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Application of Effective Noise Control Strategies in Speech Perception Testing Rooms

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Abstract

This project examines experimental methodologies, common test practices, and identifies relevant acoustic metrics to determine effective noise control parameters and strategies for implementation in a new speech perception testing room in Lincoln, Nebraska. The nature of speech perception testing demands that the experiment facility be as quiet and non-disruptive as possible to ensure that auditory stimuli is not interfered with. Influences of ambient acoustic conditions, like background noise and reverberation time, interfere with speech perception testing by introducing new variables that are often difficult to account for if left uncontrolled. A room-in-room chamber (sound booth) is often a best-case practice for minimizing acoustical room effects, but such chambers are not always feasible for non-standard room layouts, and they are also often cost-prohibitive. Therefore, alternative acoustic treatment options must be explored. An examination of speech-related acoustic metrics has been conducted to determine if other available metrics within the acoustical field can better describe and standardize speech perception testing facilities. Consideration has also been given to the gamut of test batteries that are often implemented in speech perception experiments to determine the specific acoustical concerns related to each test method. Case studies of noise control strategies have also been examined to determine the most effective methods of mitigating acoustic concerns in speech perception test facilities. In reviewing the nature of speech perception tests, examining relevant standards, identifying relevant metrics, and reviewing design case studies, a comprehensive approach has been developed to provide quality acoustical consultation to the client.

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Review of Literature

Speech Perception Testing

Speech perception testing covers a variety of test batteries that seek to measure speech reception performance, sentence intelligibility, and common phonetic/perceptual confusion. Such testing has many clinical applications, particularly in pediatric audiology. In this context, speech perception testing is used to "assess the benefits of amplification technology, plan and monitor habilitation, and assess auditory processing skills." (Madell, 2011) Speech perception tests also have precedence for use in evaluation and tuning of cochlear implants (Tyler et al., 2002; Nilakantan et al., 2018). Through speech perception testing, speech-language pathologists and audiologists are able to determine what a patient does and does not hear.

Relevant Acoustical Metrics

Although the presence of sound and noise is often interpreted qualitatively by human occupants, there exist several quantitative metrics to determine the acoustical properties of a space. Room acoustic and speech intelligibility metrics have been considered for application to speech perception testing rooms.

Background Noise Level

The metric most directly related to the presence of ambient noise is Background Noise Level (BNL) or Sound Pressure Level (SPL). Expressed logarithmically through decibels (dB), BNL can be measured across frequency using a sound level meter. Background noise level is the most rigorously codified metric within speech perception testing standards, and ambient noise requirements for the CB3 laboratory space have been adapted from the ISO 8253 standard for audiometric testing.

Reverberation Time

Reverberation time (RT) is the length of time that it takes for a sound to drop in level by 60 decibels (dB). It is often perceived as the "liveliness" or echo of a space. The ability to hear and understand what is being said (speech intelligibility) is related to RT, as excessively long RT can seriously degrade speech intelligibility.

For the purposes of speech perception testing, the reverberation time should be as low as possible. Using typical space recommendations outlined in Architectural Acoustics: Principles and Design, a target RT of <0.5 seconds has been selected (Mehta et al., 1998).

Clarity Index

Clarity index (C50) is the ratio of early to late sound energy as stipulated by a cutoff time. Cutoff times between “early” and “late” reflections are determined by the intended use of the space. Speech-based applications typically use a cutoff of 50 milliseconds. A higher clarity index equates to more early sound energy, resulting in a clearer and more distinct sound (which is desirable for speech-oriented spaces).

Recommended values for C50 span from -5.0 to +5.0 dB for musical performing spaces per in ISO 3382-1-2009. For a speech oriented space like the CB3 Lab, a target value of C50 > 5 dB has been selected.

Speech Transmission Index

Originally developed to quantify optical distortion of light received from stars, Speech Transmission Index (STI) utilizes a modular transfer function to account for room distortion caused by reverberation and noise. It can be measured using either an impulse response or an STI measurement system, and works reasonably well for a variety of room applications.

An STI greater than 0.8 is qualitatively interpreted as being Excellent for speech intelligibility.

Speech Intelligibility Index

Speech Intelligibility Index (SII) calculates the audibility of certain octave bands and weights the audibility based on contribution to speech intelligibility. There are several methods, each using a different number of octave bands. The most accurate method uses 21 bands within the speech critical band (150 to 8500 Hz). The calculation procedure for SII is outlined in ANSI/ASA S3.5 1997 (R2017).

An SII value greater than 0.75 is qualitatively interpreted as being Good for speech intelligibility.

Articulation Loss of Consonants

Articulation Loss of Consonants, developed originally by Peutz for analysis of Dutch syllables, describes the degradation in speech intelligibility through the expected percentage of lost consonants in a difficult acoustic environment. It is calculated from the reverberation time, signal-to-noise ratio, and the size of the room:

An ALCons value less than 5% is qualitatively interpreted as being Excellent for speech intelligibility.

Limitations

Although the aforementioned metrics are highly applicable to speech-oriented rooms, many do not meet the specific needs of speech perception testing. A testing chamber may achieve a qualitative rating of "Excellent" from the perspective of STI, ALCons, and SII, yet still fail to meet ambient noise requirements set forth by ISO 8253. Many of these metrics and their associated qualitative assessments were outlined for less critical spaces (lecture halls, conference rooms, restaurants, atria). Speech perception testing rooms are strictly speech critical, and the corresponding metrics must be equally stringent. In some cases, however, the aforementioned speech metrics may not precise enough for more stringent considerations. Consider, for example, the equation used to calculate Articulation Loss of Consonants:

$$AL_{Cons} = 9T_{60}\left\{\frac{1}{1+(\frac{r_l}{r})^2}\right\}\left[1.071T_{60}{}^{-0.0285}\right]^{(25-L_{S/N})} + \alpha \qquad \text{(Eqn 1)}$$

Where T_{60} is the reverberation time (seconds)

$L_{S/N}$ is the signal to noise level at the 2000 Hz octave band (dB)

r_l is the limiting distance, obtained from source directivity and the room constant

r is the distance of interest (m)

α is the correction factor for listener acuity (1.5% to 12.5%)

The ALCons assessment of an ideal testing space with minimal noise at the 2000 Hz octave band and low reverberation time is controlled by listener acuity, introducing a subjective assessment of listening ability into the otherwise quantitative metric. Furthermore, ALCons is limited in spectral considerations, and should be used with caution for situations involving noise and reverberation in other frequency bands. ALCons is not alone in its limitations, as most speech intelligibility metrics are plagued with similar but altogether unique issues that arise at the outer bounds wherein speech perception testing rooms lie. Furthermore, no standard utilizes speech intelligibility metrics when defining requirements for these spaces. Instead, in the context of speech perception testing rooms, background noise level and reverberation time are the principal acoustical metrics to be considered.

