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DO FREQUENCIES BELOW 160 HZ PLAY A ROLE IN SPEECH PRIVACY BETWEEN ROOMS?

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ABSTRACT

Speech privacy is a critical acoustic design parameter of working rooms and meeting spaces. It consists of two key components: audibility and intelligibility. Audibility refers to whether speech can be heard, while intelligibility relates to how well the speech can be understood. Previous research has indicated that both audibility and intelligibility of speech can be best predicted by the uniformly weighted signal-to-noise ratio, SNR_{uni32}. This metric is derived by calculating signal-to-noise ratios at one-third octave bands between 160 and 5000 Hz, with the constraint that the SNR at each band cannot be less than -32 dB. However, there is not much research to validate this finding. In this study, we analyze the performance of SNR_{uni32} using a new dataset of subjective audibility and intelligibility ratings collected through a controlled laboratory experiment. The experiment involved 20 participants. Furthermore, we evaluate whether the inclusion of low frequencies below 160 Hz in the SNR_{uni32} calculations would improve its predictive accuracy for speech privacy assessment.

Keywords: *speech privacy, signal-to-noise ratio, audibility, intelligibility*

1. INTRODUCTION

Speech privacy between rooms is crucial for preventing conversations being overheard. While a high level of speech privacy is essential in meeting rooms and spaces designated for confidential discussions, it is also important in accommodations, where inadequate speech privacy can lead to disturbances and discomfort.

Speech privacy comprises two key components: speech audibility and speech intelligibility [1]. Speech audibility refers to the detectability of any speech sounds transmitted between adjacent spaces, regardless of whether the content is discernible. This includes even muffled voices and indistinct mumbling.

Speech intelligibility, in contrast, refers to the degree to which spoken words can be clearly understood. The most usual objective parameter to predict speech intelligibility in rooms is Speech Transmission Index (STI). STI is perhaps the preferred parameter today to predict and quantify speech intelligibility in rooms. However,STI alone have been found to be inadequate to predict speech privacy between adjacent spaces, because speech privacy also concerns speech audibility [1]. Speech intelligibility may be zero, when audibility is still high. This concerns especially low frequencies of speech, because speech intelligibility depends very little on low frequencies.

Gover and Bradley [1] found that the most reliable objective predictor of subjective speech privacy was uniformly weighted signal-to-noise ratio SNR_{uni32}, calculated by:

$$SNR_{uni32} = \frac{1}{16} \sum_{f=160}^{5000} max[L_S(f) - L_N(f); -32] \quad (1)$$

where, f [Hz] represent one-third octave band center frequencies, L_S [dB] is the speech level inside the room, and L_N [dB] is the background noise level. $L_S(f) - L_N(f)$ is the signal-to-noise ratio in a single one-third oc-

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tave band and it is never less than -32 dB, at which point speech would be inaudible [1].

While the research led by Bradley and Gover is convincing, there is a lack of other studies which would have verified their findings on SNR_{uni32}.

Thus, the aim of this study was to validate and evaluate the performance of SNR_{uni32} against new psychoacoustic data which is obtained using slightly different methodology than Bradley and Gover did. The aim of this work is to determine whether the previously established SNR_{uni32} thresholds for audibility and intelligibility are supported by the new dataset.

We also investigate whether extending the frequency range to include also 80, 100, and 125 Hz one-third octave bands could improve the prediction accuracy. The modified parameter is referred to as $SNR_{uni32LF}$.

2. METHODS AND MATERIALS

2.1 Overview of the subjective data

The subjective data was collected through a psychoacoustic experiment conducted at the psychophysics laboratory of Turku University of Applied Sciences. Twenty participants were recruited for the study.

The experimental stimuli comprised speech sounds simulating transmission through a wall, combined with steady-state, broadband masking sound. Speech was reproduced via a loudspeaker positioned at ear level, 1.8 meters in front of the listener. Masking sound was reproduced by a loudspeaker placed behind and above the listener at an equal distance.

We simulated speech transmission through two different wall types with three levels of weighted sound reduction index (Rw): 42, 48 and 56 dB. The wall types represented typical sound insulation (R) spectra of lightweight and heavyweight wall constructions. The frequency dependence of sound reduction index were selected from previous studies [2, 3] and are shown in Fig. 1.

