Noise Levels and the Speech Intelligibility of Teachers in Classrooms

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Ambient noise levels and teachers' speech levels were measured in representative classrooms at the National Technical Institute for the Deaf (NTID) and at one of the other colleges at the Rochester Institute of Technology (RIT). The measurements were made during the first and last 10 minutes of class periods in four pre-selected rooms. These physical measures were interpreted in terms of Speech Interference Levels (SIL) and used to calculate Articulations Indices (AI) so that the basic intelligibility of the teachers' speech, which was not measured, could be estimated. The rooms were selected to represent "good" and "bad" acoustics and the results confirmed that the teacher speech had higher intelligibility in the better rooms. The results also showed significant time and time room effects. That is, even though the speech levels did not decrease significantly during the final ten minutes, the noise levels generally increased and therefore the intelligibility decreased in all but the "better" NTID classrooms. The "teacher" effect was as great as the time and room effects and interacted with the room effects. The overall range in the AI calculations was 0.7 to 0.9, which corresponds to very good, excellent, or outstanding speech intelligibility ratings. Methods of estimating the AI and corresponding speech intelligibility from older and/or incomplete physical measures are presented and comparisons are made between these data and measures taken in classrooms in other schools.

Deaf educators face a challenge in providing classroom characteristics optimal for transmitting information. Olson and Tillman (1968), Tillman, Carhart, and Olson (1970), and Erber (1971) found that students with sensorineural hearing losses who use hearing aids have more difficulty understanding speech in noise than normal hearing classmates. Even for

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many severely and profoundly deaf young adults, listening is an important learning channel. For example, at NTID 24 percent of the students understand most everyday speech if they listen to it under optimal conditions (Johnson, 1975).

The amount of information students receive is partially dependent upon the intelligibility of the teacher's speech. Teacher intelligibility is a function of at least three major factors: (a) acoustic factors, (b) language or linguistic factors in the spoken utterances, and (c) articulatory factors in the teacher's speech. Acoustic factors include level and spectrum of ambient noise, the voice level of the teacher, and the reverberant characteristics of the room, which in turn depend on the size, shape and amount of sound absorption in the room. Language factors include vocabulary size, word familiarity, context, the number of syllables in a word, and the phonetic elements in the word. Speech factors include dialect, emotional state, and articulatory capabilities of the teacher.

The purpose of this study was to evaluate acoustic factors important to teachers' speech intelligibility. Specifically, speech and noise levels were measured and evaluated in terms of permissible distances between teachers and students using the concepts of A-weighted sound level meter readings, Speech Interference Levels (SIL), and the Articulation Index (AI).

THEORETICAL BACKGROUND MATERIAL

The most important acoustic factor in making speech intelligible is to have it more intense in key frequency regions. This may be accomplished by reducing the ambient noise, having the teacher increase her/his vocal effort, or decreasing the distance between students and teachers.

There are at least three common ways of measuring or specifying noise levels and particularly the speech interfering aspects of the noise levels. These can be classified as integrating, averaging, and peak fitting. Sound level meter readings integrate levels at all frequencies over the observation time using a frequency weighting network. The most commonly used networks are the (essentially) flat or C-weighted and the A-weighted which gives progressively less weighting to sounds below 1000 Hz (see Appendix). Speech Interference Levels (SIL) average the octave-band levels in selected octave bands. The exact choice of which octave bands to select depends on the levels of speech intelligibility you are trying to predict, which in turn depends primarily on the overall noise levels. Webster and Cluff (1974) showed, however, that the best compromise sets of octaves are those centered at 0.5, 1, 2 and 4 kHz. These octaves have been standardized by the American National Standards Institute (ANSI) (Anonymous, 1969). Matching the peaks of noise spectra to sets of pre-plotted noise contours, referred to as peak fitting, has been shown by Klumpp and Webster (1963) to be the least effective of the three generic methods for predicting the speech interfering aspects of noise.

Of these three ways of specifying noise levels, the one that is most valid for noises of all spectra is the SIL. A generally acceptable, but less valid, measure for diverse spectra noise is the A-weighted overall SPL. Both of these measures were used in the present study. The C-weighted level used by many investigators in the past (or assumed to be used since no qualifying statements to the contrary were made) has been shown by Klumpp and Webster (1963) to be a poor measure of the speech interfering aspects of noise. In the absence of an A-weighted measure an estimate of it can be made from the (assumed) C-weighted measure. Past surveys of classroom noises where both C- and A-weighted measures were made or 1/3-, 1/2- or full-octave band measures were made so that C- and A-weighted measures could be calculated show that "typical" classroom noises show C minus A readings of 3 dB. In this paper all (assumed) C-weighted measures will be decreased by 3 dB when A-weighted measures are needed.

If the noise level is known and a speech level and the type of language to be communicated (sentences, key words, etc.) is known or assumed, the permissible distance between two communicators, can be predicted. However, before these relationships are shown some characteristics of speech levels and their dependence upon distance away from the talker's lips and the relationship between phoneme, word, and sentence intelligibility are discussed.[1]

Figure 1 shows the intensity range capabilities of the human voice and identifies certain descriptive vocal efforts or vocal levels. These descriptive terms are somewhat misleading because what a "normal" vocal effort is varies with ambient noise and listener-audience conditions. For example, in a one-to-one conversation in a quiet living room (with communicators less than three feet away), the voice level and spectrum labeled RELAXED is certainly normal for that situation. NORMAL is defined as an average vocal level based on several people seated one meter away from a microphone and asked individually to speak at a "normal voice level." Each one knows s/he is being tested and therefore speaks somewhat louder and more distinctly than usual. NORMAL as determined under these test conditions averages 65 dB SPL and has the spectrum (level in each octave band) shown in Figure 1. Note that the range of human vocal efforts varies from 45 dB SPL for a whisper to 88 dB SPL at maximum. Usable ranges for communicating (conversing) purposes range from 55 dB to 84 dB.