Equipment and Testing Chamber Requirements

Speech perception testing can be performed using supra-aural earphones monaurally or binaurally, by bone vibrator, or with loudspeakers in a sound field per ISO 8253-3. From an acoustical perspective, speech perception testing rooms must be as quiet and non-disruptive as possible to minimize the introduction of confounding variables. Across the different modes of stimuli presentation, requirements for ambient sound pressure level differ.

The ISO 8253 standard set is divided into three parts on the basis of stimuli delivery method:

- ISO 8253-1:2010 governs pure-tone air and bone conduction audiometry
- ISO 8253-2:2009 governs pure-tone and narrow-band sound field audiometry
- ISO 8253-3:2012 governs speech audiometry

For pure-tone threshold audiometry discussed in Parts 1 and 2 of ISO 8253, maximum allowable ambient noise levels are listed in Table 2 of each standard. Though Part 3 of the standard is most applicable to the scope of this project, it is critical to note that ISO 8253-3 states that ambient noise requirements “can be less stringent than those for pure-tone threshold audiometry” methods defined in Parts 1 and 2. Although the standard does not specify the degree of leniency that should be applied, a conservative approach dictates that ambient noise levels for speech audiometry should not exceed the levels specified for the pure-tone equivalent. Thus, for speech perception testing conducted via supra-aural earphone or bone conductor, limitations are determined from ISO 8253-1. For speech perception testing conducted using loudspeakers, limitations are determined from ISO 8253-2.

A comparison of maximum permissible ambient noise levels across octave bands (presented in Figure 1) depicts the significant difference in ambient noise requirements between stimuli delivery methods. Since supra-aural equipment presents stimuli directly to the ear, ambient noise requirements are more relaxed (especially at higher frequencies where typical supra-aural equipment provides significant sound attenuation). Sound field audiometry, however, delivers stimuli to the testing chamber through loudspeakers and thus is more apt to be negatively impacted by ambient background noise.

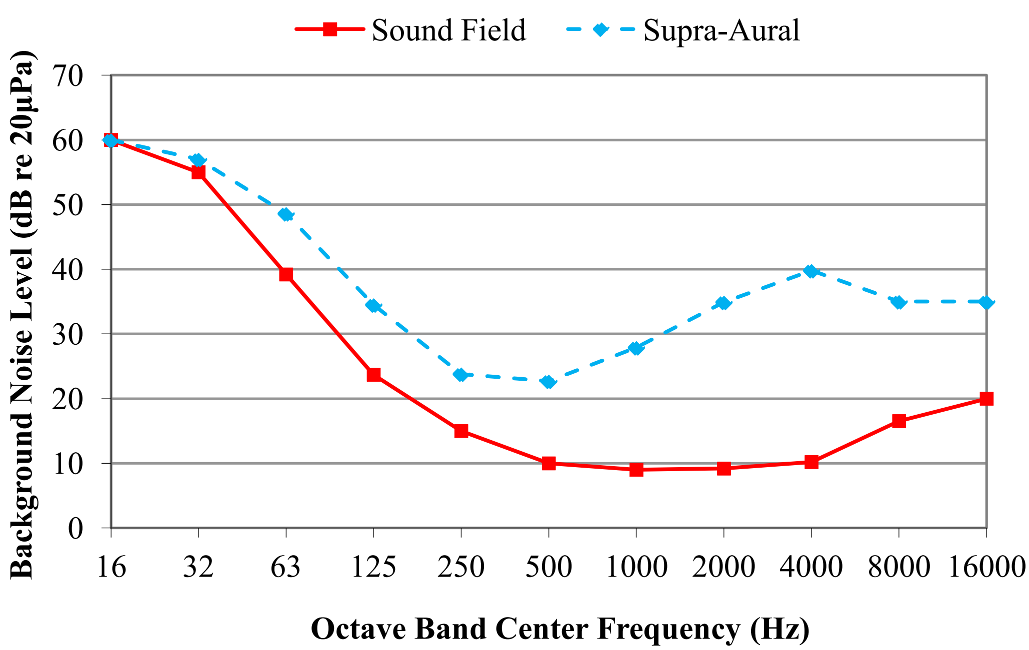

Figure 1 – Comparison of Ambient Noise Requirements across Pure-Tone Test Methods

For most speech perception testing applications, a room-in-room sound booth is a best-case practice to ensure sufficient sound isolation is provided. However, sound booths are not always feasible for unusual room layouts where size is constrained. Sound booth installation can also often be cost-prohibitive. As a result, exploration of other acoustical treatment options is necessary.

Noise Control Practices for Speech Perception Testing

Little to no published research has been done on specific noise control practices for speech perception testing, and the majority of available case studies are related either to pure-tone audiometry or other speech-oriented spaces. An early study found that audiometric booths afford adequate attenuation within noisy environments except at the lowest frequencies (Ancell and Hardy, 1961), but no consideration was given to the influence of intruding sound fields in non-sound booth testing environments.

Drawing from other types of speech-oriented spaces, common practice ceiling treatments (baffles and reflectors) have found to be effective at improving speech intelligibility in lecture halls and similar spaces (Yang and Hodgson, 2007). Unfortunately, many of these solutions are inapplicable to speech perception testing rooms due to space constraints.

