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STATISTICAL BASIS FOR RATING SPEECH PRIVACY OF CLOSED ROOMS

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1. INTRODUCTION

The degree of privacy offered by a closed room is an indication of how audible or intelligible conversations occurring within are in the adjoining spaces. This depends not only on the passive sound insulation provided by the building, but also on the levels of speech and background noise. The sound insulation is a fixed physical quantity that can be measured, but the speech and noise levels fluctuate from moment to moment: they are statistical quantities. The degree of privacy can therefore be described in a "risk" sense, where a particular level of sound insulation will be associated with a certain probability of a privacy lapse, when speech levels are high and/or noise levels are low. This paper describes results from using measured statistical distributions of speech and noise levels to rate and predict the privacy of closed rooms [1].

2. SPEECH PRIVACY METHOD

Previous investigations have identified a signal-to-noise index that is well correlated with the intelligibility of speech transmitted through walls [2]. This index (SNR_{UNI32}) is the arithmetic average (i.e., uniformly-weighted sum) of the 1/3-octave band level differences of speech ($L_{S,Rec}$) and noise (L_N) at the listening position, over the 16 bands from 160 to 5k Hz:

$$SNR_{UNI32} = \frac{1}{16}\sum_{160Hz}^{5kHz}\left[L_{S,Rec}(f) - L_N(f)\right]_{-32\text{dB}} . \qquad (1)$$

The subscript –32dB indicates that the quantity in brackets is to be clipped to a minimum of –32 dB.

The speech level at the listening position $L_{S,Rec}$ can be determined from the speech level inside the closed room L_S and a measure of the sound insulation to the listening position, LD. In each 1/3-octave band, $LD(f)$ is the difference in levels between a diffuse-field average test noise field in the closed room and the corresponding received level at the listening position. This is measured using broadband noise, several loudspeaker and microphone positions within the room, and microphones at receiving positions in the adjoining spaces, usually 0.25 m from the boundaries of the room [3].

Substituting $L_{S,Rec} = L_S - LD$ into Eq. (1), the expression for the index becomes

$$SNR_{UNI32} = \frac{1}{16}\sum_{160Hz}^{5kHz}\left[L_S(f) - LD(f) - L_N(f)\right]_{-32\text{dB}} \qquad (2)$$

which, by ignoring the –32 dB limit and summing the terms individually, can be written

$$L_S(avg) - L_N(avg) = LD(avg) + SNR_{UNI32} , \qquad (3)$$

where "(*avg*)" indicates the arithmetic average of 1/3-octave band values from 160 to 5k Hz. $LD(avg)$, then, is a single-number indicator of the sound insulation. Through the index SNR_{UNI32}, Eq. (3) relates the difference between average speech level *inside* the closed room and the background noise level at the listening position *outside* the room, to the sound insulation.

By setting SNR_{UNI32} = –16 dB (which is the threshold of intelligibility, where 50% of listeners could correctly identify at least one word) Eq. (3) becomes

$$L_S(avg) - L_N(avg) = LD(avg) - 16\text{dB} . \qquad (4)$$

For given speech and noise levels, Eq. (4) indicates the required $LD(avg)$ to obtain threshold conditions. That is, the minimum required sound insulation to ensure speech privacy. Conversely, for a known $LD(avg)$, Eq. (4) indicates speech and noise level combinations that result in threshold conditions.

3. SPEECH AND NOISE LEVELS

The cumulative distribution functions of speech and noise levels can be used to determine the probability that the speech will be loud enough and the noise will simultaneously be quiet enough so that speech will be intelligible. This probability then can be used in rating the speech privacy.

Fig. 1 shows the cumulative probability of occurrence of speech and noise levels (10 s L_{eq}) measured for a large range of meetings in different buildings [4]. It indicates that 10% of the time the speech level was higher than 64 dBA, and 10% of the time the noise level was lower than 33 dBA. Assuming independence, the joint probability of speech exceeding 64 dBA and the noise simultaneously being lower than 33 dBA was 1%. By assuming reasonable spectral shapes for the speech and noise (to convert dBA to dB(*avg*)) the data in Fig. 1 are converted to yield Fig. 2. The horizontal axis is the difference between the average speech level in the closed room and the average noise level at the listening position outside the room: precisely the quantity on the left-hand side of Eq. (4).

4. STATISTICAL RATING

Using Eq. (4), the axes of Fig. 2 can simply be re-labelled as shown in Fig. 3. This graph indicates the probability of speech being intelligible for a given value of *LD*(*avg*)–16 dB, which is the single-number measure of sound insulation (from measurements) offset by 16 dB.

