An analysis of wind noise at the front and rear microphones of hearing aids

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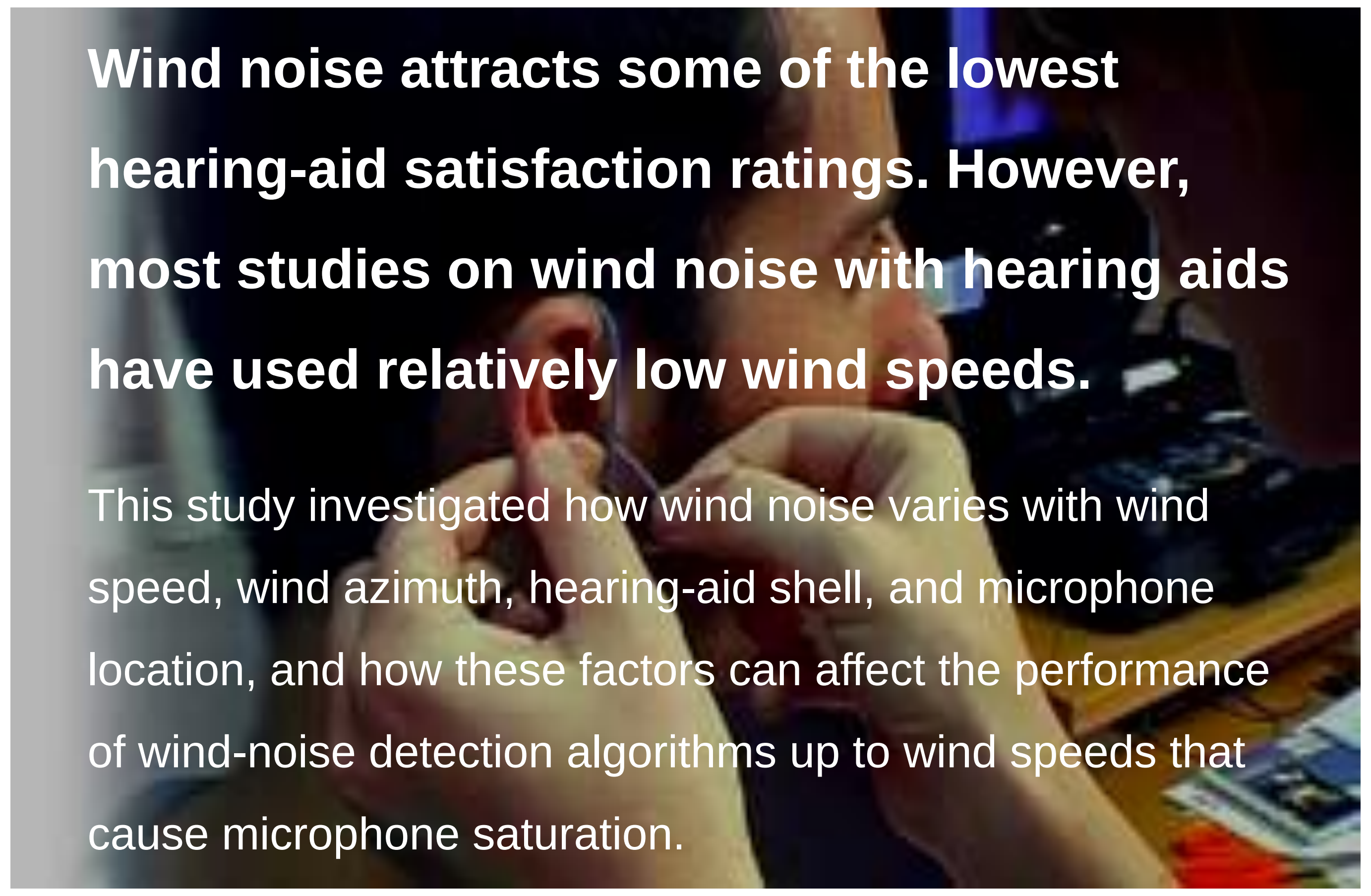

Wind noise attracts some of the lowest hearing-aid satisfaction ratings. However, most studies on wind noise with hearing aids have used relatively low wind speeds.

