



Investigation into Background Noise Conditions During Music Performance

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ABSTRACT

We recapitulate a series of studies of the perceptual role of low levels of background noise in quiet spaces for music listening. These include structured listening exercises in two quiet music rooms – Jordan Hall in Boston and the EMPAC Concert Hall in Troy, NY – wherein background noise levels were electronically manipulated while subjects listened critically to live and recorded music in these rooms. Our findings indicate meaningful preference for lower background noise levels, even at levels well below NC-15, while listening to music in unoccupied rooms. Also studied were sound levels during several concerts at another quiet music room – Distler Hall in Medford, MA – to understand better the relationship between background sound levels in the occupied room and in the unoccupied room. Our findings agree with previous studies showing minimum audience noise levels during performances only slightly above unoccupied room background noise levels.

1 INTRODUCTION

Quiet background noise conditions are an essential feature of high quality performance spaces, and achieving quiet conditions is a central goal of the design of performance rooms. Designers and professional organizations have adopted disparate background noise criteria for such spaces as high as NC-25¹ and as low as the threshold of hearing, and commonly used standardized metrics are not defined for levels below NC-15.

This paper presents conclusions and further questions raised by a series of studies of the perceptual role of low levels of background noise in quiet spaces for music listening; these studies have been reported previously in greater detail.² This paper seeks to alert the room acoustics community to the perceptual effects of background noise at levels close to the threshold of hearing and to the need for appropriate metrics for noise at these low levels.

Two sets of studies are reported:

- a. Structured listening to music played in two unoccupied music performance rooms while manipulating electronically the levels of background noise.

- b. Measurements of sound pressure levels in a music performance room during concerts with audience.

These studies and the discussion in this paper focus on music performance. It is our expectation that the basic findings apply equally to speech-based theatre and other sound-critical forms of live performance.

We view these studies as preliminary and hope that they prompt further research.

2 STRUCTURED LISTENING WITH VARIED BACKGROUND NOISE

On two occasions, in two different quiet music performance halls, we have made studies of listening to music while electronically manipulating background noise levels in the hall using a large number of loudspeakers placed at the perimeter and upper levels of the halls, surrounding the listening area. We began by making each hall as quiet as it could be, by switching off HVAC serving the hall and quieting other apparent noise sources. Then we added small amounts of filtered broadband noise to the hall to achieve slightly elevated noise levels, the loudest of which were approximately NC-15 and the quietest of which were close to or below the threshold of hearing in most frequency bands. (In both halls, residual noise in the 125 Hz region limited our study to some degree.) Music was played through a loudspeaker placed on the performance platform at a level realistic for a quieter solo instrumental performance, and listeners heard the same music played over different noise spectra. Live music performance (soprano voice and cello) was also used, and subjective responses from listeners were similar between live and recorded music.

Figure 1 shows measured background noise spectra for several “samples” presented blind to subjects at the Experimental Media and Performing Arts Center (EMPAC) Concert Hall at Rensselaer Polytechnic Institute (RPI) in Troy, NY on July 17, 2011. Listeners evaluated the noise samples for subjective loudness without music playing, and then evaluated them for annoyance or intrusiveness while listening to music. Both evaluations correlated strongly with objectively measured loudness of the noise samples: see Figure 2.

Listeners did not respond to noise Sample 7 as louder than no-noise samples 3, 6, and 8, despite its higher noise levels in middle frequency bands, probably because these samples had similar levels in the controlling 125 Hz band.

In a similar study performed at Jordan Hall at New England Conservatory in Boston, Mass. on June 24, 2010, listeners reported that music changed character when noise levels were slightly elevated, becoming less spatial and more frontal, less warm, and drier. These effects were not reported during the study at EMPAC Concert Hall, which is a highly reverberant room as configured for the study (curtains retracted, hall mostly unoccupied).

EMPAC Concert Hall, Rensselaer Polytechnic Institute, Troy, NY
 Frequency spectra of noise samples
 Measured 17-July-2011