Source speech spectrum was the normal speech spectrum from ISO 3382-3 [4], but the levels of 125 Hz, and 250 Hz octave bands were raised to match the level of 500 Hz octave band. The whole spectrum was then scaled to match 75 dB L_{Aeq} in overall level. This level represents loud speech in a room.

Fig 1 illustrates the source speech spectrum and examples of the speech spectra after transmission through the walls. The original speech materials were sentences from a Finnish audio book spoken by a male voice.

Steady-state masking sounds included five different spectral shapes which are illustrated in Fig. 2. They were played back at three different levels: 35, 40 and 45 dB L_{Aeq}.

Audibility of speech was assessed by the question: "1. Can you hear speech or mumbling in the noise? (yes/no)". Intelligibility of speech was assessed by the question: Can you make out one or more words? (yes/no)".

All levels of wall type (2), wall sound reduction index (3), masking sound type (5), and masking sound level (3) were combined. The stimuli also included the masking sounds without speech at all three masking sound levels. Therefore, the total number of rated sounds was 105 (90 + 15).

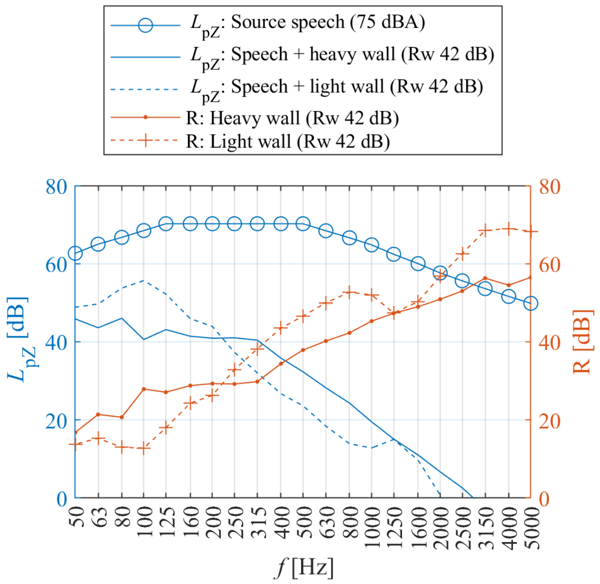

Figure 1. Left axis, blue color: Sound level (L_{pZ} [dB]). Source speech spectrum and the spectra of speech transmitted through the walls (Rw = 42 dB); Right axis, red color: Sound reduction index R [dB] for light and heavy walls (Rw = 42 dB) used to simulate transmitted speech.

2.2 Data analysis

We calculated the percentage of "yes" responses over all participants per each question and stimuli. We then fitted a sigmoidal Boltzmann function to the percentage scores and extracted the 50% threshold values as well as the co-

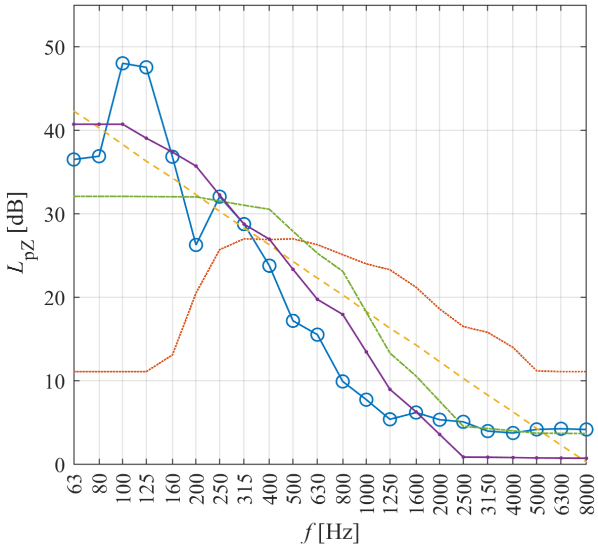

Figure 2. One-third octave band frequency spectra of the masking noises used in the collecting the subjective dataset. All spectra correspond to SPL of 45 dBA.

