University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Architectural Engineering -- Faculty Publications

Architectural Engineering and Construction, Durham School of

8-2010

Examining the Relationships between Monaural and Binaural Classroom Acoustics Parameters and Student Achievement

Lauren M. Ronsse
University of Nebraska - Lincoln, lronsse@unl.edu

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

Paul L. Sim
University of Nebraska - Lincoln

Follow this and additional works at: http://digitalcommons.unl.edu/archengfacpub

Part of the Architectural Engineering Commons

Ronsse, Lauren M.; Wang, Lily M.; and Sim, Paul L., "Examining the Relationships between Monaural and Binaural Classroom Acoustics Parameters and Student Achievement" (2010). *Architectural Engineering -- Faculty Publications*. 5.
http://digitalcommons.unl.edu/archengfacpub/5

This Article is brought to you for free and open access by the Architectural Engineering and Construction, Durham School of at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Architectural Engineering -- Faculty Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Examining the relationships between monaural and binaural classroom acoustics parameters and student achievement

Lauren M. Ronsse (1), Lily M. Wang, PhD, PE (1), and Paul Sim (1)

(1) Architectural Engineering Prog., Univ. of Nebraska - Lincoln, Peter Kiewit Institute, Omaha, NE, U.S.A

PACS: 43.66.Pn, 43.55.Hy

ABSTRACT

This study investigates the relationships between several classroom acoustics parameters and student achievement. Detailed binaural room impulse response measurements were conducted in four elementary school classrooms in a midwestern public school system in the United States. Unoccupied background noise levels were also recorded in these spaces. Previous studies have compared how different room acoustics metrics predict speech intelligibility, while another investigation examined perception-based binaural metrics in a typical classroom. This study extends these previous research areas by comparing both binaural classroom acoustics metrics and unoccupied background noise levels to each other and to the standardized student achievement scores of students in the surveyed classrooms. The binaural metrics examined include interaural level differences, interaural cross-correlations, and comparisons of the speech transmission index and frequency-to-frequency fluctuations between the two ears. The results will indicate which classroom acoustics parameters, if any, are most strongly related to student achievement.

INTRODUCTION

While many factors influence elementary school student learning, previous research has shown that occupied noise levels in classroom spaces highly correlate to standardized student achievement scores (Dockrell and Shield, 2006; Shield and Dockrell, 2008). However, more research is necessary to determine which unoccupied room acoustics parameters impact standardized student achievement scores so that classrooms may be effectively designed to optimize student learning. Sato and Bradley (2008) found that occupied noise levels are affected by unoccupied noise levels in classrooms. Also, research has shown high unoccupied background noise levels negatively impact elementary student reading comprehension standardized achievement scores (Ronsse and Wang, 2010).

While classroom noise levels influence student achievement, more work is needed to determine what other room acoustics parameters may have similar impacts on student learning. Previous studies have compared how different room acoustics metrics relate to speech intelligibility (Bradley, 1998). Another investigation examined perception-based binaural metrics in a typical classroom (Shinn-Cunningham *et al*, 2005). This study extends these previous research areas, further investigating how unoccupied background noise levels and binaural classroom acoustics metrics relate to standardized student achievement scores.

METHODS

Site visit procedures

This study was conducted in four classrooms in the Council Bluffs Community School System in Council Bluffs, Iowa, USA. Two classrooms contained students at the 2nd grade level (typically 7 – 8 years old), and two classrooms contained students at the 4th grade level (typically 9 – 10 years old) during the 2008 – 2009 academic year. Detailed notes and photographs were taken in each room to document the room finishes, shapes, and sizes. Each room had a closed plan design with an approximately rectangular shape. The room finishes included hard gypsum board or concrete masonry unit walls, thin carpet on the floors, and sound-absorbing lay-in ceiling tile. Acoustical measurements were conducted in these classrooms from May – June 2009.

Background noise level measurements

Background noise levels (BNL) were logged continuously over a five minute time period using a Larson Davis 824 sound level meter, recording two samples per second. The BNLs were recorded with the mechanical systems operating in the cooling mode while the classrooms were unoccupied. The meter was positioned on a tripod at the approximate center of the room, 1.12 m above the floor. The researchers subjectively evaluated the uniformity of the BNL in each room, and conducted additional BNL measurements as necessary to document any non-uniform noise levels.