Methodology

Using a Larson Davis 831 sound level meter, an omnidirectional loudspeaker, and a laptop containing the software EASERA, Sine Sweep impulse response measurements were conducted per the engineering method of ISO 3382-2 Reverberation time in ordinary rooms (2008). In accordance with the standard, impulse response measurements were conducted at no less than 6 source-microphone combinations. Consideration was also given to ensure that measurements were conducted outside of the direct sound field and beyond the calculated critical distance from the source (see Equation 2).

$$d_{crit} = 2\sqrt{\frac{V}{cT}} = 2\sqrt{\frac{(56.6\ m^3)}{(344\ m/s)(0.5\ sec)}} = 1.14\ m \qquad \text{(Eqn 2)}$$

Where V is the volume of the space in m^3

c is the speed of sound, taken to be 344 m/s

T is the estimated reverberation time, taken to be 0.5 seconds

Where possible, microphone positions were selected such that the distance from the microphone to the nearest reflecting surface (i.e. walls and floor) were at least a quarter of a wavelength. However, given the small and atypical layout of the room, this was not satisfied across all measurement positions. Reverberation time, clarity index, and ALCons were calculated by EASERA from the impulse response and arithmetically averaged for further analysis.

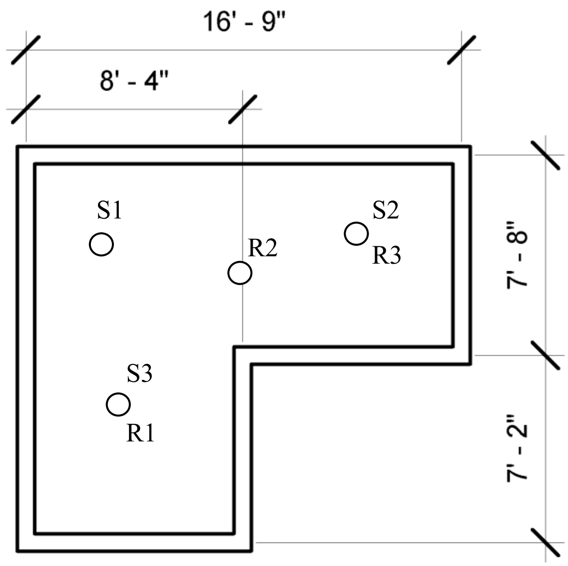

Figure 2 – Plan View of Measurement Locations

Ambient noise level measurements were also taken in the CB3 laboratory space near the anticipated patient testing chair per the engineering method of ANSI-ASA S12.72 Measuring Ambient Room Noise (2015). As such, the spatially averaged sound pressure level was recorded by rotating the sound level meter in a 1-meter diameter circle with the microphone held at a ¾ arm's length within the measurement volume at a speed not exceeding 0.2 m/s. Although a single measurement conducted in this manner is sufficient for the engineering method, three additional measurements were taken for redundancy. Background noise measurements were logarithmically averaged for each one-third octave band.

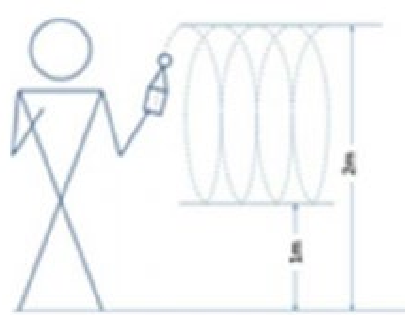

Figure 3 – ANSI-ASA S12.71 Recommended Measurement Technique

Measurement Results

For background noise measurements, raw un-weighted sound pressure levels were corrected using A-weighting factors (inversion of 40 phon equal loudness contour) and tabulated across octave bands to produce A-weighted sound pressure levels. Un-weighted sound pressure levels were plotted on the Noise Criterion (NC) Chart depicted in Figure 4 to determine an appropriate NC Rating.

Frequency (Hz)	Avg. BNL (dBA)
16	-8.7
32	7.4
63	14.3
125	23.2
250	26.3
500	26.3
1000	31.6
2000	36.0
4000	38.4
8000	37.4
16000	30.6

Table 1 – Background Noise Measurements

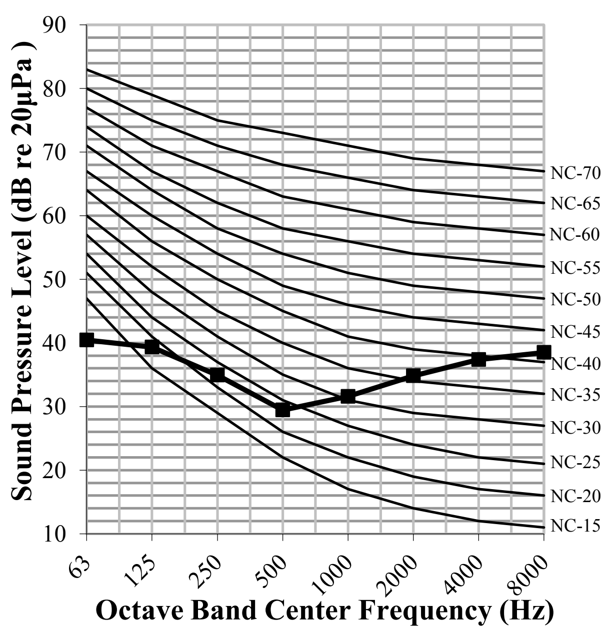

Figure 4 – NC Rating Chart with Measured BNL

The CB3 Laboratory achieves an NC-41 Rating, though it should be noted that the predominance of high-frequency noise heavily penalizes the overall rating. Since the NC Rating method does not account for spectral deviations, it is important to also consider the RC- Mark II method.

