DOI: 10.61782/fa.2025.0654

FORUM ACUSTICUM EURONOISE 2025

ON-AXIS SOUND PRESSURE LEVELS AND SOUND POWER OF NORMAL SPEECH FOR SPEECH INTELLIGIBILITY, PRIVACY AND SECURITY

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ABSTRACT

In room acoustics, assessment of speech intelligibility, privacy and security requires the on-axis sound pressure level and sound power level of speech at a normal vocal effort level. For open-plan offices, ISO 3382-3 quotes octave band sound pressure and sound power from 125Hz to 8kHz for unisex speech (an average of male and female speech) to represent speaking with a normal vocal effort. However, limited sound power data are available with phonetically balanced speech in one-third octave bands, particularly for male and female talkers below 160Hz where unisex speech may not be suitable. This paper reports anechoic measurements of normal speech (720 sentences) from 12 native British English speakers (six male, six female) in one-third octave bands from 63Hz to 20kHz thereby including the Extended High Frequency (EHF) range above 7kHz. Whilst male and female talkers are similar in the mid-frequency range, there is greater variation between individual talkers and between sentences in the low- and high-frequency ranges. Measured data are converted to octave bands for comparison with ISO 3382-3, ANSI S3.5 and EN 60268-16 to indicate which values may need reconsideration in the building acoustics frequency range.

Keywords: *speech, intelligibility, sound pressure, sound power*

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1. INTRODUCTION

The on-axis sound pressure level and the sound power level of speech are used to assess speech intelligibility, privacy and security inside buildings. This paper reports measurements for normal vocal effort speech from British English speakers in one-third octave bands from 63Hz to 20kHz.

ISO 3382-3 [1] formalises the assessment of the acoustic performance of open-plan offices for an occupant speaking with a normal vocal effort. This Standard only gives octave band values from 125Hz to 8kHz for unisex speech, an average of the values from male and female talkers. However, for speech security outside meeting rooms [2] it is often necessary to use one-third octave bands instead of octave bands because of the spectral features that commonly characterise the airborne sound insulation. Unfortunately, limited sound power data is available with phonetically balanced speech in one-third octave bands, particularly for male and female talkers below 160Hz where large differences can occur. There has been recent interest [3] in the Extended High Frequency (EHF) range (i.e. above 7kHz) and the information that it provides for speech perception and recognition. However, little or no sound power data is available between 7kHz and 20kHz and whilst this frequency range is not usually critical for building acoustics, these data are included in this paper to add to the discussion on the EHF range.

2. EXPERIMENTAL SETUP

Twelve talkers (six male, six female) were recorded in an anechoic chamber. These talkers were native British English speakers with an accent that was similar to Received Pronunciation (Standard Southern English) and between 21 and 47 years of age. Talkers produced all 720 IEEE sentences (72 word lists where each list comprises ten

sentences) in a pseudo-random order. Before the recording session, the talkers were asked to "speak normally as you would in everyday conversation" to elicit a normal vocal effort. The recordings from the on-axis microphone in front of the mouth at a distance of 1m are available online [4]; however, these were low-pass filtered at 9 kHz as they were used to assess STOI and other metrics [5,6] which have an upper frequency at or below 8kHz.

Sound power measurements were based on the procedures in EN ISO 3745:2012 [7] for precision measurements in an anechoic chamber. The sentences were recorded using half-inch, free-field microphones into a Bruel and Kjaer LAN-XI Type 3050 front end and Bruel and Kjaer Time Data Recorder. Sixteen microphones were arranged in a hemispherical array that surrounded the talker on their right side such that symmetry was assumed for the sound field on their left side. The centre of the hemisphere was at the mouth position and the radius was 1m. Talkers were seated, and no microphone was placed underneath the seat; this was considered when calculating the sound power.

3. RESULTS

3.1 On-axis sound pressure level

For brevity, the comparison with previous on-axis sound pressure level measurements, the one-third octave band data are converted to octave bands. Figure 1 shows the male and female data from the current paper with previous measurements by Pearsons *et al.* [8] and Cushing *et al.* [9] as well as values quoted in the following Standards: ISO 3382-3:2022 [1], ANSI S3.5:1997 [10], EN 60268-16:2011 [11], EN IEC 60268-16:2020 [12]. The ANSI S3.5 'standard' spectrum is the same as the ISO 3382-3 spectrum between 250Hz and 8kHz. All curves have been normalised, so each spectrum gives 60dBA which is representative of a normal vocal effort at 1m on-axis. Note that only the current study provides data in the 63Hz and 16kHz octave bands.