In addition to decreasing the ambient noise, another way to increase the

[1]The remainder of this section and the next two sections are tutorial in nature, and not specific to this study. They are included so that (future) researchers can relate their findings to previous studies where incomplete data on noise and speech levels might exist. If speech discrimination scores are unavailable, as in this study, the AI and/or SIL can be used as secondary measures for cross comparisons among studies. For those familiar with this information, skip to "Previously Measured Classroom Noise Levels".

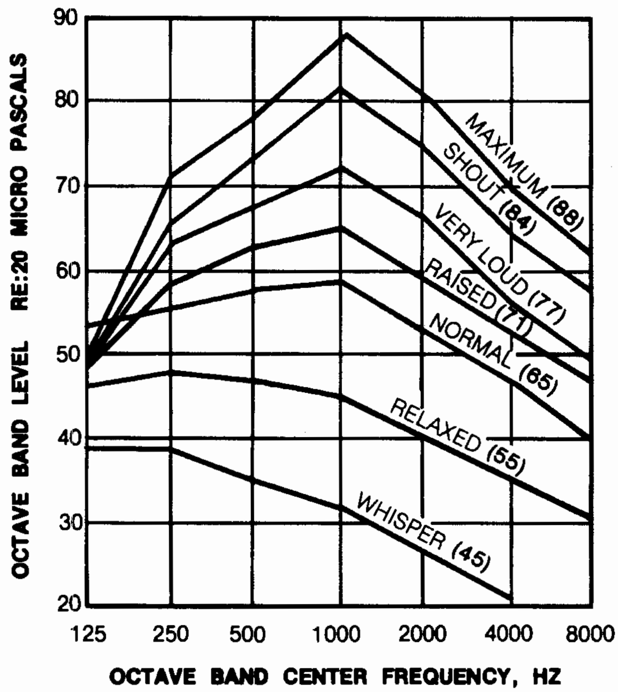


Figure 1. Long-term average speech spectra for different vocal efforts of a typical male talker facing a listener at a distance of 1 meter (3+ feet). The overall SPL is shown in parentheses after each vocal effort. From Western Electro-Acoustic Lab. Rep. 3710, 1959.

level of speech at the listener's ear is to get the talker(s) and listener(s) closer together.

Figure 2 shows how the speech level falls off with distance from the lips. In an anechoic room (a room with no echoes or reverberation) or in free space (outdoors) the level will continue to fall off at a 6 dB rate for each doubling of the distance beyond one meter.

The remaining information needed to interpret communications effectiveness in noise is the relationship between vocal effort (speech levels), noise levels and communication situations. Pearsons, Bennett and Fidell (1977) measured speaking levels, listening levels, and noise levels under a variety of different environmental conditions; e.g., in homes, schools, department stores, hospitals, trains and airplanes. These results together with data of Webster and Klumpp (1962) are plotted in Figure 3. An A-weighted equivalent level (L_{eq}), which integrates the levels over both time and frequency, is the noise measure used in Figure 3. Note that at equivalent noise levels below 50 dB(A) the observed average speech level in homes is 55 dB SPL which

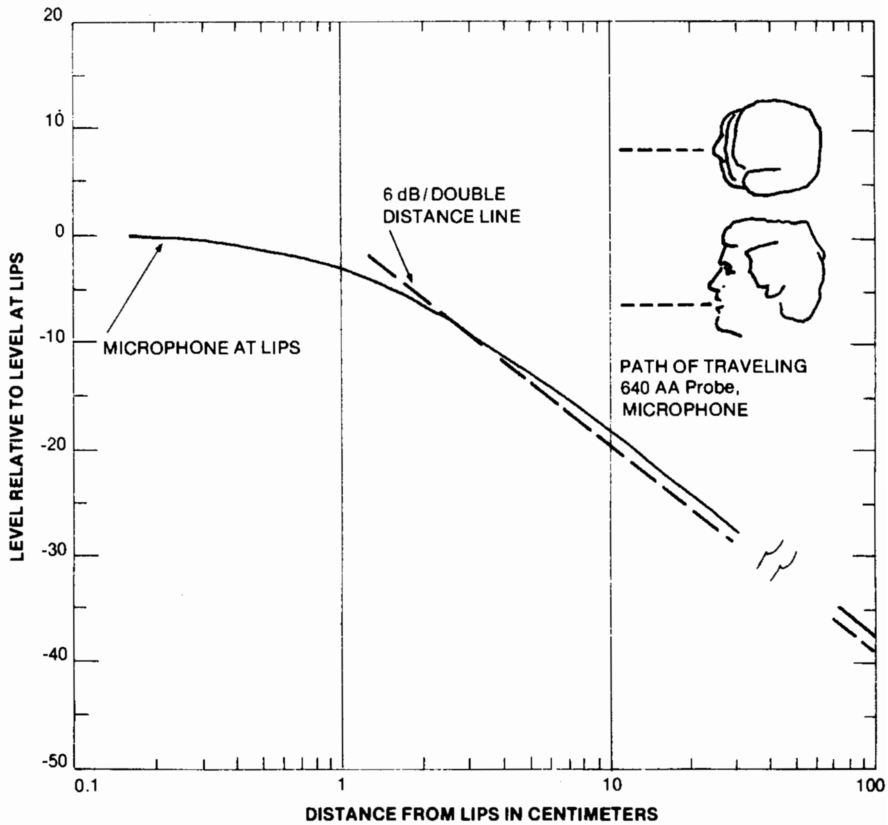


Figure 2. Fall off in voice level with distance from lips, from Western Electro-Acoustic Lab. Rep. 3710, 1959.

from Figure 1 would be classified as "relaxed". However, in classrooms, as the noise increases from 45 to 55 dB(A), the speech levels increase from 67 to 77 dB(A), from just above "normal" to "very loud". Both the base speech level and the rate of increase of speech level is greater in the classrooms surveyed by Pearsons et al. (1977) than has been measured in other surveys. The fact that the speech levels measured by Pearsons et al. (1977) in classrooms are noticeably higher than speech levels measured in homes shows the effect of the communicating situations. The same effect is shown in the Webster and Klumpp (1962) data (WK) where near perfect word intelligibility was required in noise levels of 65 to 85 dB(A). When only two communicators were involved the vocal efforts increased from 62 to 72 dB(A), when ten (10) communicators (5 pairs) were required to maintain near perfect word intelligibility in the same ambient noise levels (65 to 85 dB(A)) the speech level increased from 73 to 79 dB(A). The interesting point in the Webster and Klumpp (WK) data is that doubling the number of communicating people increased the speech level of the talkers to the same degree as increasing the noise level by 10 dB.