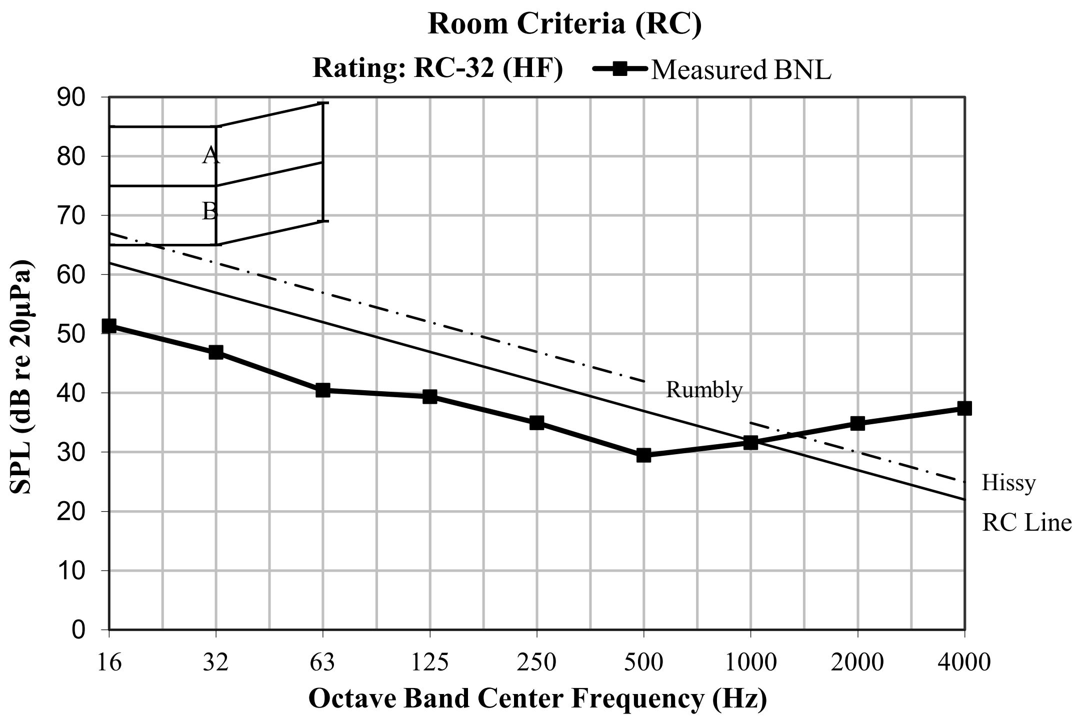

Figure 5 – RC Mark II Chart with Measured BNL

The CB3 Laboratory achieves a RC-32 (HF) rating with a Quality Assessment Index (QAI) of 22.16 dB. Per Chapter 48 of the ASHRAE Handbook: HVAC Applications, the HF denotation indicates that the room exhibits a “Hissy” sound quality, and the QAI in excess of 10 dB indicates that the acoustic environment is likely to be deemed unacceptable by most occupants.

For speech perception testing considerations, these ratings indicated that treatment to the CB3 Laboratory was likely necessary. Ultimately, however, the primary goal was to meet requirements set forth by the ISO 8235 standards with respect to maximum permissible ambient noise for audiometric testing. Compliance with ISO 8253 was evaluated by comparing measured background noise levels to the maximum allowed ambient noise levels as prescribed for each of the two delivery methods (see Figure 6).

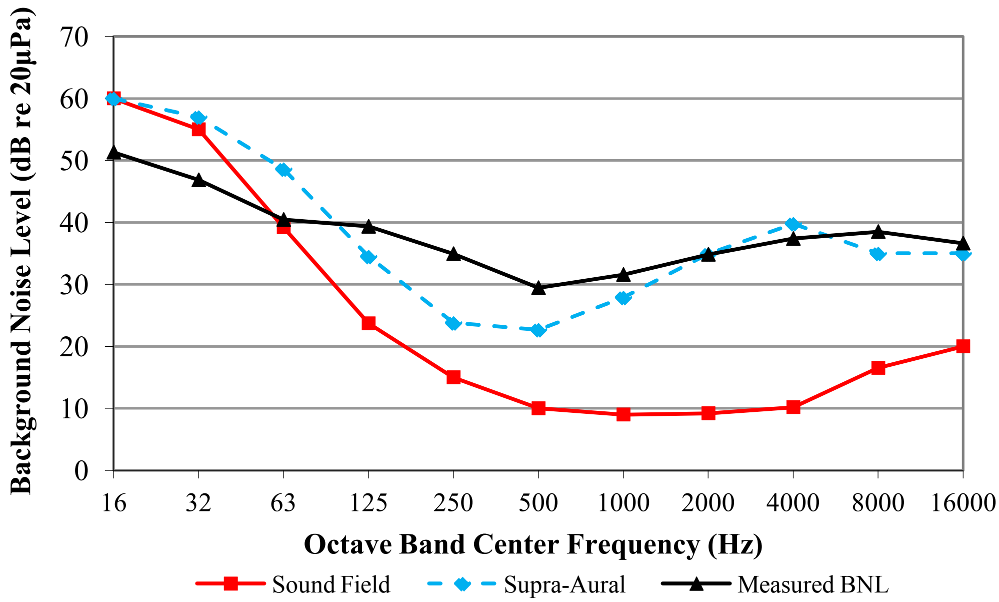

Figure 6 – ISO 8253 Compliance

For audiometric methods utilizing bone conduction or supra-aural headphones, measured ambient noise exceeds required levels across octave bands centered from 125 Hz to 1000 Hz. For methods utilizing sound field/loudspeaker stimuli, measured ambient noise significantly exceeds maximum allowable levels across octave bands centered above 63 Hz.

Although the conservative approach adopted here concludes that the CB3 Laboratory was not suited for any form of audiometric testing in its measured state, it is important to note that the aforementioned ambient noise requirements do not pertain to stimuli delivered through circumaural headphones, as such equipment typically provides sufficient attenuation for most testing environments. If circumaural headphones were not to be used for speech perception testing, acoustical treatment options needed to be explored to reduce ambient noise levels.

A summary of the averaged results of the RT measurements is shown in Table 2 below.