The individual data points (♦) in Fig. 3 correspond to measurements of *LD*(*avg*) made through a real wall. There is one data point for each of 63 receiving positions tested (all were 0.25 m from the wall). The shaded areas and "Risk Category" labels were added to aid users in interpreting the results: for the measured data, most locations were "Risk Category 3" (1–5 likely privacy lapses per day) but several were "Risk Category 4" (5–26 lapses per day), corresponding to a higher likelihood of speech being intelligible, owing to lower sound insulation to those points. It is up to the user to decide on requirements.

5. CONCLUSIONS

To rate the speech privacy of a closed room, measurements of the sound insulation are required. Using distributions of speech and noise levels measured in meetings allows interpretation of the sound insulation measurements in a statistical manner. In this way, the physical measurements of sound insulation can be translated directly to a "risk" of privacy lapse.

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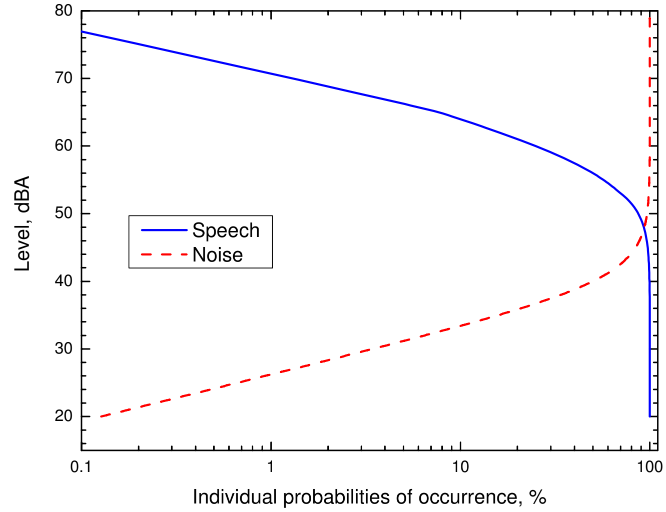

Fig 1: Probability of occurrence of speech and noise levels.

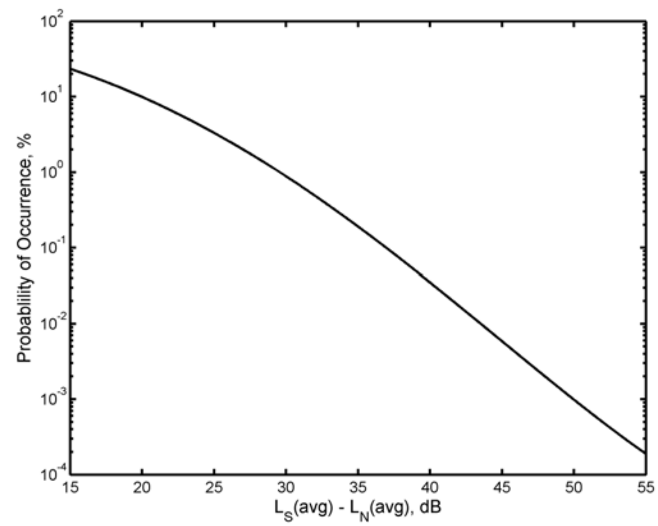

Fig 2: Joint probability of occurrence of speech–noise differences.

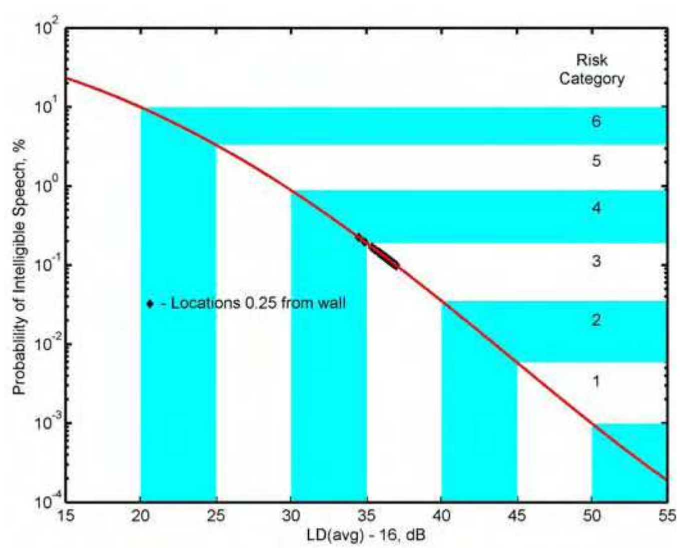

Fig 3: Speech privacy risk chart.