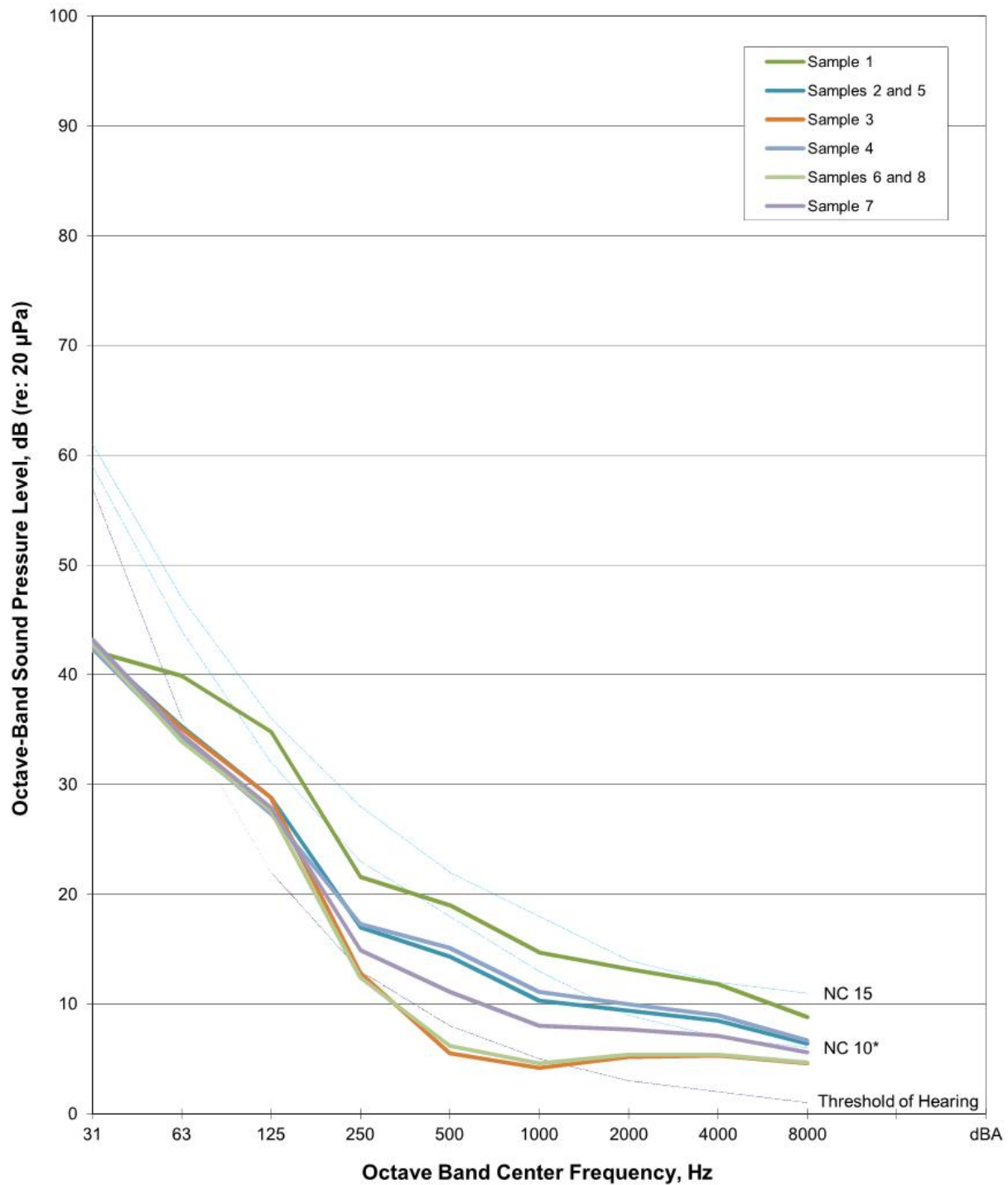


Figure 1: Frequency spectra of noise samples at EMPAC Concert Hall structured listening session. At high frequencies, measured levels of some samples were likely controlled by instrument noise. (* NC-10 curve calculated relative to NC-15 curve.)