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
T20 (sec)	0.35	0.37	0.33	0.31	0.31	0.29	0.25
Target Value	<0.5						

Table 2 – Measured reverberation times across octave bands

As depicted in Table 2, measured reverberation time in the laboratory space satisfies the target requirement of <0.5 seconds. Therefore, no treatment is necessary to mitigate reverberation time. Although typical speech perception testing rooms are often sufficiently small and absorptive to have low reverberation times, it is important to confirm with measurements.

The average clarity index was measured to be 9.0 dB, which falls within the recommended parameters for speech intelligibility. Average ALCons was measured to be 2.0%, which indicates that the existing room is well suited to speech. Despite these positive assessments from the other associated metrics, it was still important to explore noise control solutions to meet the requirements of ISO 8253-3.

Client Recommendations

Treatment recommendations were developed from parameters determined at the initial client meeting. The client indicated that testing planned for the CB3 Laboratory would utilize loudspeakers to deliver speech stimuli to subjects and ensure that younger subjects would not tamper or play with supra-aural or bone conduction headphones. During the initial visit, the client discovered a few spare pyramidal foam panels in the laboratory storage closet. If possible, the client wished that these be incorporated in the final recommendations. Three treatment options were provided to the client:

1. Line the supply air ducts with a fiberglass acoustical insulation or wrap the supply air duct with duct lagging to reduce duct-borne noise.
2. Mount 2"-thick fabric-wrapped acoustical panels on lateral walls of the testing area (see Figure 7) to improve noise reduction through added absorption. If able, adhere the spare pyramidal foam to the walls of the testing are to provide additional sound absorption.
3. Hang an acoustical curtain to isolate the testing area from the laboratory space and improve blocking of sound transmitted from the corridor.

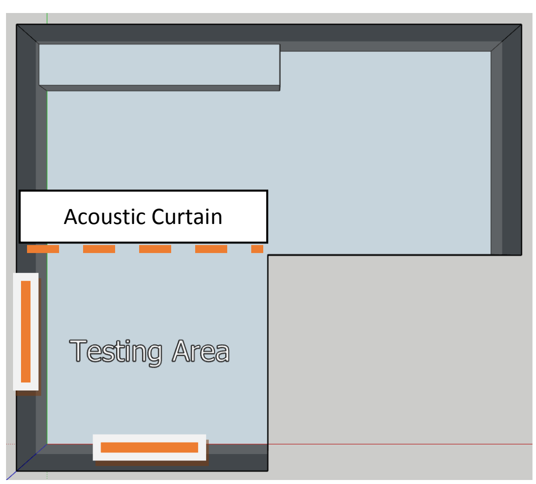

Figure 7 – Floor Plan with Treatment Locations

All three options were predicted to provide a noticeable improvement in ambient noise reduction. A fourth option, using circumaural headphones for delivery of speech stimuli, was also recommended as an alternative for the client. Per the client's wishes, a cost estimate comparison was provided.

Treatment	Material Cost	Labor Cost
Duct Lining	$1-2/ft^2$	$1000-2000
Duct Lagging	$500-1000/roll	$0-2000
Acoustical Wall Panels	$255/panel	varies
Quilted Fiberglass Vinyl Curtain	$250/curtain	varies
Circumaural headphones	$200-300	$0

Table 3 – Treatment Cost Estimate

After weighing the different treatment options, the client decided to re-format the method of stimuli presentation from loudspeakers to circumaural headphones to minimize cost and maximize ease of use. Although the recommended room treatments would have helped to reduce ambient noise, it was deemed unlikely that any affordable room treatment would be able to reduce ambient noise to the required levels for the strict ISO 8253-2 requirements set forth for loudspeaker testing methods. Furthermore, the use of circumaural headphones is the superior option in terms of installation time with no added labor cost. In selecting the circumaural headphones, the client can rest assured that the requirements of ISO 8253 are being met and speech stimuli is being delivered without significant interference from ambient noise.

Conclusion

Through the examination of speech perception test practices and the identification of relevant metrics, the ambient acoustic conditions of a new speech perception testing room in Lincoln, Nebraska have been analyzed. Testing of the laboratory space found that ambient noise levels were in excess of requirements for pure-tone threshold audiometric testing via both supra-aural and sound field delivery methods. However, exploration of the standards that govern these methods revealed a lack of explicit ambient noise requirements for speech audiology. Under uncertain requirements, additional consultation with the client became necessary to determine the degree of treatment needed in the laboratory space. After weighing design options, the client ultimately decided to pursue a non-architectural solution: re-formatting stimuli to be presented through circumaural headphones instead of through loudspeakers within the laboratory space. Since circumaural headphones typically provide sufficient attenuation such that ambient noise considerations are nullified, the client was satisfied that all requirements for the space were met.

Further research concerning permissible ambient noise for speech audiometry is necessary to determine the degree of leniency that can be applied to such spaces, as no such requirements have been outlined. Furthermore, although the use of circumaural headphones is a valid noise control solution, it may require that laboratory investigators make significant changes to their planned course of testing. Concerns regarding young subjects and their propensity to tamper with any equipment placed on their head are valid, and architectural noise control solutions should not be abandoned entirely. Although few published case studies of noise control applications in speech perception testing rooms exist, additional consultation with product manufacturers may yield architectural solutions that are more affordable, allowing investigators to utilize the presentation method of their choosing.

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APPENDIX: Client Test Report

April 28, 2019

Center for Brain, Biology and Behavior
C89 East Stadium, Lincoln, NE 68588

Re: Wang Lab
Acoustical Test Report

1. INTRODUCTION

This report summarizes the results of measurements conducted on 1/29/2018 to evaluate the room acoustics of the CB3 Speech Perception testing laboratory space. The primary concern for this space is aptitude for **speech perception testing without use of a sound booth**. After reviewing literature regarding typical speech perception testing conditions, it is understood that the goal for the Wang Lab is to neutralize acoustical room effects (namely reverberation and ambient noise) that may impede speech perception testing or otherwise introduce confounding variables.

Once you have a chance to review the results of this test, further consultation will be necessary to select a design that meets your requirements for the space.