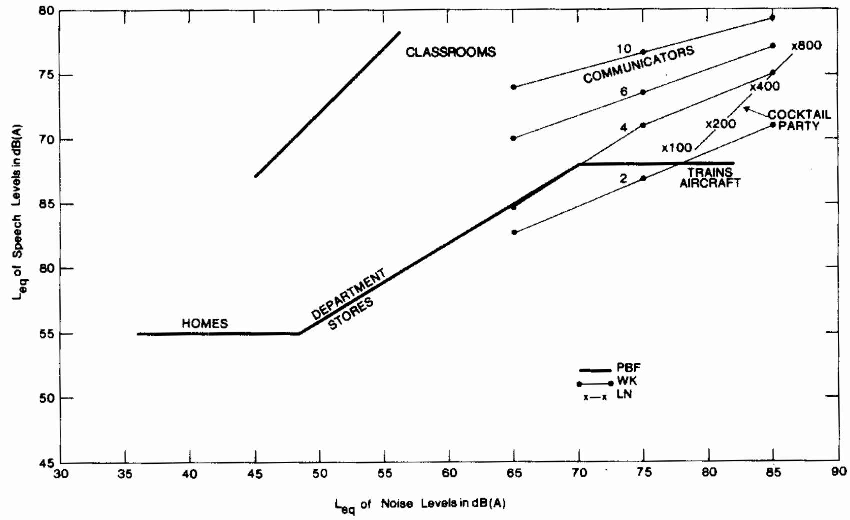


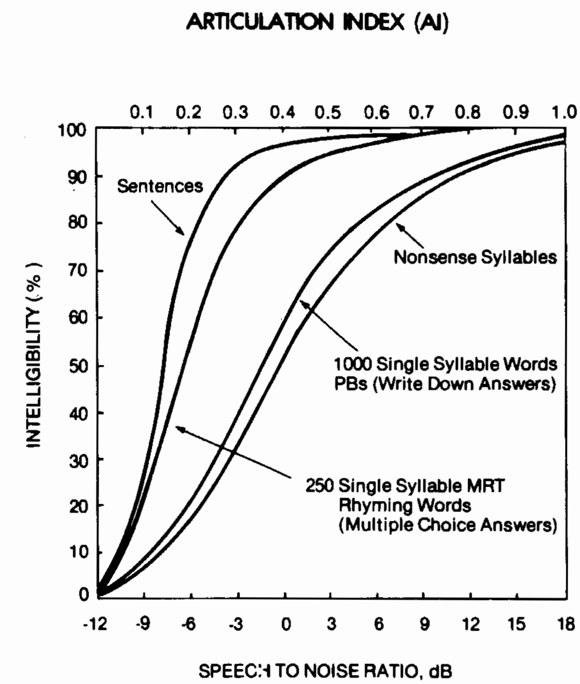
Figure 3. Averaged measured speech levels in given measured noise levels. Two sets of data are plotted: from Pearsons, Bennett & Fidell (1977) - PBF; and from Webster and Klumpp (1962) - WK. Adapted from Webster (1984).

Figure 4 shows the importance of the language variable or the type of speech used in determining what percent will be intelligible in various combinations of vocal effort (speech level) and ambient noise. Note for example that 98 percent of SENTENCE material will be intelligible using a RELAXED voice in 52 dB(A) of noise, but to get 98 percent of a vocabulary of 1000 one-syllable WORDS correct the noise can be only 37 dB(A). If a NORMAL speech level were assumed, the corresponding allowable ambient noise levels would be 10 dB higher, or 62 dB for a criterion of 98 percent correct for SENTENCES and 47 dB(A) for 1000 word vocabulary of one-syllable WORDS spoken as individual words with no contextual or grammatical cues (not in sentences).

The question might be asked, "Why is anyone interested in anything except sentence intelligibility?" Consider in response that someone is designing a school that will be teaching foreign languages, mathematics or science in some of the classrooms. Some words will be heard in isolation and at least to some students will sound like nonsense syllables. The point is every speech sound must be audible since the use of context from accompanying words/phrases to assist in making closure is not always available to students.

The information in Figure 4 implies the foreign language-type room will have to be 15 dB quieter than rooms where, say, history is taught. The alternative is for the instructor to speak 15 dB louder, which s/he likely will not be able to maintain for much of a class period.

Using the information or methods of measuring the speech interfering aspects of noise, the range of vocal levels (Figure 1), the decrease of speech levels with distance (Figure 2), the relationships between speech levels and noise levels (Figure 3), and keeping in mind the relationship among the intelligibility of various language units (Figure 4), the relationships between ambient noise levels, speech levels and distance between communications is plotted in Figure 5.



V. Loud	89	86	83	80	77	74	71	68	65	62	59
Raised	83	80	77	74	71	68	63	62	59	56	53
Normal	77	74	71	68	65	62	59	56	53	50	47
Relaxed	67	64	61	58	55	52	49	46	43	40	37

Figure 4. Percent sentences, words, or syllables correct as a function of Articulation Index (AI) (TOP), of rms speech-to-noise differential when measured using A-weighting and the A-weighted noise levels for given speech levels (BOTTOM). Adapted from Amer. Nat. Stands. Inst. (ANSI) S3.5-1969 (R1978).