This study investigated how wind noise varies with wind speed, wind azimuth, hearing-aid shell, and microphone location, and how these factors can affect the performance of wind-noise detection algorithms up to wind speeds that cause microphone saturation.

Introduction

Kochkin (2010) reported that only 58% of users of hearing aids (≤ 4 years old) had a degree of satisfaction with wind noise, which was lower than for all other types of noise. The literature on wind noise with hearing aids predominantly used relatively low wind speeds of up to 5 m/s (18 km/h, 11 mph) (Dillon et al, 1999; 2000; Beard & Nepomuceno, 2001; Thompson & Dillon, 2002) or 7 m/s (25 km/h, 16mph) (Grenner et al, 2000). Chung et al (2009; 2010) used wind speeds of up to 13.5 or 22.5 m/s, although broadband limiters in the hearing aids could affect the measured output levels from between 4.5 and 9 m/s. The current study aimed to more clearly characterise the wind-noise spectrum at the input of hearing aids up to microphone saturation.

The literature typically shows wind-noise levels at the output of a single omni-directional or directional microphone. The current study aimed to show how wind noise can vary between two omni-directional microphones in the same device, and how this is affected by wind speed, wind azimuth, and the hearing-aid shell design. The potential effects of these factors on some example dual-microphone, wind-noise detection algorithms were also investigated to further quantify the problems faced by hearing-aid designers.

Ear-Level Devices

Two BTE shells and a comparison CIC device were mounted on a KEMAR head (see Figure 1). Shielded cables were soldered to the omni-directional microphone ports and exited from the lower half of each device.