2. ROOM ACOUSTICS AND IMPORTANT PARAMETERS

A variety of objective parameters have been measured to evaluate the room acoustics of the CB3 Wang Lab. This section explains the different acoustical metrics and provides desired target values for each of those metrics:

2.1. Reverberation Time (RT)

Reverberation time (RT) is the length of time that it takes for a sound to drop in level by 60 decibels (dB). It is perceived as the "liveliness" or echo of a space. The ability to <u>hear</u> and <u>understand</u> what is being said (speech intelligibilty) is related to RT, as excessively long RT can seriously degrade speech intelligibility.

For the purposes of speech perception testing, the reverberation time should be as low as possible. Using typical space recommendations outlined by Mehta, Johnson, and Rocafort in *Architectural Acoustics: Principles and Design*, **a target RT of <0.5 seconds has been selected.**

2.2. Background Noise Level (NC Rating and dBA)

Speech intelligibility is also related to the background noise level. The background noise of a space is represented by a single number criterion called the Noise Criterion (NC). The NC Rating is determined by comparing the measured sound levels to charts that compensate for human sensitivities to noise and reduce the sound levels measured at various frequencies to a single number. NC levels are most often used in the design process to indicate the level of the background noise for each room.

Background noise can also be characterized through dBA (A-weighted sound pressure level in Decibels). The decibel is a logarithmic quantity which, when A-weighted, accounts for relative loudness perceived by the human ear across frequency bands.

High background noise is often the result of mechanical ventilation noise or noise infiltration from other areas. Low background noise is key to providing good listening spaces, particularly for speech perception testing.

A recommended level for background noise has been determined from Section 7 of ISO 8253-1:2010: Acoustics - Audiometric test methods - Speech audiometry across frequency and is further described in Part 4.

2.3. Clarity Index (C50)

Clarity index is a measure of how distinctly separate sounds can be heard as they propagate through a space. Put another way, the clarity index is the ratio of early to late sound energy. A **higher clarity index** equates to more early sound energy, resulting in a **clearer and more distinct sound** (which is desirable for speech-oriented spaces). Cutoff times between “early” and “late” reflections are determined by the intended use of the space. Speech-based applications typically use a cutoff of 50 milliseconds.

Recommended values for C50 span from -5.0 to +5.0 dB for musical performing spaces per in ISO 3382-1-2009. For a speech oriented space like the CB3 Lab, **a target value of C50 > 5 dB has been selected.**

2.4. Articulation Loss of Consonants (ALCons)

Articulation Loss of Consonants describes a loss in speech intelligibility through the expected percentage of lost consonants in a difficult acoustic environment. It is calculated from the reverberation time, signal-to-noise ratio, and the size of the room.

An ALCons value of < 5% is interpreted as being excellent for speech intelligibility.

3. TEST PROCEDURE

Measurements of existing reverberation time and background noise in the CB3 lab space have been performed to inform design recommendations. Reverberation time measurements were conducted per the engineering method of ISO 3382-1:2009. Thus, an impulse response was measured at three receiver positions from three source locations.
A sine sweep signal was generated using the software EASERA to excite the space, and the resulting response was measured to calculate Clarity Index and AlCons within EASERA.

Background noise measurements were then conducted at the three receiver positions using a Larson Davis Model 831 Sound Level Meter per *ANSI-ASA S12.72 Measuring Ambient Noise.*

4. TEST RESULTS

Frequency (Hz)	Avg. BNL (dBA)
16	-8.7
32	7.4
63	14.3
125	23.2
250	26.3
500	26.3
1000	31.6
2000	36.0
4000	38.4
8000	37.4
16000	30.6