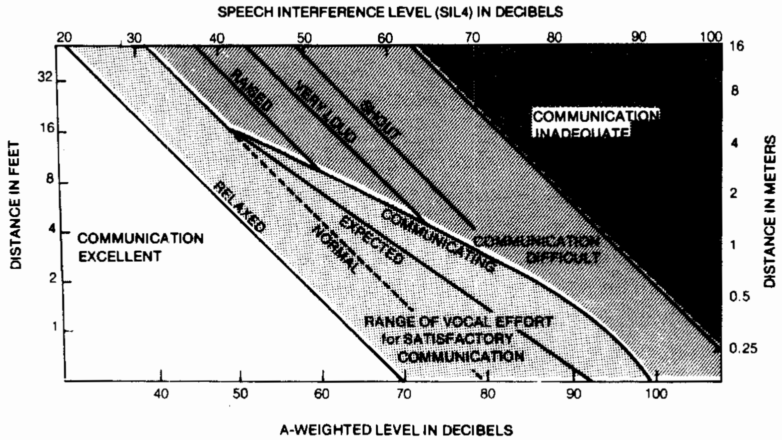


Figure 5. Permissible distance between a teacher and students for specified vocal efforts and ambient noise levels, adapted from Webster (1969). NOTE: The difference in decibels between the SIL4 (500, 1000, 2000, & 4000 Hz average) and A-weighted values of 7 dB is based on a noise spectrum when the C-weighted minus A-weighted difference (C - A) is 3 dB.

The curves on Figure 5 assume "satisfactory communication" or 95 percent sentence intelligibility. Note that above an ambient noise level of about 50 dB(A), two vocal effort lines diverge from the NORMAL and with increasing noise levels cross over the RAISED and VERY LOUD vocal effort lines. These vocal efforts, called EXPECTED and COMMUNICATING reflect the observed but not always consciously recognized fact that people raise their voice (speech) levels in increasing levels of noise and as the importance of the informative in the communication task increases. Normal hearing people with normal feedback mechanisms for monitoring with their own ears the relative level of their own speech with respect to the noise background they are in raise their speech level about 3 dB for each 10 dB increase in ambient noise level (Lane, Tranel, & Sisson, 1970). This is their EXPECTED voice level in noise. People for whom it is important to be heard and to hear and comprehend a response (namely those in a critical communicating situation, as for example teachers in classrooms), raise their voice levels 5 dB for each 10 dB increase in ambient noise level (Webster & Klumpp, 1962). This is their COMMUNICATING voice level in noise. It would be neither natural nor expected for people in general and teachers in particular conversing in noise levels above 50 dB(A) to use a NORMAL or a RELAXED vocal effort or speech level.

The information in Figure 5 assumes the teacher and student are facing each other. When the information in this format was first presented (Webster, 1969), it was for the case where the talker and listener were NOT reading each others lips and the allowable noise levels for given vocal effort/distance conditions were 5 dB lower. This statement is included as a word of caution to prevent the two similar appearing curves from being used interchangeably.

Figure 5 assumes that normally hearing talkers (teachers) will automatically and unconsciously increase their vocal efforts as the noise level increases. Other factors such as what happens to vocal effort as the distance between the teacher and the student increases, as the number of students increase, or in rooms of different sizes and reverberation times are not adequately known or accounted for.

It is often informative, convenient, and necessary in generalizing results to the work of others to measure voice levels as well as noise levels and calculate the expected speech intelligibility using the Articulation Index (AI) method developed by French and Steinberg (1947) and made more universal

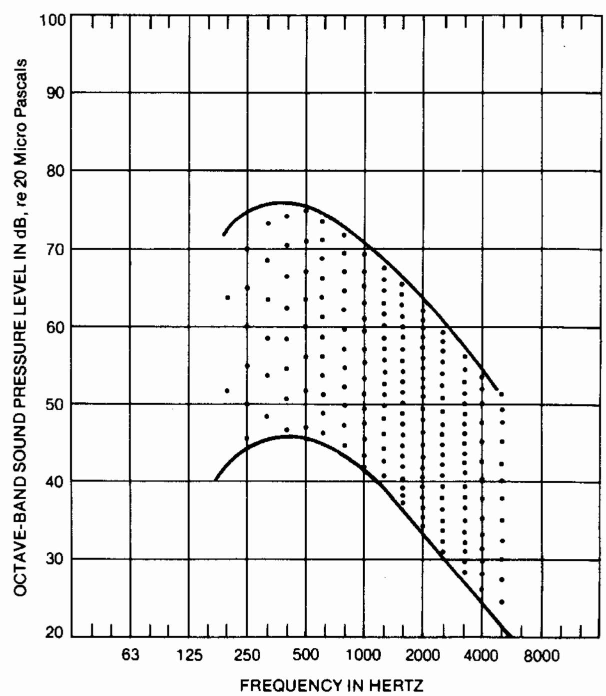


Figure 6. The Articulation Index (AI) range for NORMAL vocal effort. To calculate the AI draw the octave — or third-octave band noise spectra on this figure and count the number of dots between the noise spectrum and the upper edge of the voice spectrum. This number of data divided by 200 (the total number of dots) yields the AI, a value somewhere between 0.0 and 1.0, from Cavanaugh et al. (1962).

and validated by Kryter (1962a, 1962b). Although an American National Standards Institute (ANSI) document (Anonymous, 1969) describes the calculation procedure precisely, two simplified methods exist which can handle most situations. The first of these, adapted from Cavanaugh, Farrell, Hirtle, and Watters (1962) is illustrated in Figure 6. To use this figure adjust the dot pattern to correspond to the voice level, plot in the measured noise spectra, count the dots between the noise spectra and the upper speech level limit and divide by 200. This yields an AI value between zero and one (since there are 200 dots). To adjust for voice level it is only necessary to note how much the measured overall voice level deviates from 65 dB since the pattern as drawn on Figure 6 is for a "normal" voice level of 65 dB (at one meter).

A simpler way of estimating AI is by means of Figure 7, adapted from Kryter (1970). To use this method find where, within the AI parameter lines of 0.1 to 0.9, the measured noise and speech levels intersect and read off the estimated AI. If the persons are facing one another increase the AI by 0.2. When the AI is known from Figure 6 or 7 refer to Figure 4 and/or Table 1 to determine the expected intelligibility score (percent correct) for different types of speech material. The AI values calculated from Figures 6 or 7 are for a distance of one meter between a talker and a listener. To estimate the AI at other distances refer to Table 2 which is tabulated on the assumption that:

1. The talker maintains the same vocal effort (voice level) and it falls off at a 6 dB rate for each doubling of the distance between the talker and the listener and
2. The noise level is constant over the entire room.