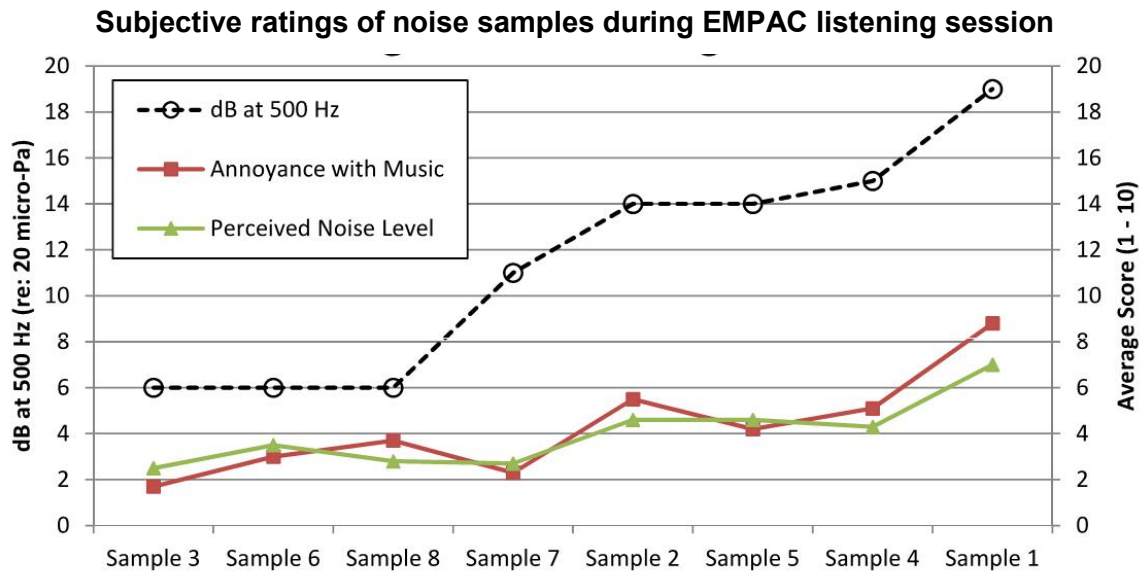


Figure 2: Subjective rankings of noise samples at EMPAC Concert Hall structured listening session. Listeners' reported annoyance at noise during music listening correlates well to perceived noise level of noise heard alone and to objectively measured sound level.

3 MEASURED LEVELS DURING CONCERTS WITH AUDIENCE

We attended a series of five concerts at Distler Hall at the Granoff Music Center at Tufts University and recorded sound pressure levels during these concerts. The hall is a rectangular recital hall with approximately 300 seats on one level. It is known for its intimacy, generous reverberation, and low level of mechanical background noise. The aim of this study was to learn more about the relationship between the background noise level of an unoccupied hall and the sound levels in the occupied hall during performances. In particular, we wanted to know how closely the quietest moments during concerts approach the background noise levels of the unoccupied hall, and to investigate the suggestion made by some designers that the background noise floor typical performances is set by audience noise rather than building mechanical noise. This topic has been studied previously by Newton and James³ and by Jeong, Marie, and Brunskog,⁴ and our findings are consistent with these previous studies.

Figure 3 on the next page presents the sound spectra measured during the loudest and quietest moments (15-second L_{99}) of two concerts, April 18 and 22, 2012, compared with background sound levels measured in the unoccupied hall following each of these concerts. At both concerts, the quietest moments exceeded the background sound of the hall by only between 3 and 5 dB in the 1,000 Hz octave band, and by less than this amount in other octave bands. This indicates that, at these quietest moments, the background sound of the hall contributes significantly to the overall sound pressure levels at all frequency bands and controls the overall sound pressure level at many bands.

The concert on April 18 was a student chamber music concert, with an audience of about 80 people. The concert on April 22 featured a concert choir with orchestra and soloists. The performers numbered over 150, and the audience more than 300. During both concerts, audiences were well-behaved, and there were many quiet points when we were able to hear what we believed to be the background sound of the hall. This occurred most frequently at the conclusion of musical movements, and occasionally during a particularly quiet musical note.

**Loudest and quietest moments during two concerts,
compared to background sound in the unoccupied hall on the same dates**
Distler Hall at Tufts University, 15-second L_{99} and L_1 measurements