Binaural room impulse response measurements

Sixteen binaural room impulse response (BRIR) measurements were gathered in each room, with source azimuth rotations and receiver positions as shown in Figure 1. For each measurement, the source was located at the front of the classroom, approximately 0.91 m from the wall and 1.68 m above the floor. The four source azimuth rotations included 0 degrees from center, 45 degrees from center, 90 degrees from center, and 180 degrees from center to simulate a teacher facing various directions while speaking. The receiver was directly facing the front of the room for each measurement, located in four different positions throughout the room. For the center position, the receiver was located at the approximate center of the room. The receiver was located 1.52 m to the front, side, and back of the center position for the three other positions.

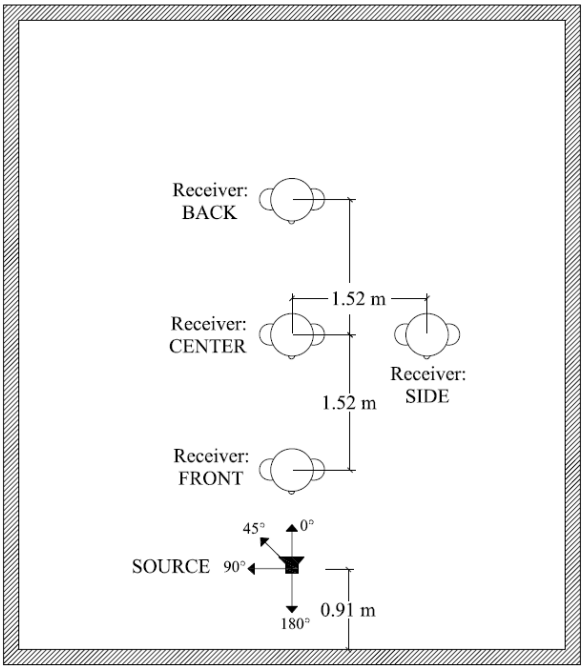

Figure 1. Plan view of source and receiver configurations for binaural room impulse response measurements (not to scale)

A small JBL LSR6325P loudspeaker was used for the source to simulate the directivity pattern of a human talker. The level of the loudspeaker while generating pink noise was set to 65 dBA (re 20 μPa) at a distance of 1 m directly in front of the speaker. The signal used for each BRIR measurement was a pink-weighted logarithmic sweep generated and recorded by the Electronic and Acoustic System Evaluation and Response Analysis (EASERA) computer software program.

For the receiver, a Brüel and Kjaer Type 4104 binaural microphone headset was placed on the head of an adult female seated in a student chair in each classroom. The same head was used for all of the measurements. BRIR measurements with the receiver in the center position were also gathered with the microphone headset placed on the head of another adult female in one of the classrooms (Classroom D) to study the effect of using a different head.

In one of the classrooms (Classroom C), the BRIR measurements were repeated three times to quantify their repeatability, changing both the source azimuth rotation and receiver position between each set of measurements.

Binaural classroom acoustics metrics

Binaural metrics, including interaural level differences (ILD), interaural cross-correlations (IACC), and comparisons of the speech transmission index (STI) and frequency-to-frequency fluctuations between the two ears, were calculated from the measured BRIRs.

The IACC and STI values reported are those calculated by EASERA. IACC values range from zero to one, with lower values indicating low levels of signal correlation between the two ears, and high values indicating high levels of signal correlation between the two ears. More information on the IACC metric may be found in Ando (1977). The IACC values were calculated in each octave band from 125 – 8,000 Hz from the full impulse response.

STI values also range from zero to one, with low values indicating poor speech intelligibility, and high values indicating good speech intelligibility (Houtgast and Steeneken, 1985). This metric incorporates the negative effects of high background noise on speech intelligibility. The magnitude of the difference in STI values between the left and right ears for each BRIR measurement was calculated.

The ILD and frequency-to-frequency fluctuations were calculated in MATLAB, following the calculation procedures reported by Shinn-Cunningham *et al* (2005). The ILDs are the difference in signal level between the two ears, calculated in one-third octave bands from 200 – 16,000 Hz. They are reported as a dB value, with the level in the left ear taken in reference to the level in the right ear.