With this background information on how to interpret voice and/or noise levels in terms of expected speech intelligibility at various distances between the teacher and students in a classroom, it is time to examine the existing

Table 1

Word Intelligibilities and Usability Ratings for Various Articulation Index (AI) Values

Value of AI	Expected Intelligibility Score: Sentences	MRT[a]	PB[b]	Usability Rating
0.9	100	98	96	Outstanding
0.7	100	98	90	Excellent
0.5	97	95	75	Good
0.3	93	80	40	Acceptable
0.1	30	20	10	Unacceptable

[a]MRT = Modified Rhyme Test (Multiple Choice of 6)
[b]PB = Phonetically Balanced (1000 Words and Write Down Answers)

Table 2
AI Corrections for Distances Greater Than 1 Meter

AI at 1 Meter	AI at Following Distances 2m	4m	8m	16m	32m
0.9	0.7	0.5	0.3	0.1	0.0
0.7	0.5	0.3	0.1	0.0	0.0
0.5	0.3	0.1	0.0	0.0	0.0
0.3	0.1	0.0	0.0	0.0	0.0
0.1	0.0	0.0	0.0	0.0	0.0

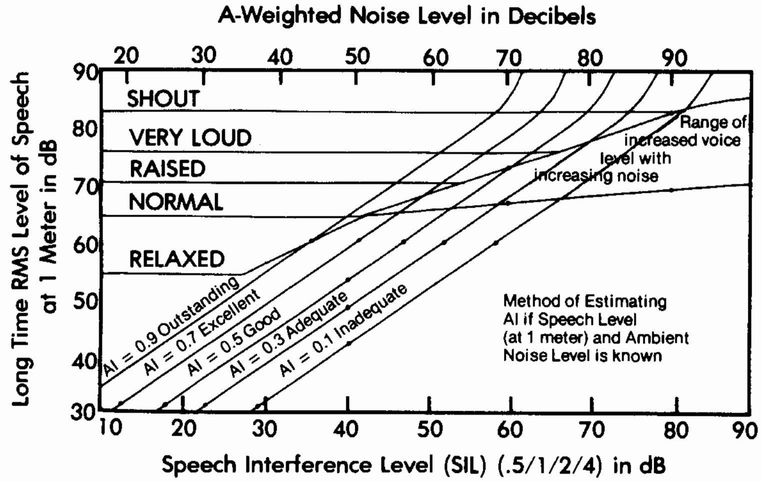


Figure 7. Method of estimating Articulation Index (AI) if noise level and vocal effort is known, adapted from Kryter (1970).

data on classroom noises and to outline the scope of the measures made at NTID.

SURVEY OF BACKGROUND NOISE SPECTRA AND LEVELS

There have been at least three studies where large numbers of noises have been measured; Karplus and Bonvallet (1953), Klumpp and Webster (1963), and Cluff (1969). Botsford (1969) showed how well these spectra can be classified into groups by taking the difference between their C-weighted and A-weighted (C - A) levels. Webster and Cluff (1974), using Botford's C - A scheme, show how well 953 diverse manufacturing, neighborhood, and earth moving vehicle noises measured by Karplus and Bonvallet agree with 112 environmental noises of Cluff. The Webster and Cluff data are shown in

Figure 8. Note that: (a) if C - A = 10±2 dB the average noise spectrum drops by 4.5 dB in each octave band when measured in octave bands (the spectrum level of these noises would fall off at a -7.5 dB per octave rate), (b) if C - A = 5±2 dB the drop off is -3 dB per octave measured in octaves (spectrum level is -6 dB/octave), (c) if C - A = 1,2 dB the noise measured in octave levels is relatively flat (spectrum level, +3 dB/octave), (d) if C - A = 0 dB the octave bands increase about 1 dB in each octave (spectrum level, +4 dB), and (e) if C - A is negative the octave band increase is about 3 dB/octave (spectrum level +6 dB/octave).

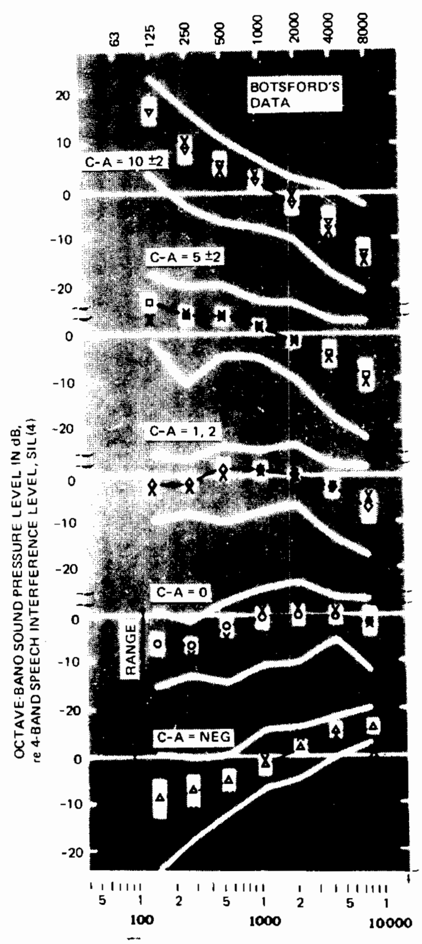


Figure 8. Classification of Cluff's (1969) 112 environmental noises by C-weighting minus A-weighting difference in decibels. The X's are Botsford's (1969) data, from Webster and Cluff (1974).

