THE ROLE OF SPECTRUM IN SUBJECTIVE INTERPRETATION OF SPEECH PRIVACY ESTIMATES: AN ANALYSIS OF PROMINENT METRICS

Viken Koukounian[1]
K.R. Moeller Associates Ltd, Burlington, Ontario, Canada.

1 Introduction

Suitable levels of speech privacy should to be recognized as a core objective in all spaces, and part of a larger conversation about our health and wellbeing in the built environment [1]. Reliable psychoacoustic metrics are necessary to determine whether spaces meet occupant needs and expectations, allowing assessment of the impact of factors, such as 'freedom' from distraction, intelligibility and audibility on, for example, comfort, focus and productivity.

2 Methods & Results

Speech privacy theory is derived from that of speech intelligibility. More precisely, losses in speech intelligibility between two positions—whether in open plan or between definably separate spaces—are interpreted as an improvement of privacy. This investigation reaffirms the importance of spectrum and demonstrates the limits of two prominent metrics—the Articulation Index (AI) and Speech Privacy Class (SPC)—by considering the sensitivity of their estimates and their associated subjective interpretations, particularly as some consider applying SPC to open-plan environments.

2.1 Theoretical and literary

Speech privacy metrics

The purpose of AI is to estimate intelligibility; therefore, it assigns greater importance to the one-third octave bands (1/3 OB) between 200 Hz and 5 kHz, which contribute more significantly to intelligibility [2]. The purpose of SPC is to estimate levels of privacy beyond the limits of AI—where speech is not intelligible, but still audible—which is accomplished by averaging 1/3 OB between 160 Hz and 5,000 Hz (L_{avg}). Though there is a correlation between intelligibility and audibility, there is extensive literature demonstrating even a small amount of information in a spectral band in the range of 370 Hz to 6 kHz can result in improved intelligibility [4]. This work reinforces the importance of such differences when assessing privacy between any two positions. Both AI and SPC are, fundamentally, a calculation of the signal-to-noise ratio: the difference in level (herein, DL) between the source and receiver and the ambient sound level at the receiver location. To address the impossibly wide array of environments and acoustic conditions, analytical and numerical strategies are used. Specifically, the contributions of DL are captured in unit steps between 0 and 25 dB. The effects of spectra—which, practically, are a function of both the DL and ambient sound level—are equivalently demonstrated by varying only the ambient conditions.

[1]viken@logison.com

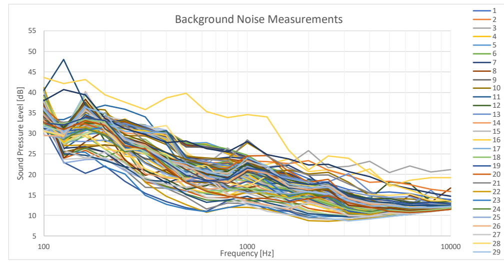

Figure 1: Measurements of ambient conditions—with building systems operational—at 98 locations, prior to occupancy. (μ = 31.6 dBA, σ = 2.9dB, Max. = 43.6 dBA, Min. = 23.8 dBA).

The importance of spectrum

Sound insulating solutions often take primacy over control of background sound, despite the latter's mathematically equivalent impact on speech privacy. However, in spaces that do not control background sound with a sound masking system, it is especially variable and inconsistent. In one investigation, 1,500 unique measurements from different sites were used to produce a distribution of background noise conditions. Their results found a standard deviation of 6 dB (12 dB range) in overall level [5]. While these results are specific to the facilities tested, each architectural environment will have variations; see Figure 1.

While walls are used to offer some degree of acoustical isolation from noise intrusion, sound masking systems are implemented with a view to providing temporal constancy, spectral balance and spatial consistency in ambient conditions. A previous investigation demonstrated the impact of changes in overall masking sound level (holding spectrum constant) on intelligibility. For decibel steps between 42 and 48 dBA in that particular environment, intelligibility estimates (i.e., 'comprehension' of "sentences upon first presentation" [SFP] speech tests) decreased from 76% to 68%, 59%,45%, 35%, 25%, and 14% respectively underlining the importance of having a consistent overall sound level at all locations across a space [6]. Expectedly, the estimates differed between locations for reasons relating to level difference between the source and receiver positions.

A recent investigation explored the impact of architectural details on the behaviour of sound [7]. It looked at the level differences (SLD) (magnitude of nonconformity from

Table 1: Ratios of measurement locations (RML) that are 'Out of Compliance' (OoC). The average overall (AODL) and spectral

Speakers per Zone	RML that are OoC	AODL μ (min.–max.)	SLD μ (min.–max.)
1	0/18 = 0%	–	–
3	4/18 = 22%	1.0 (0.7–1.5)	2.6 (2.2–3.5)
6	17/18 = 94%	1.1 (0.5–1.9)	2.7 (2.2–4.0)
18	16/18 = 89%	1.4 (0.5–3.0)	3.4 (2.3–5.1)

Table 2: Eight different spectra, equal in A-weighted overall sound level, representing a wide range of real-world spectral conditions