The frequency-to-frequency fluctuation metric is the average difference in level occurring between two adjacent frequencies. This metric is calculated in dB/Hz, as the average level difference occurring from 0 – 22,050 Hz. The magnitude of the difference in frequency-to-frequency fluctuations occurring between the two ears was also calculated.

Standardized student achievement scores and poverty rates

The standardized student achievement scores from the Iowa Test of Basic Skills were reported as average scores from all of the students in each classroom for the 2008 – 2009 academic year for each of the four classrooms analysed. Results were obtained from both the reading comprehension and math subject areas. These scores are reported as the percent of students scoring above a certain proficiency level, which is determined by the state of Iowa for each school year. The percent of students scoring above the 41st percentile was defined to be the percent of proficient students for the 2008 – 2009 academic year.

The average poverty rates for each school were also obtained. The poverty rates were reported as the percent of students who lived in households below a certain income level, averaged per school.

RESULTS

Standardized student achievement scores and poverty rates

The results from the standardized student achievement tests for each of the four classrooms analysed are shown in Table 1. Table 1 also contains the average poverty rates for the students in each classroom.

Table 1. Standardized Student Achievement Scores and Poverty Rates

	Achievement Scores (% Proficient)		Poverty Rates
	Reading Comp.	Math	
Classroom A (2nd Grade)	75.0	75.0	34
Classroom B (2nd Grade)	92.3	61.5	72
Classroom C (4th Grade)	100.0	72.7	34
Classroom D (4th Grade)	69.2	76.9	72

Background noise level and reverberation time

The A-weighted equivalent sound levels (L_{Aeq}) from the five minute unoccupied background noise measurements for each classroom are shown in Table 2. The reverberation times for the classrooms, reported as T20 values calculated by EASERA, are also shown in Table 2. The T20 values are the average reverberation times in the 500, 1000, and 2000 Hz octave bands averaged between the right and left ears.

Table 2. Unoccupied Background Noise Levels and Reverberation Times

	$L_{Aeq,\,5\,min}$ (dBA)	T20 (sec)
Classroom A (2nd Grade)	36	0.46
Classroom B (2nd Grade)	38	0.40
Classroom C (4th Grade)	36	0.46
Classroom D (4th Grade)	38	0.44

Speech transmission index

The STI values measured for both the left and right ears range from 0.7 – 0.9 for all receiver positions and source azimuth rotations in each classroom analysed. In general, the trend in the change in STI values is similar among all of the classrooms as the receiver position and source azimuth rotation varies. The STI values are typically highest in the front receiver position, and decrease as the source azimuth rotation changes from 0° to 45° to 90°. See Figures 2 and 3 for the STI values measured at the left and right ears respectively for Classroom A.

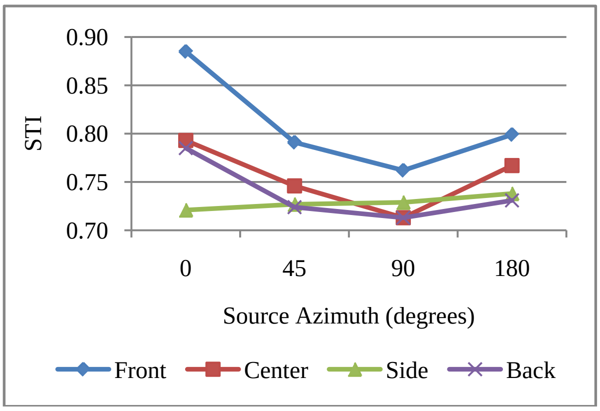

Figure 2. Left ear speech transmission index values in Classroom A

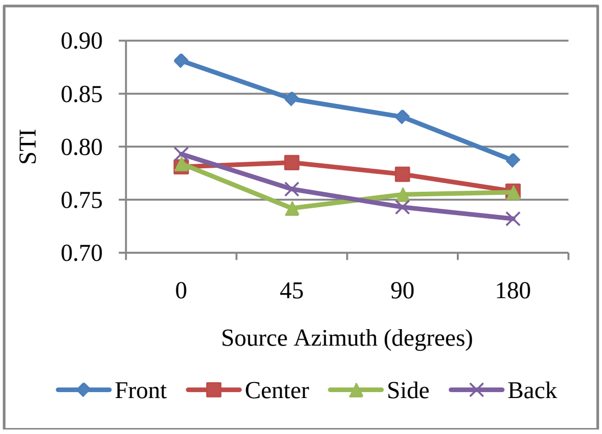

Figure 3. Right ear speech transmission index values in Classroom A

The difference in STI values between the right and left ears for each BRIR measurement in all of the classrooms ranges from 0 – 0.08.