TYPICAL INDOOR NOISE SPECTRA

Specific studies of noises in classrooms and other types of indoor special rooms are more limited but some are summarized in Figure 9. The data in Figure 9 include those of Hoth (1941), who surveyed 28 randomly selected business locations and found the average spectrum of room noise had a slope of -2.3 dB/octave when measured in octave bands (or -5.3 dB/octave spectrum level); the average spectrum of noise in New York City offices with similar characteristics had a slope of -3 dB/octave when measured in octave bands. Webster and Gales (1954) measuring audiometric test rooms found the drop off was 2.7 dB/octave. Erber (1971), who measured classroom noise at the Central Institute for the Deaf, found the noises typically had a -4.5 dB per octave slope when measured in octave bands.

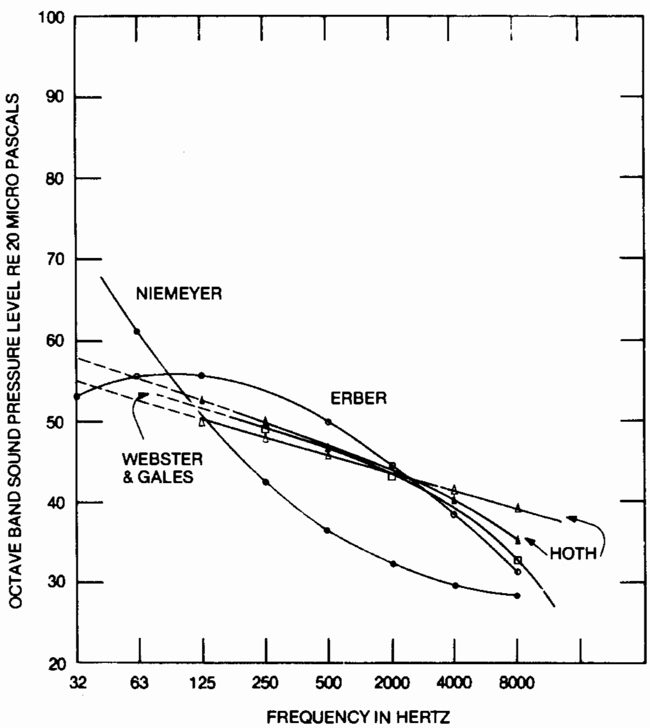


Figure 9. Typical room noise spectra equated to an A-weighted overall level of 50 dB.

Extensive measures in Germany reported by Niemeyer (1976) showed that "standard" background room noises typically had a -8 dB/octave slope up to 250 Hz and -3 dB/octave through the speech range.

PREVIOUSLY MEASURED CLASSROOM NOISE LEVELS

Concerning noise levels, Watson (1964) found the mean noise level in a number of primary schools for normal hearing children to be 59 dB(C) or 56 dB(A). In a survey of 47 occupied classrooms, Sanders (1965) found mean noise levels using the B-weighting network to be 69 dB in kindergartens, 59 dB in elementary schools, 62 dB in high schools, and 52 dB in units for the partially deaf. Ross and Giolas (1971) selected a classroom considered to be average in terms of size (600-800 ft^2), location, furnishings, and acoustics and found the ambient room noise to be 60 dB(C). Houtgast (1981), in ten classrooms for normal hearing children (ages 9-15), found window-closed levels of 50 ± 5 dB(A), average 47.4; and window-open levels of 56 ± 5 dB(A), average 55.6.

CLASSROOM NOISES AT NTID AND RIT

Noise levels and speech intelligibility in NTID and non-NTID RIT classrooms had not been extensively surveyed previously. A classroom survey was proposed to determine: (a) if noise conditions in NTID and RIT classrooms interfered significantly with the speech intelligibility of the teacher, (b) if the teacher's intelligibility decreased from the beginning to the end of class sessions, and (c) whether there were any differences in these quantities between NTID and RIT classrooms. To accomplish these aims, noise levels and voice intensity levels were sampled twice at the beginning and twice at the end of class sessions in each of four preselected classrooms.

METHOD

Rooms and Subjects

Using as criteria the generalizations of Niemoeller (1971), two audiologists made an acoustic survey of all NTID labs and classrooms and representative non-NTID RIT classrooms. They were looking for rooms that were generally small, less than 2000 cubic feet, with reverberation times of 0.4 or less and unoccupied ambient noise levels below 30 dB(A). Credit was given for carpeted floors, heavy, rigid doors and short distances between the teacher's position and the front row of student seating. They rated the rooms as average, above average and below average. Random choices of one above and one below average room at NTID and RIT were made from the compiled lists. Class schedules were checked and two sessions, generally one in the morning and one in the afternoon in each room were selected. Two teachers in each of these classes were asked to cooperate in the study and willingly cooperated.

Apparatus

A Nagra tape recorder (Model IV-S) was used to record speech and voice samples in each of the four rooms and sound level measurements were made simultaneously on a Bruel and Kjaer sound level meter (Type 2204).

Procedures

Since it was assumed that NTID students would take preferential seating in RIT classrooms, recordings and measurements were made from the position in both RIT and NTID classrooms judged most advantageous for listening. Generally, this was the first row available for seating, directly in front of the teacher.

Speech and noise level measurements were made at the beginning and end of each class session. Peak teacher voice intensities were sampled twice at the beginning of class and twice at the end of class. During each time sample, the peak intensities (meter deflections) were noted three times. The average of these three readings was used as the peak intensity for that sample.

The room noise was measured in the same way except that each observation was of the average room noise, not the peak room noise. Extreme care was taken to measure the noise levels before, between, or after spoken syllables, speech peaks. In addition, continuous recordings of room noise while the teacher was speaking were made during the first 10 and last 10 minutes of class. If the roll was called, this time was excluded from the sample.

The above set of measurements was made using first the A-weighting network and then with all networks removed (linear).

Statistical Analysis

A total of 32 measures were taken on eight different teachers (a morning and afternoon teacher in a "good" and "poor" room in both NTID and RIT). These 32 speech and noise levels were used to calculate Articulation Indices (AI) by interpolating AI values at the intersections of the speech and noise levels in Figure 7. These 32 AI's were analyzed in a 4-factor repeated measurements design with partial nesting. Comparisons among means were made with the Newman-Keuls range test.