	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	LA_{eq}	L_{avg}
NRC OMS	48.0	47.2	46.0	44.7	43.7	42.2	40.7	38.7	37.0	34.7	32.7	30.7	28.2	25.7	22.7	19.7	48.0	36.5
Alt. Spectrum	44.7	44.7	44.2	43.7	42.7	41.7	40.7	40.2	38.7	36.7	34.2	31.7	29.7	26.7	24.7	22.7	48.0	36.8
Investigation	48.1	48.1	46.0	45.1	43.6	41.6	39.9	39.2	38.1	35.1	32.8	29.8	26.8	25.6	22.6	19.7	48.0	36.3
Project 1	45.6	47.4	43.6	40.7	38.7	37.2	36.3	38.9	38.9	36.8	36.3	34.6	34.4	34.1	34.5	35.1	48.0	38.3
Project 2	38.7	38.5	38.5	36.3	36.8	40.9	43.7	38.6	36.2	38.7	34.5	36.6	33.4	35.0	31.1	28.9	48.0	36.6
Project 3	48.7	54.9	50.6	46.1	41.1	36.4	31.2	29.1	27.7	25.7	22.3	21.9	21.6	20.7	19.3	17.5	48.0	32.2
Project 4	41.0	41.0	41.5	39.8	37.9	37.3	34.8	35.6	36.4	38.0	38.9	37.0	36.8	36.8	35.2	34.2	48.0	37.6
Project 5	45.1	47.9	45.6	40.4	36.3	36.1	35.7	37.4	39.5	42.4	37.2	32.9	26.0	22.0	20.5	16.1	48.0	35.1

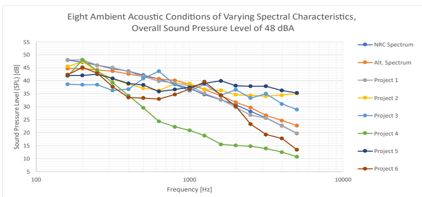

Figure 2: Eight different spectra, equal in A-weighted overall sound level, representing real-world spectral conditions.

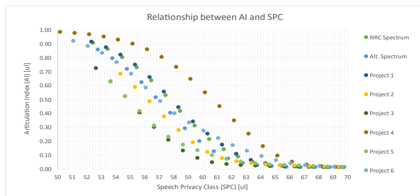

Figure 3: The relationship between AI and SPC, for each spectrum, for a range of DL conditions.

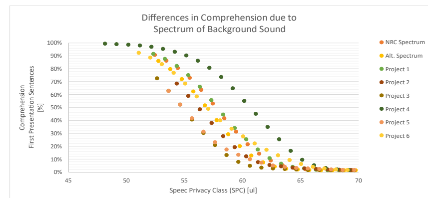

Figure 4: The relationship between SFP comprehension and SPC, for each spectrum, for a range of DL conditions.

the target value) are shown alongside the smallest and largest differences relationship between size (i.e., number of loudspeakers) of control zones within a sound masking system and the variability of masking sound (overall sound level, 1/3 OB). Results for that specific space are in Table 1.

2.2 Analytical, numerical, and empirical tools

The following analyses consider intelligibility scores from SFP tests, which better correlate with 'comprehension' than the alternatives. We reiterate that spectral differences can result from either DL or ambient conditions.

Analytical and numerical methods are used to assess equivalencies between the AI and SPC. The spectra in Table 2 (also Figure 2), which represent a broad range of real-world conditions, are evaluated across a range of DL conditions that correspond with typical values between locations in open-plan spaces. The results are presented in Figure 3. The relationship allows for mathematical substitution; see Figure 4.

3 Discussion and Conclusion

Figure 3 asserts that, for each spectrum, there is a distinct relationship between AI and SPC. Meaning, for small changes in SPC (due to spectral differences affecting L_{avg}), there can be large differences in comprehension; see Table 3. The issue is not that there are wide ranges of acoustic conditions resulting in large differences in comprehension, rather, that a small range of SPC values is resulting in a wide range of comprehension values. Specifically, the overlay of all data from each spectrum shows that, even for a single SPC value, there is a large range of comprehension values.

Table 3: Minimum, average, maximum and standard deviation statistics values of comprehension [%] values for 48 dBA ambient conditions with variable spectra for different DL values.

DL	SPC_{avg} (Min.–Max., σ)	SFP_{avg} (Min.–Max., σ)
3 dB	55 (51–57, 2.0)	62% (31%–98%, 23.3%)
5 dB	57 (53–59, 2.0)	45% (17%–95%, 26.6%)
8 dB	60 (56–62, 2.0)	25% (5%–86%, 26.8%)

For the ambient conditions representing real-world spectra (Table 2), divergences between curves are observed between SPC 50 and SPC 70. This range encompasses the majority of acoustic conditions that affect comprehension (i.e., between, rather than beyond, limits).

The results herein are specific to the spectra in Table 2. However, the outcomes clearly demonstrate that SPC is not a sufficiently accurate estimator of comprehension, because frequency composition plays an important role in intelligibility. The significance (i.e., perceptual) of smaller magnitude changes in ambient sound level became apparent with the use of psychoacoustic metrics. SPC remains the appropriate tool for its intended purpose, where speech may no longer be intelligible, but still audible.

References

[1] E. Bourdeau and V. Koukounian, "The role of acoustical privacy in a hierarchical framework for acoustical satisfaction: Past, present and future," in *Inter-noise 2022*, Glasgow, UK, 2022

[2] N. R. French and J. C. Steinberg, "Factors governing the intelligibility of speech sounds," *The Journal of the Acoustical Society of America*, vol. 19, no. 1, pp. 90-119, 1947.

[3] R. M. Warren and K. R. Riener, "Spectral redundancy: Intelligibility of sentences heard through narrow spectral slits," *Perception & Pyschophysics*, vol. 57, no. 2, pp. 175-182, 1995.

[4] J. Loverde and D. W. Dong, "Statistical distribution of ambient noise levels compiled from building acoustics measurements," *The Journal of the Acoustical Society of America*, vol. 145, no. 3, p. 1651, 2019

[5] N. Moeller, "Exploring the impacts of consistency in sound masking," *Proceedings of the Acoustics Week in Canada*, vol. 42, no. 3, 2014.

[6] V. Koukounian, "The determining impact of architecture on sound in the built environment," *Canadian Acoustics*, vol. 50, no. 2, 2022.