Frequency-to-frequency fluctuations

The frequency-to-frequency fluctuations measured for the left and right ears range from 0.7 – 4.9 dB/Hz for all of the classrooms. In general, the frequency-to-frequency fluctuations increase as the receiver position changes from front to center to side to back. The frequency-to-frequency fluctuations for the left and right ears in Classroom C are shown in Figures 4 and 5 respectively.

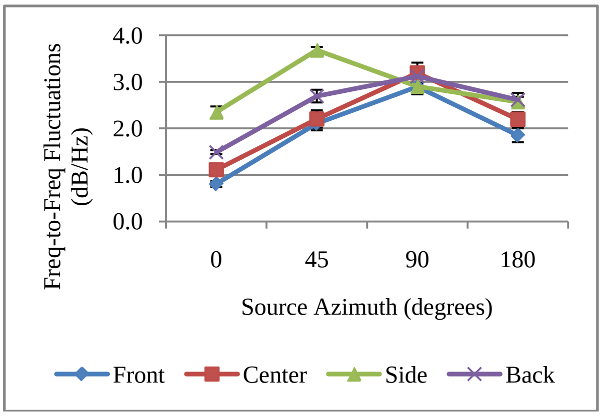

Figure 4. Left ear frequency-to-frequency fluctuations in Classroom C. The bars show the range in frequency-to-frequency fluctuations about the average value from the three repeated measurements.

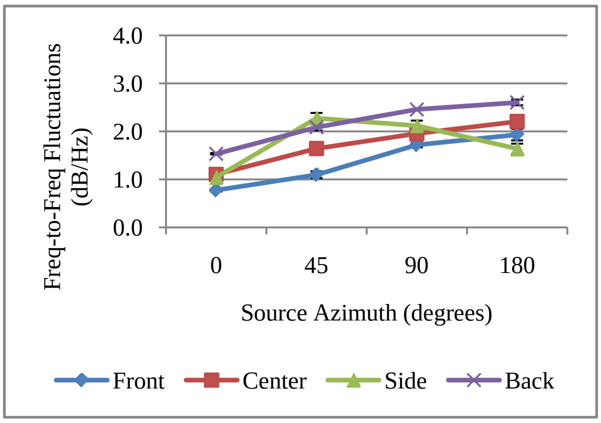

Figure 5. Right ear frequency-to-frequency fluctuations in Classroom C. The bars show the range in frequency-to-frequency fluctuations about the average value from the three repeated measurements.

The difference in frequency-to-frequency fluctuations between the right and left ears for all of the measurements ranges from 0 – 2.1 dB/Hz.

Interaural cross-correlations

In all of the classrooms, the IACCs tend to decrease as the receiver position changes from front to center to back to side. The IACCs also tend to decrease as the source azimuth rotation changes from 0° to 45° to 90°. The IACCs for the 0° and 90° source azimuth rotation for Classroom B are shown in Figures 6 and 7 respectively.

