earlier reflections to later reflections (prior to 50 ms and after 50 ms, respectively) was larger in rooms with greater volume than smaller rooms. As seen in Figure 3, C50 for rooms with HVAC on or where the HVAC status was unknown was lower than rooms with HVAC off by 3.6 and 3.5 dB, respectively. Repetition, $F(1, 193) = 2.3101, p = .13$,

Figure 2. T30 at 1 kHz (s) by repetition. Solid lines inside the boxes represent the median values. The dashed line indicates the American National Standards Institute's recommended reverberation time (0.6 s) for unoccupied classrooms.

Figure 3. C50 (dB) by HVAC status. Solid lines inside the boxes represent the median values. HVAC = heating, ventilation, and air conditioning.

and grade, $F(2, 270) = 2.0210$, $p = .13$, were not significant predictors of C50.

Discussion

The first research question focused on the reliability of measurements taken with an iOS device, application, and external microphone. Measures were completed within a controlled acoustic environment to determine the noise floor of the recording device and to confirm the calculation of reverberation time. Recorded noise levels within the classrooms were higher than the noise floor of the iOS device and microphone as measured within an anechoic chamber. The reverberation time calculations provided by AudioTools were consistent with those of known IRs (within 0.03 s), indicating good validity. As screening tools for measurements of classroom acoustics, the AudioTools application and external microphone were shown to be reliable in measuring reverberation and classroom noise levels. Within the classrooms, variations in occupied and unoccupied dBA levels were less than 1 dB and estimates of RT were less than 0.05 s across repetitions. In this study, the iOS device and AudioTools application provide reliable estimates of ambient noise and reverberation in both acoustically controlled environments and real-life classroom settings. The results of this study support the use of a smartphone application and external microphone as a cost-effective method for monitoring classroom acoustics.

The second research question examined the proportion of general education classrooms meeting ANSI guidelines for unoccupied noise levels and reverberation. Prior to examining adherence to ANSI guidelines, general acoustic characteristics of classrooms including a student who is hard of hearing were examined. The average unoccupied noise level in classrooms was 43.6 dBA. In classrooms where students were present and requested to work quietly, the average noise level was 54.7 dBA, approximately 11 dB higher than the empty classroom. Reverberation times were 0.34 s, on average, and mean C50 was 16.3 dB. Grempe and Easterbrooks (2018) found mean unoccupied noise levels in general education classrooms of 43.6 dBA and occupied levels of 60.8 dBA, which are similar to the values found using the same application (AudioTools) in the current study and past reports (Crandell & Smaldino, 2000). Noise levels in occupied classrooms were within the range of noise levels (51.7–65.3 dBA) reported for general education classrooms (see Picard & Bradley, 2001, for a summary). It is concerning that classroom noise levels have remained consistently high over the past two decades, knowing that noise in the classroom can inhibit academic ability, increase processing speed, and limit memory and learning for CHH (Crandell & Smaldino, 2000; Lewis et al., 2015; Neuman et al., 2010; Shield & Dockrell, 2008).

Almost 90% of classrooms—primarily those with HVAC systems on—had unoccupied noise levels that exceeded ANSI recommendations. The percentage of general

education classrooms in this study exceeding the guidelines is lower than the 100% found by Grempe and Easterbrooks (2018). Because mean unoccupied ambient noise levels were similar across studies, differences in the percentage exceeding guidelines could be due to varying numbers of general education classrooms in the samples (11 in Grempe and Easterbrooks and 164 in the current study). More exploration is needed to understand the small but significant difference in unoccupied noise levels between first- and fourth-grade classrooms. Perhaps, first-grade classrooms have different physical characteristics, are in different locations within the school building, or have fewer or less effective noise abatement strategies in place compared to fourth-grade classrooms.