RESULTS

The analysis of variance (ANOVA) indicated a significant school effect, $F(1,16) = 9.41$, $p < .01$; a significant room/school effect, $F(1,16) = 19.32$, $p < .01$; a significant teacher/room/school effect $F(4,16) = 13.08$; $p < .01$; a significant time effect, $F(1,4) = 10.04$, $p < .05$; and a significant time-room interaction effect, $F(2,19) = 4.42$, $p < .05$ (see Table 3).

The Articulation Index (AI) was significantly higher in the rooms selected by the audiologist to have better acoustics than in those with poorer acoustics. The AI in the better room at RIT (non-NTID) was significantly higher

Table 3
ANOVA Four factor (School, Room, Teacher, Time), repeated measures analysis of variance results

Source	MS	F Test	DF
Between Teachers			
Between Rooms	753.36		
Schools (A)	442.53	9.41[a]	(1,15)
Rooms (B/A)	908.78	19.32[a]	(2,15)
Within Rooms			
Teachers (S/B/A)	614.97	13.08[a]	(4,15)
Within Teachers			
Time (c)	385.03	10.04[b]	(1,4)
A×C	26.28	1	(1,4)
C×B/A	200.28	5.22	(2,4)
C×S/B/A	38.34	1	(4,15)
Residual Error	47.03		
Pooled Error	45.29		
C×B/A	200.28	4.42*	(2,19)

[a]p 0.01
[b]p 0.05

than in the poorer room at NTID as seen in Figure 10. Since dB(A) noise levels were the same in the better rooms at both NTID and RIT (45 dB(A)), the higher AI in the NTID room can be attributed to the greater voice intensity used by NTID teachers.

Figure 11 shows that the AI was significantly worse at the end of sessions

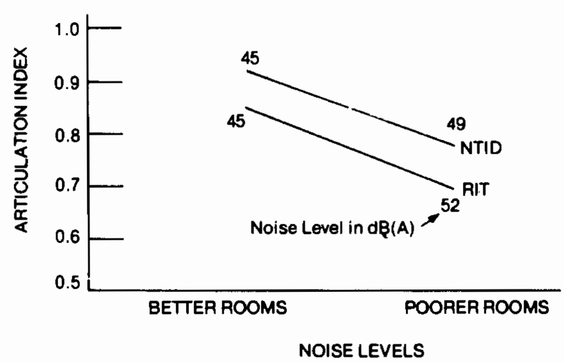


Figure 10. Articulation Indices (AI) for better and poorer rooms at NTID and RIT. Note that the Articulation Index was higher at NTID and in rooms judged by audiologists to have better acoustics.

in all classrooms except the better NTID classroom. Speech levels, however, were not significantly lower at the end of class in any classroom. The poorer conditions at the end of the sessions can be attributed to the teachers' failure to compensate for the increases in classroom noise. Classroom noise levels tend to increase as the time in class increases because of the decrease in the students' attention span with consequent noise producing actions such as fidgeting, shuffling of papers, closing of books, etc. in anticipation of the end of the class. Concerning voice levels, ANOVA results of voice levels show the only voice levels which are different are those of NTID teachers in better classrooms at the end of sessions. Those teachers lecturing in the classrooms with better acoustics raised their voices at the end of class and speech intelligibility remained excellent throughout the session.

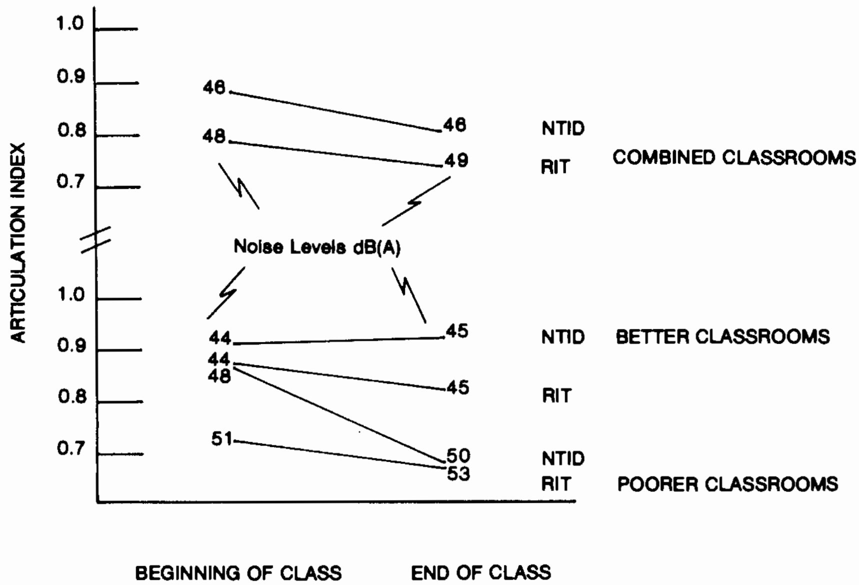


Figure 11. Articulation Indices (AI) at the beginning and end of classes in better and poorer classrooms at NTID and RIT. Note that the Articulation Index became worse at the end of class in most rooms.

In all classrooms the AI varied significantly with the teacher. However, within classrooms with poorer acoustics the variations were greater. The AI in the poor classroom at RIT when the poorer teacher was lecturing was 0.55 which according to Figure 4 corresponds to a PB equivalent of 75 percent correct.

NTID instructors initially compensated for poorer acoustics more than RIT instructors. By the end of class, however, their AI dropped to levels similar to those in the poorer RIT classroom. Instructors in the RIT room with poorer acoustics initially accepted a lower level of AI but their drop was less dramatic. From the beginning to the end of class the AI in four of the class sessions differed by 0.01 or less. Three of the four sessions showing greatest variability (0.06 to 0.23) were in poorer classrooms.

DISCUSSION AND CONCLUSIONS

Figure 12 shows how results from this study compare with previous ones. Articulation Indices were calculated from Sander's (1965) and from Ross and Giolas' (1971) data using the dot pattern method, Figure 6, and assuming spectra with a -3 dB/octave slope. The resulting AI's were: (a) kindergarten, 0.43, elementary, 0.70, junior high, 0.57, and special classrooms (for the deaf), 0.83 (Sanders, 1965); and (b) 0.60 (Ross & Giolas, 1971). The results of this study when averaged over rooms, teachers and time in class were 0.84 for NTID and 0.76 for RIT. According to these comparisons the speech intelligibility, as indicated by Articulation Index (AI) calculations, are as good or better at NTID/RIT as at the other intitutions where measurements have been made.