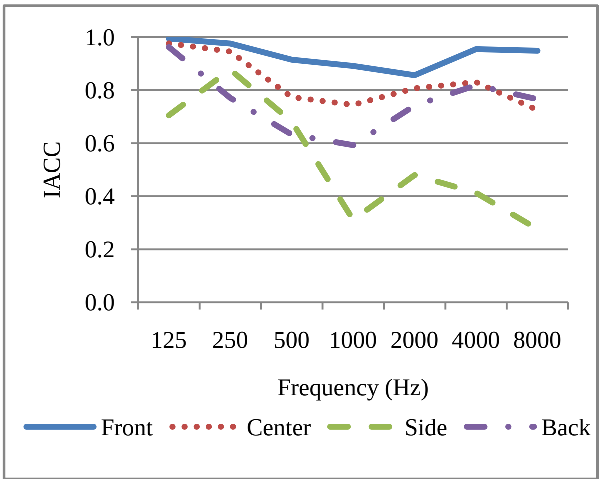

Figure 6. IACC values for the 0° source azimuth rotation for Classroom B

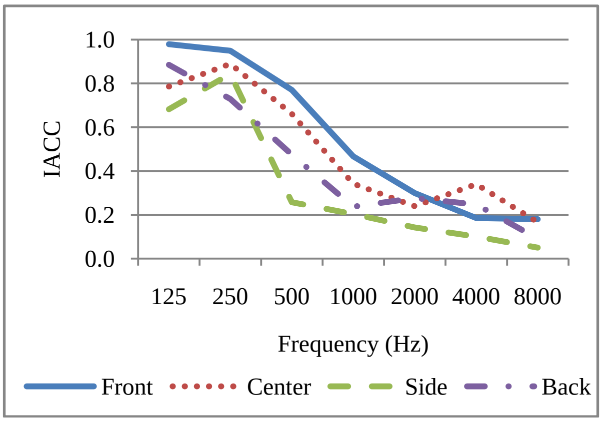

Figure 7. IACC values for the 90° source azimuth rotation for Classroom B

Interaural level differences

In general, the magnitude of ILDs is highest for the side position when the source azimuth rotation is 0°. Also the magnitude of the ILDs tends to increase with frequency for all source rotation azimuths and receiver positions. The ILDs for the 0° and 90° source azimuth rotations for Classroom D are shown in Figures 8 and 9 respectively.

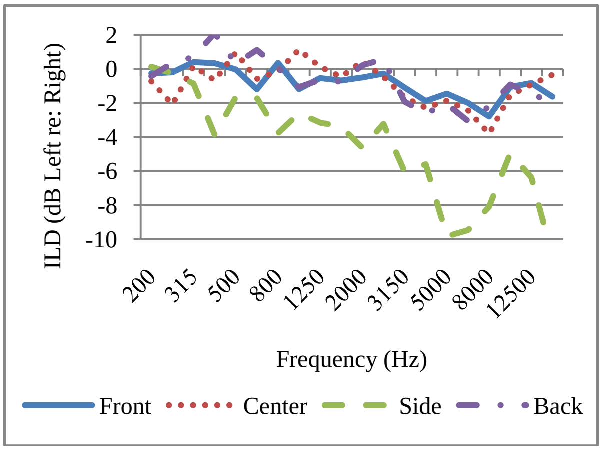

Figure 8. ILD values for the 0° source azimuth rotation for Classroom D

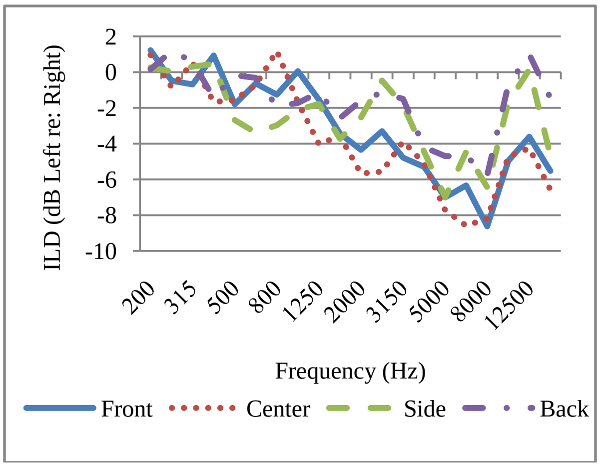

Figure 9. ILD values for the 90° source azimuth rotation for Classroom D

Measurement repeatability

All of the binaural metrics were computed from the three sets of repeated BRIR measurements conducted in Classroom C. The range about the mean value from the three repeated measurements for STI is less than 0.02, which is less than the maximum STI difference of 0.08 that occurs between the two ears. The range about the average value from the repeated measurements is less than 0.45 dB/Hz for the frequency-to-frequency fluctuations. This range is also less than the maximum frequency-to-frequency fluctuation difference of 2.1 dB/Hz that occurs between the two ears.

The typical range about the mean for the IACC values is shown in Figure 10. This figure shows the IACC values for the 45° source azimuth rotation for Classroom C.