In the mid-frequency range (250Hz-2kHz) there is close agreement between average values from the current study and those from Pearsons *et al.* (42 male talkers, 35 female talkers) and Cushing *et al.* (34 male talkers, 16 female talkers). The current study is based on recordings of 720 IEEE sentences whereas Pearsons *et al.* and Cushing *et al.* only used a single sentence ('*Joe took father's shoe bench out, she was waiting at my lawn*'). The largest differences between the current study and these previous studies occur in the 125Hz and 8kHz octave bands. The variation between individual sentences indicates that whilst a single sentence can be sufficient to assess the mid-frequency range it is not sufficient at low- and high-frequencies where there can also be significant variation between talkers.

At 125Hz, the EN 60268-16:2011 male spectrum is 4.7dB higher than male talkers from this study whereas the EN IEC 60268-16:2020 male spectrum is within 0.7dB. This suggests that the change in the 2020 version of this Standard was appropriate. The ANSI S3.5 'idealised' unisex spectrum lies within the confidence intervals from male and female talkers.

At 4kHz and 8kHz, the values in the EN, ANSI and ISO Standards are beneath the lower 95% confidence interval of the male and female talkers; hence values in these bands may require re-consideration in future revisions.

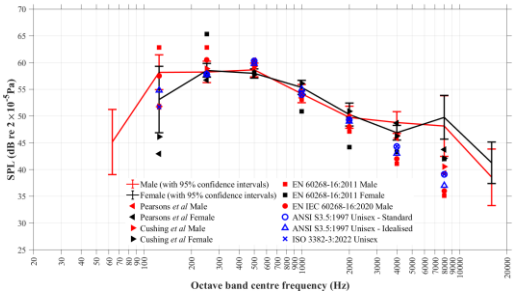

Figure 1. On-axis sound pressure levels converted to octave bands to allow comparisons with other data (all spectra normalised to 60dBA).

3.2 Sound power

Uncertainty in the sound power level in one-third octave bands due to spatial sampling with the sixteen microphones was calculated according to EN ISO 3745 for all talkers. Below 1.25kHz, the uncertainty is below 1dB, and between 2kHz and 20kHz it is in the range 1dB to 2dB.

Figure 2 shows the sound power level for male and female talkers in one-third octave bands. Above 160Hz it is reasonable to average the male and female data to give unisex sound power data. However, between 63Hz and 125Hz the male and female levels are significantly different with male talkers having higher sound power levels. The uncertainty in the sound power estimate is below 0.5dB in this range. However, the 95% confidence intervals are relatively large at low frequencies because of the variation between the six male and six female talkers.

Figure 3 shows normalised sound power for male talkers, female talkers and a unisex spectrum (average of male and female talkers) in octave bands for comparison with the unisex spectrum in ISO 3382-3. Between 125Hz and 2kHz, the unisex spectrum from this study is similar to ISO 3382-

3; however, at 125Hz, 4kHz and 8kHz, ISO 3382-3 values are too low to be representative of normal speech.

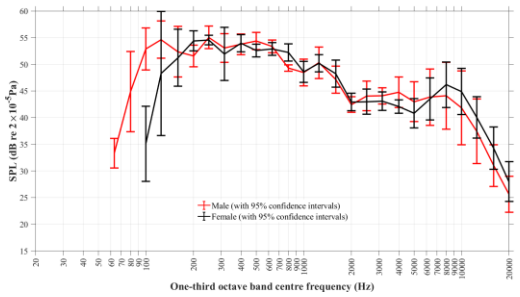

Figure 2. Sound power level in one-third octave bands after normalisation so that the on-axis sound pressure level is 60dB L_{Aeq}.

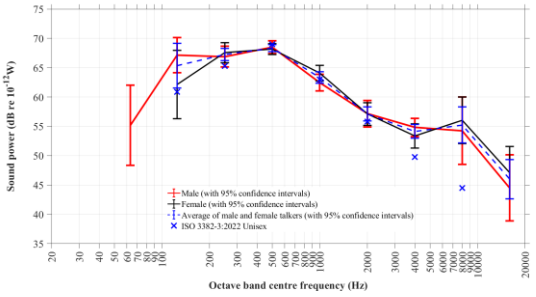

Figure 3. Sound power levels (after normalisation so that the on-axis sound pressure level is 60dB L_{Aeq}) converted to octave bands to allow comparison with ISO 3382-3:2022.

4. CONCLUSIONS

One-third octave band measurements of the on-axis sound pressure level and sound power have been carried out for normal speech from 63Hz to 20kHz to extend the data that were previously available in the literature. For the on-axis sound pressure level, comparisons with octave band data indicates that values in the EN, ANSI and ISO Standards are too low at 4kHz and 8kHz. For sound power, the unisex sound power spectrum in ISO 3382-3 between 125Hz and 2kHz is similar to the current study; however, at 125Hz, 4kHz and 8kHz, the values in ISO 3382-3 are too low to be representative of normal speech.

5. REFERENCES

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