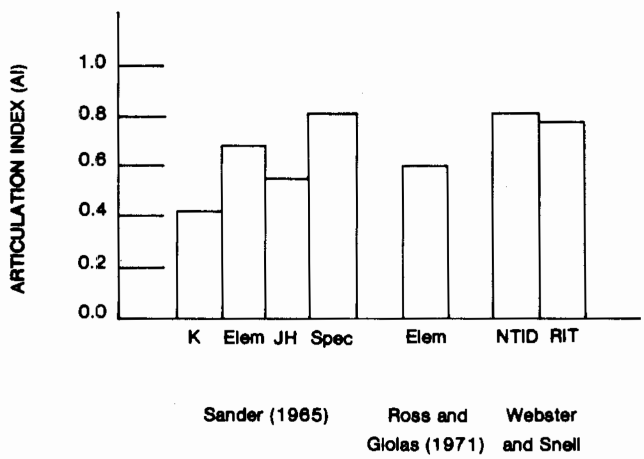


Figure 12. The average articulation indices for seven different schools. The indices for NTID and RIT differed significantly from one another (.01).

Articulation Indices of 0.7 to 0.9, a range encompassing the means of six of the eight class sessions at NTID and RIT have been assigned speech intelligibility ratings of very good to excellent by Kryter (1970) and excellent to outstanding in Figure 7, an adaptation of a figure of Kryter (1970, p. 90).

Using these ratings, based on normal hearing listeners only, noise conditions in NTID and RIT classrooms do not interfere significantly with teacher intelligibility. A comparable rating scale for hard-of-hearing listeners using amplification needs to be developed since Olson and Tillman (1968), Tillman et al. (1970), Erber (1971), and Plomp (1978) show that students with sensorineural hearing losses who use hearing aids will have relatively more difficulty understanding speech in noise than normal hearing classmates.

For normal hearing students the speech intelligibility associated with a given AI is the same whether the speech level was 65 dB(A) and the noise level 55 dB(A) or whether the respective levels were 75 dB(A) and 65 dB(A). As pointed out in the introduction, for students wearing hearing aids the absolute levels, especially of the noise, make a difference. Levitt (1982) citing Dugal, Braida and Durlach (1980), Macrae and Brigden (1973) and Danaher and Pickett (1975) also points this out. In explaining why an AI calculated on the data of normal hearing listeners does not adequately predict the speech intelligibility of hearing-impaired listeners, he cites the rollover effect, the fact that " . . . percent-discrimination does not always increase monotonically with increasing signal intensity.", and the etiology of the hearing impairment.

Plomp (1978) has developed a theory showing that the internal noise and the distortion inherent in a hearing aid limit the ambient noise levels in which it can be used effectively. Duquesnoy (1982) found the limiting levels of noise for five types of hearing-impaired people divided into five classes according to average pure tone (PTA) hearing levels. Using Plomp's (1978) assumptions and equations and assuming the teachers were speaking in a normal manner consistent with the ambient noise levels, Duquesnoy (1982) found the following limits: (a) normal hearing people are not adversely affected by noise levels up to 65 dB(A), (b) hearing-impaired people with PTAs averaging 33 ± 3 dB are limited by noise levels of 55 dB(A), (c) as the PTA average increases to $57+3$ dB the limiting noise level falls to 45 dB(A) and (d) for PTAs greater than 60 dB the speech-to-noise differential must be increased in some other manner before a hearing aid will be of any benefit whatsoever.

According to Plomp (1978) and Duquesnoy (1982), the NTID/RIT classrooms would be marginal for students with PTAs up to 60 dB wearing hearing aids. To accomodate students with PTAs greater than 60 dB, that is, those who are severely/profoundly deaf, but who still rely to some extent on hearing aids something else must be done: Noise levels should be reduced to 25 dB(A) (Borrild, 1978), 30 dB(A) (Niemoeller, 1968; Gengel, 1971; Kenna, 1981) or 31 dB (Plomp, 1978); the reverberation time should be reduced as much as is practicable (see Nabelek & Pickett, 1974; Nabelek & Mason, 1981; and Houtgast, 1981); the teacher's face should always be visible and her/his speech level at the student's ear (hearing aid) should be increased. Concerning the speech-to-noise ratio required for hearing-impaired listeners: Nabelek and Pickett (1974) say " . . . 10 dB . . . when wearing hearing aids in reverberant rooms." Erber (1971) says, " . . . 10-15 greater S/N notes (i.e., about 0 to +5 dB S/N) than normal hearing children. . . ." The most obvious way of increasing the teacher's speech level is to pick it up with a microphone relatively close to the lips (within 6 inches) and transmit it by hardwire, induction loop, FM or infra-red to a receiver coupled to the student's hearing aid (or to an earphone worn by the student). If this method is used to complement or supplement efforts to reduce noise levels and reverberation times in classrooms for deaf and/or hard-of-hearing people, reference should be made to Bergman (1983), Vaughn (1983), and Vaughn, Lightfoot and Gibbs (1983). They describe and give the specifications and prices of "group hearing aids."

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APPENDIX

The A-weighted network of a sound level meter, abbreviated dB(A), discriminates against low frequency noise in a manner approximating the 40 phon equal loudness contours (Fletcher & Munson, 1933; Stevens & Davis, 1938), or 25 dB at the octave centered at 63 Hz, 15 dB at 125 Hz, 8 dB at 250 Hz, and 3 dB at 500 Hz (Peterson & Gross, 1967).

The C-weighted frequency network is essentially flat over the usable frequency range. When used it should be abbreviated dB(C). However, since it is the oldest and in the older literature the most common and is generally the equivalent of no weighting at all (i.e., flat), the (C) is often omitted.