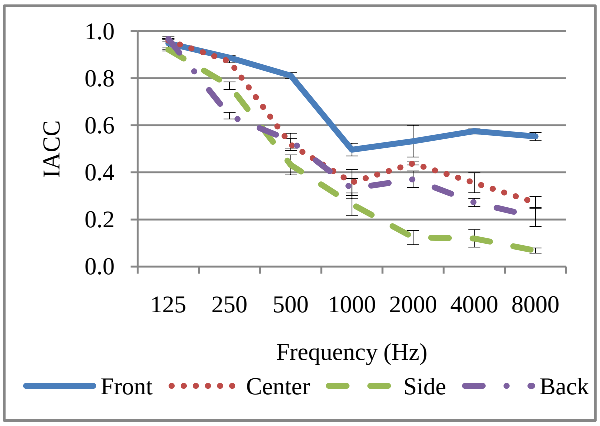

Figure 10. IACC values for the 45° source azimuth rotation for Classroom C. The bars show the range in IACC about the average value from the three repeated measurements.

The typical range about the mean for the ILD values from the three sets of repeated measurements is shown Figure 11. This figure shows the ILDs for the 45° source azimuth rotation for Classroom C.

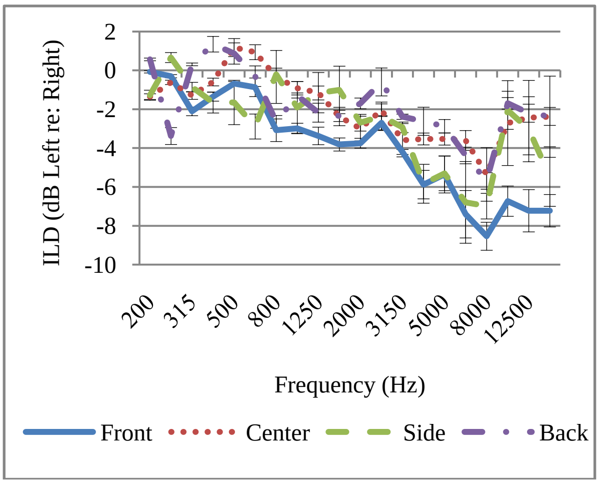

Figure 11. ILD values for the 45° source azimuth rotation for Classroom C. The bars show the range in IACC about the average value from the three repeated measurements.

Head comparisons

In general, the STI and frequency-to-frequency values are very similar between the BRIR measurements for the two different heads. The difference in STI between the two heads is 0.01 or less for all source azimuth rotations. Also, the difference in frequency-to-frequency fluctuations between the two heads is 0.30 dB/Hz or less for all source azimuth rotations. The difference between the two heads for the IACC metric is generally small as well, but the largest difference of 0.3 occurs in the center receiver position for the 180° source azimuth rotation.

The largest differences between the two heads occur for the ILD metric, at the 0° and 180° source azimuth rotations, particularly at the higher frequency ranges. These differences are shown in Figures 12 and 13 respectively.

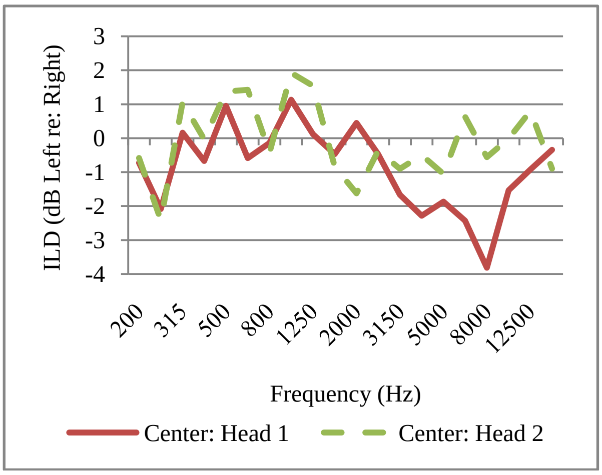

Figure 12. ILD values for the 0° source azimuth rotation for Classroom D. The results from the BRIR measurements with the microphone headset on two different heads are shown.