Similar to previous research in general education classrooms (Knecht, Nelson, Whitelaw, & Feth, 2002), excessive reverberation does not seem to be a concern, as 98% of classrooms met the ANSI recommendation for reverberation. Grade was the only significant contributor to reverberation. Fourth-grade classrooms had longer reverberation times than first-grade classrooms. No relationship was found between reverberation and room volume. There is a potential that larger rooms had more acoustic treatments in place to combat negative effects of reverberation compared to rooms with smaller volume. Because C50 is a measure of early-to-late reflections and larger rooms have longer late reflections, it is not surprising that better (higher) C50 was found in larger rooms compared to smaller. Smaller rooms would have shorter late reflections, effectively decreasing the ratio of early-to-late reflections within C50. C50 was lower (worse) when HVAC status was on and unknown compared to HVAC off. In rooms with higher noise levels, such as those with HVAC on or HVAC status unknown, early reflections of C50 could have been lost in the noise floor, making C50 smaller. In combination with the grade effect seen for unoccupied noise levels, further investigation is warranted to examine whether first- and fourth-grade rooms and smaller and larger rooms had different acoustic treatments in place.

Current strategies to measure classroom acoustics rely on a trained professional's use of a sound-level meter, which can be costly for schools. An inexpensive, reliable, and easy-to-use system for measuring classroom acoustics would allow teachers to monitor acoustics in their own classrooms, which could increase awareness of noise and reverberation in the classroom and adherence to ANSI guidelines. Applications, as screening tools for measuring effects of acoustic intervention, are relatively inexpensive and require little training to use. Informing teachers about their classroom's particular acoustic characteristics would be beneficial, as many teachers may not be familiar with how background noise and reverberation affect understanding within the classroom (Richburg & Goldberg, 2005).

Noise levels may vary by the type of classroom, age range of the students in the classroom, and the events taking place within the room throughout the day (Crukley, Scollie, & Parsa, 2011). This article offers some insight into the acoustics of a normally functioning classroom in

a rather ideal situation, as the occupied sound-level measurements were snapshots taken when the students were working quietly at their desks. It may be more meaningful with respect to overall access to instruction if teachers understand how noise varies during different tasks, levels of student activity, and various locations within the classroom throughout the day.

It should be noted that the measurement procedure outlined in this study and in Grempe and Easterbrooks (2018) is best to use as a screening tool and not as a definitive measure of acoustics, especially as the microphone placement and measurement location within the room may have differed from that recommended in the ANSI standards. For example, ANSI recommends performing the unoccupied sound-level measurements at the noisiest location within the room, but we measured at the student's desk regardless of whether it was the noisiest location. Although the AudioTools application provided reliable measurements, not all applications do so (Kardous & Shaw, 2016). Care should be taken to utilize an application that produces both valid and reliable results (The National Institute for Occupational Safety and Health offers one such application for download at <https://www.cdc.gov/niosh/topics/noise/app.html>). Even as a screening measure, the use of a sound measurement application can help teachers understand the impact of acoustics within their own classrooms and may motivate teachers to modify their classroom to improve the acoustic learning environment.

Teachers have reported that physical classroom modifications that improve acoustics (e.g., laying carpet/rugs on hard surface flooring, using caps on chair legs) take little time to implement, are sustainable over time, and improve student behavior (Guardino & Antia, 2012). After modifying the acoustic learning environment, it is recommended that the efficacy of the modifications be measured, a role for which the smartphone application would be ideal (Crandell, Kreisman, Smaldino, & Kreisman, 2004). However, it should be noted that some modifications may do more to alter the amount of reverberation than the ambient noise levels. Window construction (single vs. double-paned) and HVAC sound levels contribute more to noise levels and are not easily or inexpensively alterable (Knecht et al., 2002). Furthermore, HVAC systems may run continuously throughout the school day during periods of hot weather and through cold winter months. Teachers who have thermostatic control of their classroom may turn off the HVAC to teach acoustically dependent lessons, although they may sacrifice classroom comfort to do so. School administration should consider using remote-microphone systems in classrooms where noise levels cannot be reduced to ensure optimal auditory access of instruction for both typical and hard of hearing students.

The results of this study are important in that, despite having ANSI standards for classroom noise levels, classroom noise is still a very real concern. Although the recommendations are voluntary, it is in the best interest of schools and educators to ensure that students who have typical hearing or who are hard of hearing have optimal

auditory access to instruction in the classroom. Future research should examine how physical characteristics of classrooms and the implementation of modifications to decrease noise levels and reverberation—legally required if stated within a student's Individualized Education Program—impact access to instruction for students who are hard of hearing.

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