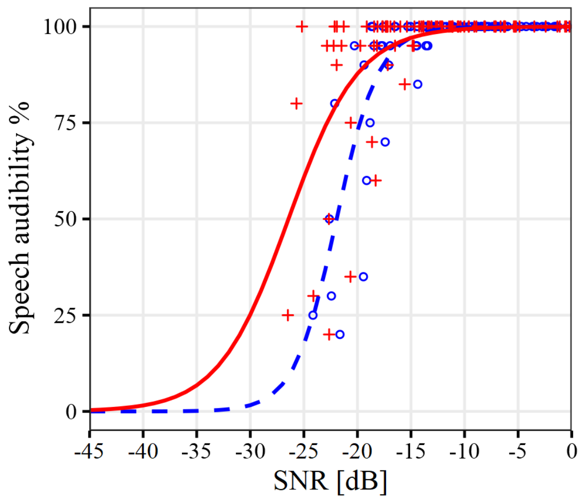

Figure 3. Speech audibility (%) vs. SNR_{uni32} (red crosses and solid line) and $SNR_{uni32LF}$ (blue circles and dashed line).

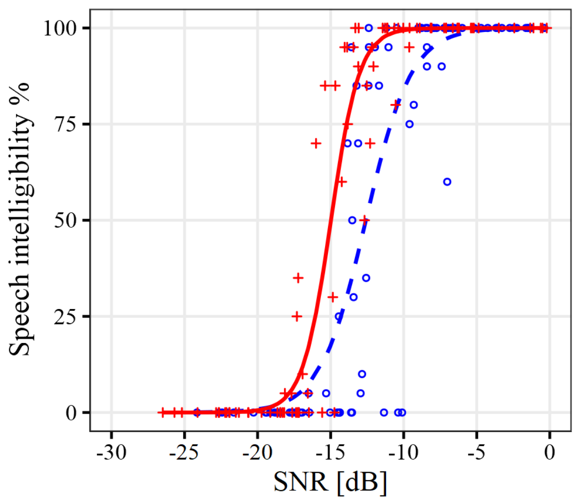

Figure 4. Speech intelligibility (%) vs. SNR_{uni32} (red crosses and solid line) and $SNR_{uni32LF}$ (blue circles and dashed line).

efficients of determination (R^2). We used the same Boltzmann function as Gover and Bradley [1].

3. RESULTS

Figures 3 and 4 and Table 1 summarize the results. The y-axis in Figs. 3 and 4 indicate the percentage of "yes" responses given for each stimulus on the questions of audibility and intelligibility, respectively. The estimated 50% threshold values as well as the coefficients of determination (R^2) of the fitted Boltzmann functions are tabulated in Table 1.

Table 1. SNR_{uni32} and $SNR_{uni32LF}$ audibility and intelligibility thresholds and coefficients of determination (R^2) of fitted Boltzmann functions.

	Audibility		Intelligibility	
	Thr.	R^2	Thr.	R^2
SNR_{uni32}	-26.4	0.39	-15.0	0.97
$SNR_{uni32LF}$	-21.9	0.71	-12.6	0.76

In the new dataset, the audibility threshold for SNR_{uni32} parameter was estimated to be -26.4 which is lower than the threshold of -22.5 dB reported by Gover and Bradley [1]. The intelligibility threshold for SNR_{uni32} parameter was estimated to be -15.0 dB which is well in line with -15.5 dB reported previously. It is also notable, that for intelligibility data, R^2 value was as high as 0.97, which indicates very good fit to the data.

The coefficients of determination also indicate that extending SNR_{uni32} to 80, 100 and 125 Hz one-third octave frequency bands seems to increase its prediction accuracy for speech audibility (R^2 = 0.39 vs. R^2 = 0.71) but not for speech intelligibility (R^2 = 0.97 vs. R^2 = 0.76).

Thus, it seems that by including the lower bands, the parameter $SNR_{uni32LF}$ may better predict speech audibility than the original SNR_{uni32}. Hearing low frequencies are notoriously difficult to completely avoid by sound insulation or by using sound masking. Considering speech, the low frequency components are often perceived as indistinct mumbling.

Concerning speech intelligibility, the frequencies below 160 Hz seem to make little difference as $SNR_{uni32LF}$ did not fit the intelligibility rating data equally well as the original SNR_{uni32}.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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