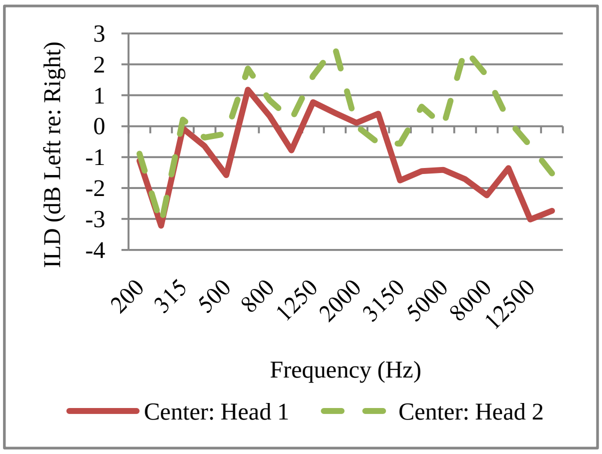

Figure 13. ILD values for the 180° source azimuth rotation for Classroom D. The results from the BRIR measurements with the microphone headset on two different heads are shown.

DATA ANALYSIS

As shown in Table 2, the unoccupied BNLs and reverberation times are similar for all of the classrooms. However, a wide range occurs among the student reading comprehension achievement scores in the four rooms. Therefore, the binaural metrics are further related to the reading comprehension scores. The standardized achievement scores shown in Table 1 are reported as an average value per classroom. Thus, for direct comparison, the binaural metrics were averaged among the four receiver positions in each classroom as well.

Speech transmission index

The average difference in STI between the left and right ears for all source azimuth rotations ranges only from 0 – 0.05. Therefore, relationships between this binaural metric and the standardized student achievement scores are not shown.

Frequency-to-frequency fluctuations

A wider range occurs among the average differences in frequency-to-frequency fluctuations between the left and right ears among the four classrooms. The average differences in frequency-to-frequency fluctuations between the left and right ears for the 0° and 180° source azimuth rotations versus the reading comprehension scores are shown in Figure 14.

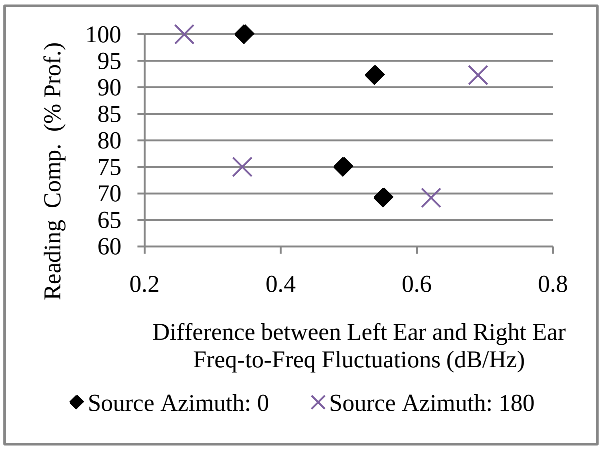

Figure 14. Scatter plot between frequency-to-frequency fluctuations (difference between left and right ears) and reading comprehension scores

With the exception of Classroom B (92.3% proficient reading comprehension score), the reading comprehension scores tend to be lower for higher differences in frequency-to-frequency fluctuations between the two ears.

Interaural cross-correlations

Sato *et al* (2008) found that listening difficulty is more strongly impacted by reverberation occurring from 1 – 4 kHz than in the other octave bands. Therefore, the average IACC value in the 1000, 2000, and 4000 Hz octave bands was compared to standardized student achievement scores. This average IACC value among all receiver positions in each classroom versus the reading comprehension scores is shown in Figure 15.

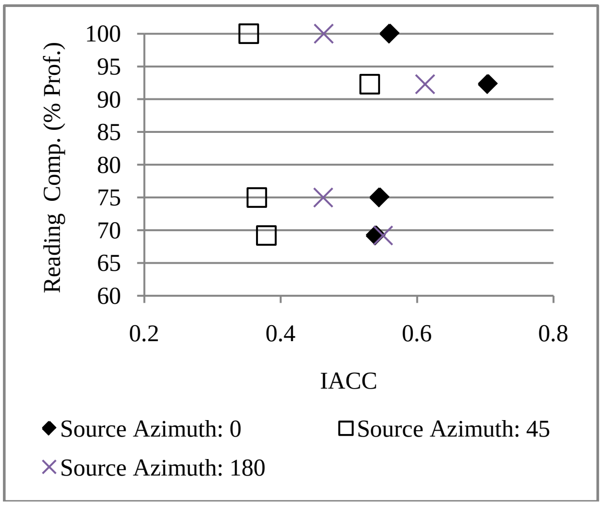

Figure 15. Scatter plot between IACCs and reading comprehension scores

Though the IACCs are similar for three of the classrooms, the IACC for Classroom B (92.3% proficient reading comprehension score) is higher than the IACC value in the three other rooms for the 0°, 45°, and 90° source azimuth rotations.