Table 1 – Background Noise Measurements

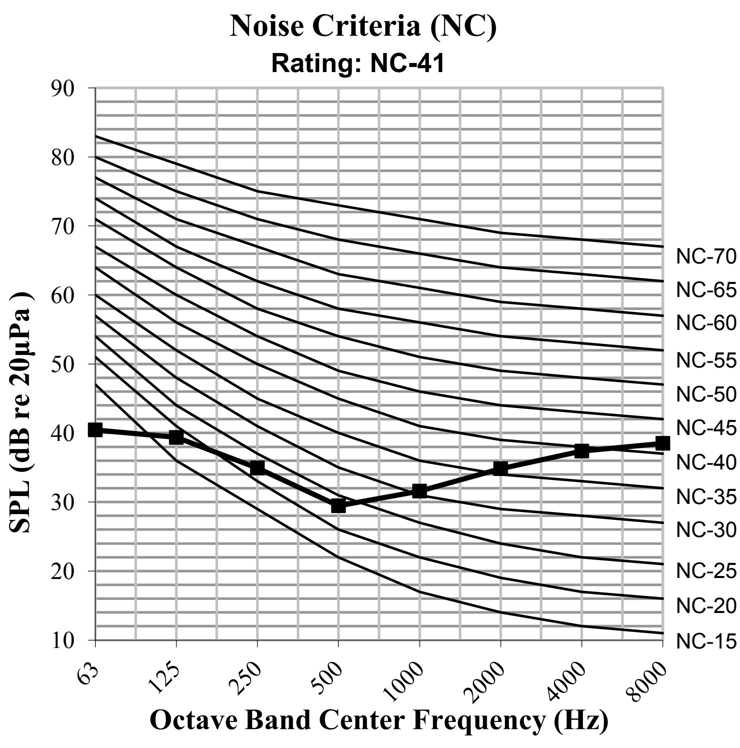

Figure 1 – NC-Rating Chart with measured BNL

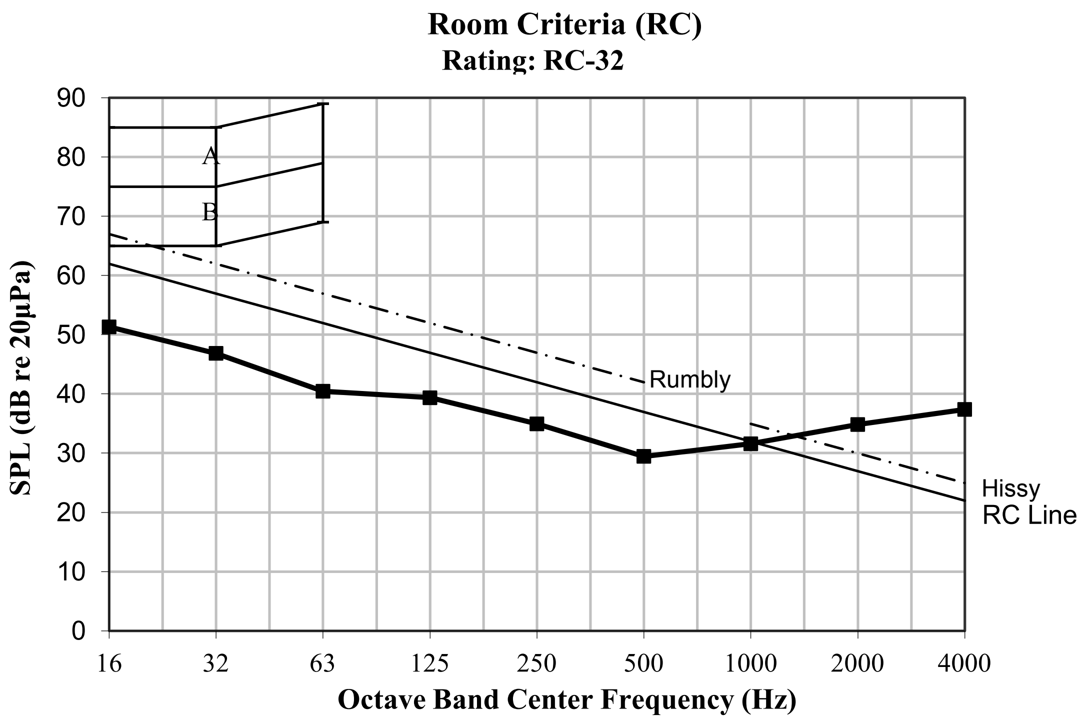

Figure 2 – RC-Mark II Rating

The CB3 Lab achieves an **NC-41 Rating**, though it should be noted that the presence of high-frequency noise is significantly penalizing the overall rating. Since the NC Rating method does not account for spectral deviations, it is important to also consider the RC- Mark II method.

The RC-Mark II method is the criteria system recommended by ASHRAE. It considers not only noise levels but also spectral quality and occupant acceptability. The CB3 Lab achieves a **RC-32 (HF) rating** with a **Quality Assessment Index (QAI) of 22.16**. The HF denotations indicates that the room exhibits a "Hissy" sound quality, and the high QAI indicates that the acoustic environment is likely to be **deemed unacceptable by most occupants**.

For speech perception testing considerations, these ratings indicate **that treatment to the space is likely necessary**. Ultimately, however, the primary goal should be to meet requirements set forth by the ISO 8235 standards with respect to maximum permissible ambient noise for audiometric testing.

The ISO 8253 standard set is divided into three parts on the basis of delivery method:

- ISO 8253-1:2010 governs pure-tone air and bone conduction audiometry
- ISO 8253-2:2009 governs pure-tone and narrow-band sound field audiometry
- ISO 8253-3:2012 governs speech audiometry

Although Part 3 of ISO 8253 is directly applicable to the types of testing planned for the CB3 Lab, this section of the standard recommends consulting Parts 1 and 2 for ambient noise maximums and notes that requirements can be "less stringent" for speech audiometry. Thus, a comparison of measured sound levels and maximum allowed ambient noise per ISO 8253-1 and ISO 8253-2 is depicted below:

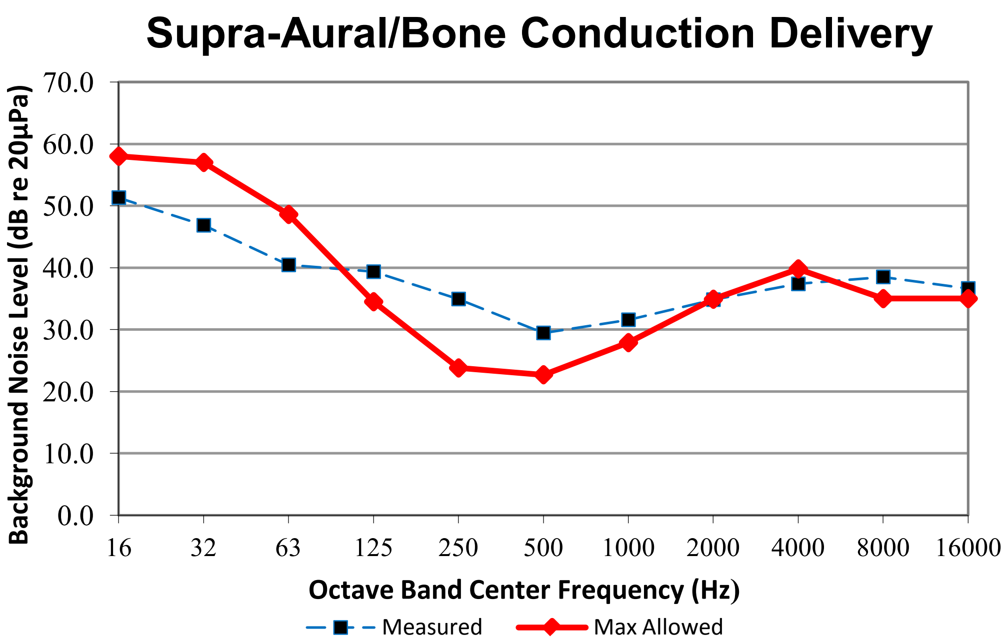

Figure 3 – ISO 8253-1 Compliance

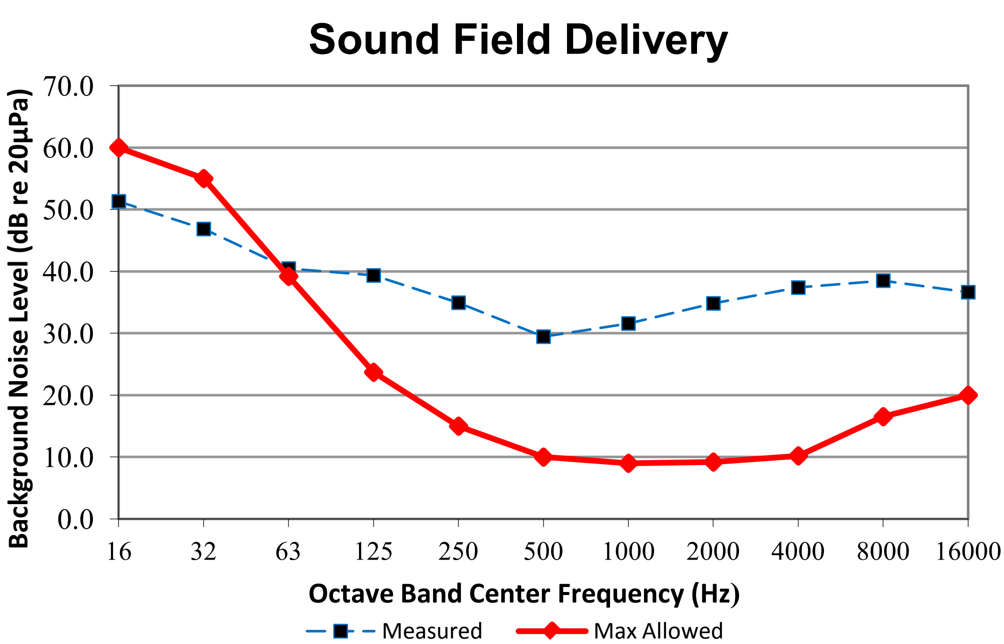

Figure 4 – ISO 8253-2 Compliance

For audiometric methods utilizing bone conduction or supra-aural headphones, **measured ambient noise exceeds recommended levels** across octave bands centered from 125 Hz to 1000 Hz (see Figure 3). For methods utilizing sound field/loudspeaker stimuli, **measured ambient noise significantly exceed maximum allowable levels** (see Figure 4).

However, as mentioned previously, it is important to note that ISO 8253-3 states that these maximums apply primarily to pure-tone threshold audiometry, and they **may be less stringent** for speech testing. Furthermore, ambient noise requirements do not pertain to stimuli delivered through circumaural headphones as they provide sufficient attenuation for most testing environments.

Acoustical treatment should be implemented to mitigate ambient noise if circumaural headphones are not to be used for speech testing.

Sine Sweep measurements were also taken in the space. A summary of the averaged results of the RT measurements is shown in Table 2 below.

	125 Hz	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
T20 (sec)	0.35	0.37	0.33	0.31	0.31	0.29	0.25
Target Value	<0.5						

Table 2: Measured reverberation times across octave bands

As can be seen in Table 2, the measured reverberation time in the CB3 lab space satisfies the target requirement of <0.5 seconds. **No treatment is necessary to mitigate reverberation time.** The average clarity index was measured to be 9.0 dB which falls within the recommended parameters for speech intelligibility. Average ALCons was measured to be 2.0%, which indicates that the existing room is well suited to speech. **However, treatment options should still be explored to reduce the ambient noise to meet the requirements of ISO 8253-3.**

5. ACOUSTICAL TREATMENT OPTIONS

See addendum.

6. ADDITIONAL RECOMMENDATIONS

Though it has been indicated by the client that the current plan is to utilize a loudspeaker sound system to deliver auditory stimuli, it should be noted that audiometric headphones (e.g. Sennheiser HDA 300) or other consumer-brand **circumaural headphones will provide significant attenuation, such that additional changes to the space are not necessary**.

If a loudspeaker system is to be used, significant changes to the room are necessary. Further recommendations can be made to determine loudspeaker orientation and type per ISO 8253-2. The loudspeaker shall be arranged at head height of the listener at an angle of incidence of 0°

7. SUMMARY

The room acoustics of the CB3 Wang Lab have been measured and evaluated using a variety of objective metrics. Based on these metrics and the desired programming for the room, preliminary design recommendations have been made to make the space more suitable for speech perception testing.

Once you have reviewed the contents of this report, further consultation will be necessary to select the desired treatment option. Please reach out via e-mail if you have any questions.

Sincerely,

Sam Underwood
samuelunderwood@unomaha.edu

8. ADDENDUM I: TREATMENT OPTIONS WITH COST ESTIMATE

Duct Lining:
$1-2/ft^2 material cost
Labor cost could exceed $1000-2000 due to retrofit

Duct Lagging:
Rolls typically cost $500-$1000
Easier to install, could potentially DIY or contact local HVAC supplier

Foam wall panels:
https://acousticalsolutions.com/product/sonex-classic-acoustic-foam/
$255 per panel (2' x 4')
Minimal labor cost, can be attached to wall easily with approved adhesives.

Quilted Fiberglass Vinyl Curtain:
$250 per curtain
Needs a hanging system, may not justify acoustical impact

9. ADDENDUM II: CIRCUMAURAL HEADPHONE OPTIONS

Sennheiser HD300 Pro ($199.95)

- https://en-us.sennheiser.com/hd-300-pro

***Sennheiser HD380 Pro ($249.00)**

- https://www.amazon.com/gp/offer-listing/B001UE6I0G

***Shure SRH1450 ($499.00)**

- https://www.amazon.com/Shure-SRH1540-Premium-Closed-Back-Headphones/dp/B00FR8DMR8/ref=sr_1_1?keywords=shure+srh1540&qid=1556482213&s=musical-instruments&sr=1-1

Bose QuietComfort 25 Noise-Cancelling Wired ($179.00)

- https://www.amazon.com/dp/B00VW7U8X4/ref=psdc_12097479011_t3_B0756CYWWD?th=1

Sony WH-CH700N Wireless Noise Cancelling ($199.99)

- https://www.sony.com/electronics/headband-headphones/wh-ch700n

Other valid options can be found with some additional browsing. Options should ideally be closed performance, circumaural headphones. We have the models marked with an * in our lab if you would like to try them out!