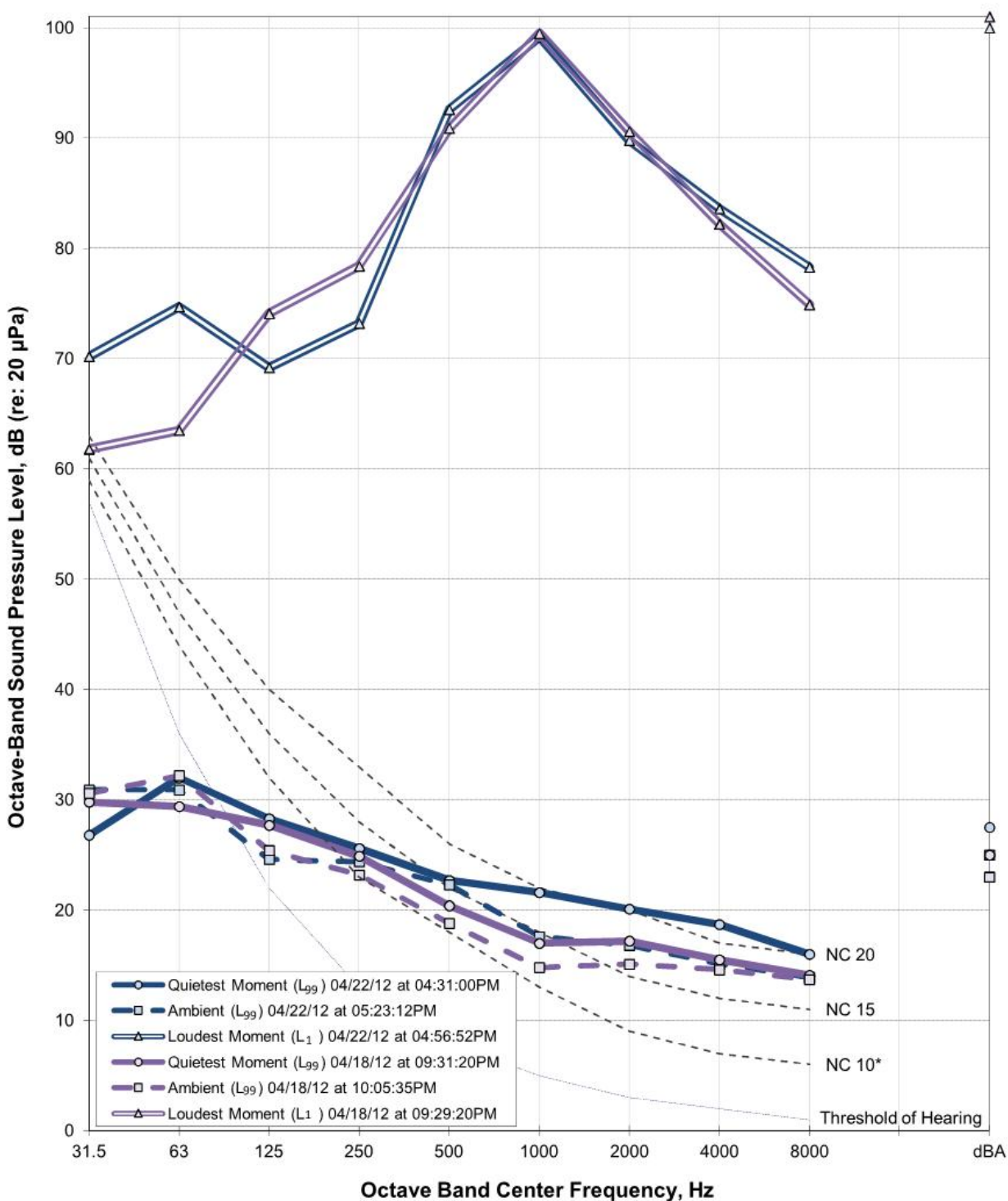


Figure 3: Loudest and quietest moments during two concerts, compared to background sound measured post-concert in the unoccupied hall. At frequency bands above 1,000 Hz, the noise floor of the measuring device was significant. (* NC-10 curve calculated relative to NC-15 curve.)

4 NEED FOR IMPROVED METRICS FOR LOW NOISE LEVELS

The most commonly used standardized metrics for background noise are not defined for levels below NC-15. Our studies show that variations among levels lower than NC-15 and higher than the threshold of hearing are perceptually significant. Well-defined metrics for noise in this region could be of value in evaluating and designing performance spaces.

5 CONCLUSIONS

Through these studies, the authors and participants have experienced the subjective effects of low levels of background noise during music listening under various controlled conditions. We have experienced that, at least under certain circumstances, background sound levels that are very near the threshold of hearing are beneficial for music listening and that music listening is negatively affected even by only slightly elevated levels of background noise. Under carefully controlled blind listening conditions, listeners were able to express meaningful preference for lower noise levels during music listening even for levels of background noise well below NC-15 and close to the threshold of hearing. As others have shown, quietest-moment sound levels during concert performances with audience can be within several decibels of the unoccupied background sound levels of the performance hall, indicating that even very low levels of room background noise have measurable impact on the concert listening environment. Though our studies are preliminary, they suggest strongly that reducing background sound levels in performance rooms provides real benefit even at very low noise levels. Well-defined metrics for noise in this region are not currently available and could be of value in evaluating and designing performance spaces.

ACKNOWLEDGMENTS

We gratefully acknowledge all those who participated in and supported this work.

REFERENCES

- ¹ For convenience and clarity, we have chosen in this paper to refer to background sound levels in terms of Noise Criteria (NC), determined by the tangent method, as defined by ANSI S12.2-2008. Values below NC-15 are calculated relative to the NC-15 curve. The authors do not intend to endorse any particular metric.
- ² J. Sacks, R.W. Wolff, and A.M. Jaramillo, "How quiet is quiet enough?", Proceedings of Inter-noise 2012 (Institute of Noise Control Engineering, 2012).
- ³ J. P. Newton and A. W. James, "Audience Noise – How low can you get?," Proceedings of the Institute of Acoustics 14, 65-72 (1992).
- ⁴ C.-H. Jeong, P. Marie, and J. Brunskog, "Audience noise in concert halls during musical performances," Journal of the Acoustical Society of America 131 (4) (April 2012).