Interaural level differences

The average ILD from 1 – 4 kHz in each classroom was also related to the reading comprehension scores. This relationship is shown in Figure 16.

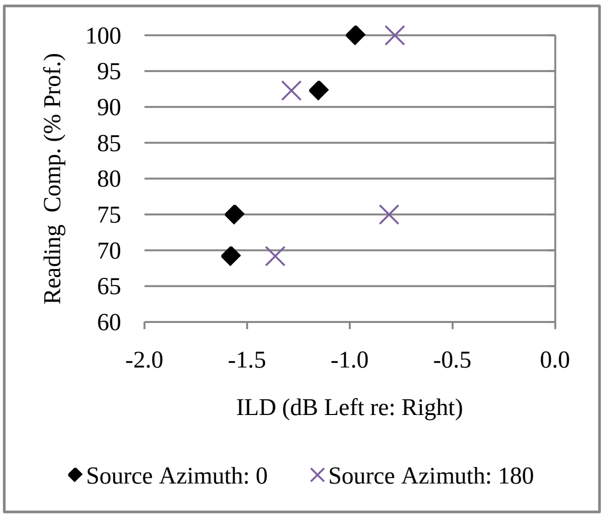

Figure 16. Scatter plot between ILDs and reading comprehension scores

As shown in Figure 16, the magnitude of the ILDs is generally lower for higher reading comprehension scores.

CONCLUSIONS

This study has shown results from unoccupied background noise level and binaural impulse response measurements in four different elementary school classrooms. Binaural metrics from these measurements have been compared to the standardized student achievement scores from students in the surveyed classrooms.

In general, this study has found that certain binaural metrics, including interaural cross-correlations, interaural level differences, and differences in frequency-to-frequency fluctuations between the left and right ears, may relate to student reading comprehension. However, further analysis of these metrics in additional classrooms is needed before definite conclusions may be drawn. Also, more work is needed to determine how classroom architectural design features impact these metrics.

ACKNOWLEDGEMENTS

The authors would like to thank the Council Bluffs Community School System for their cooperation on this project and undergraduate research assistant, Dakota Kelley, for his assistance with some of the acoustics measurements. Work supported by United States National Science Foundation Graduate Research Fellowship.

REFERENCES

Y. Ando, “Subjective preference in relation to objective parameters of music sound fields with a single echo” *J. Acoust. Soc. Am*. **62**, 1436–1441 (1977)

J.S. Bradley, “Relationships among measures of speech intelligibility in rooms” *J. Audio Eng. Soc.* **46**, 396–404 (1998)

J.E. Dockrell and B.M. Shield, “Acoustical barriers in classrooms: the impact of noise on performance in the classroom” *British Educational Research Journal* **32**, 509–525 (2006)

T. Houtgast and H.J.M. Steeneken, “A review of the MTF concept in room acoustics and its use for estimating speech intelligibility in auditoria” *J. Acoust. Soc. Am*. **77**, 1069–1077 (1985)

L.M. Ronsse and L.M. Wang, “Effects of noise from building mechanical systems on elementary school student achievement” *ASHRAE Transactions* **116** (2010)

H. Sato and J.S. Bradley, “Evaluation of acoustical conditions for speech communication in working elementary school classrooms” *J. Acoust. Soc. Am*. **123**, 2064–2077 (2008)

H. Sato, M. Morimoto, H. Sato, and M. Wada, “Relationship between listening difficulty and acoustical objective measures in reverberant sound fields” *J. Acoust. Soc. Am.* **123**, 2087–2093 (2008)

B.M. Shield and J.E. Dockrell, “The effects of environmental and classroom noise on the academic attainments of primary school children” *J. Acoust. Soc. Am*. **123**, 133–144 (2008)

B.G. Shinn-Cunningham, N. Kopco, and T.J. Martin, “Localizing nearby sound sources in a classroom: Binaural room impulse responses” *J. Acoust. Soc. Am*. **117**, 3100–3115 (2005)