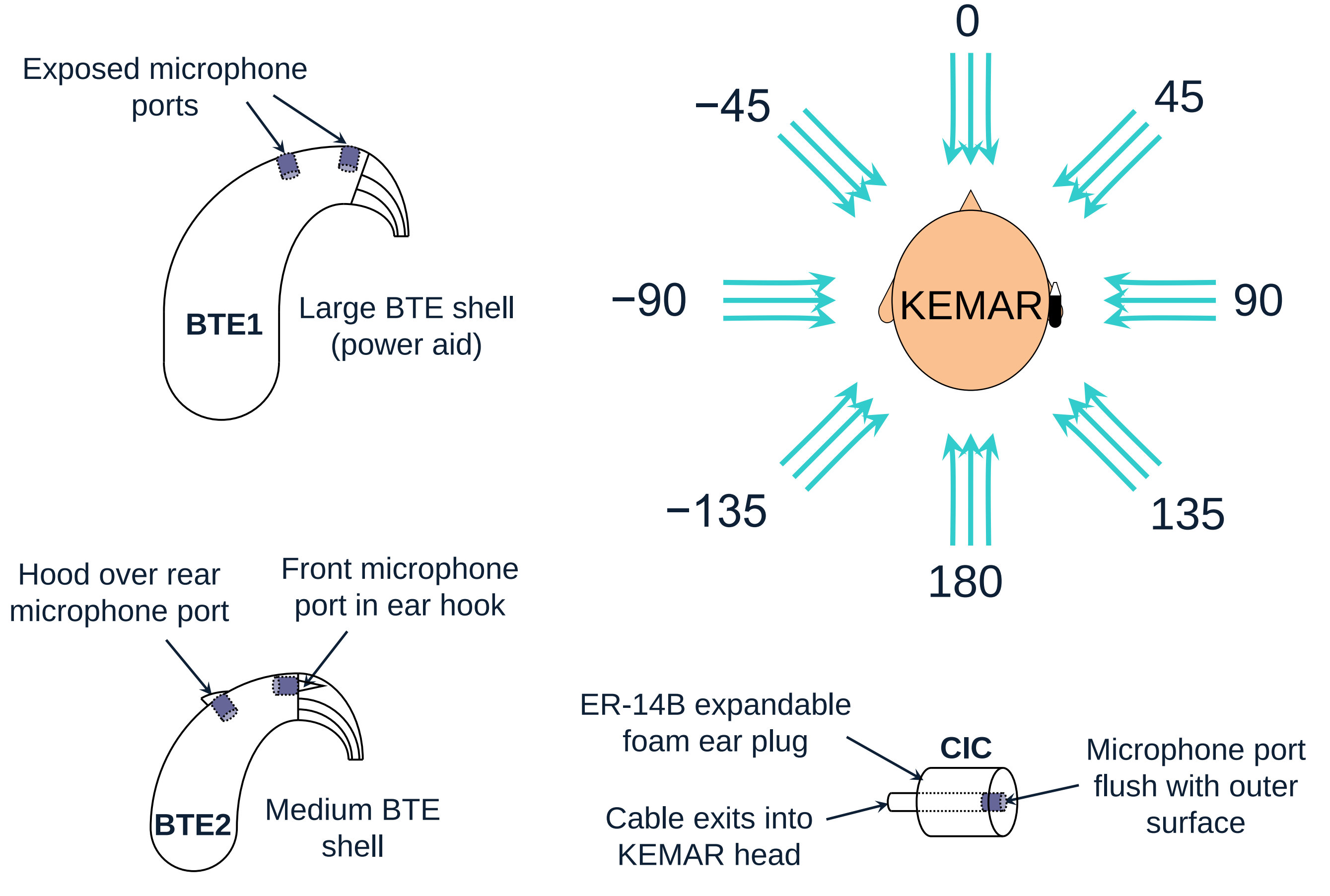

Figure 1. The devices used in this study, and the wind azimuth relative to the position on the KEMAR head. Each device contained omni-directional microphone(s) (Knowles FG series) and no other circuits. The microphone power, ground, and signal terminals were connected to shielded cables that exited each device.

Wind-Noise Recordings

The KEMAR head was mounted on a turntable and placed at the 70 x 70 cm outlet of a 'silent' wind generator (Fishburn et al, 2007). The microphone cables were connected to a 1.5-volt cell and a 32-bit sound card. Stereo, 32-bit, 44.1-kHz, 10-s recordings were made for all combinations of:

- **Wind speed** = 3, 6 and 12 m/s. (12 m/s = 43 km/h = 27 mph = 23 knots)
- **Wind azimuth** = 0, 45, 90, 135, 180, -135, -90 and -45 .

For calibration, recordings were made with each device in a Brüel & Kjær Type 4232 anechoic test box and presented with white noise. All recordings were down-sampled to 20-kHz for analysis.

Wind-Noise Analysis

A MATLAB script calculated the long-term-average, wind-noise level for each microphone from 0.5–9.5s into each file. A SIMULINK model processed blocks of 16 samples from 0.5–9.5s into every recording with the following examples of wind-detection equations based on pp. 161-162 of Kates (2008):

$$\Gamma_x = \frac{\sum_n x(n)y(n)}{\sum_n x(n)^2} \cong 0 \text{ for wind}, \cong 1 \text{ for external sounds.} \qquad \text{(Eq. 6.2)}$$

$$\Gamma_y = \frac{\sum_n x(n)y(n)}{\sum_n y(n)^2} \cong 0 \text{ for wind}, \cong 1 \text{ for external sounds.} \qquad \text{(Eq. 6.2a)}$$

$$\Delta = \frac{\sum_n (x(n)-y(n))^2}{\sum_n (x(n)+y(n))^2} \cong 1 \text{ for wind}, \cong 0 \text{ for external sounds.} \qquad \text{(Eq. 6.3)}$$

Where x(n) and y(n) are the front- and rear-microphone samples, respectively. The above equation values assume matched microphones. However, the microphones in this study were not matched, and the SIMULINK model processed the raw samples to approximate a mass-produced hearing aid.

Results – Wind spectra

The outputs of all microphones saturated at 12 m/s at all azimuths. Figure 2 shows the RMS wind-noise level in each one-third-octave band and summed across all bands. An ANOVA on the wideband levels showed all factors were significant: Microphone (F[4,119]=6.02, p<0.001), Azimuth (F[7,119]=16.3, p<0.001), and Speed (F[2,119]=788.8, p<0.001). Pairwise comparisons (Bonferroni, 95% confidence intervals) showed significantly greater levels at BTE2-Rear compared with BTE2-Front by 4.6 dB (p<0.01) and compared with CIC by 5.3 dB (p<0.001). All comparisons among levels of wind speed and 10 of 28 comparisons among levels of azimuth were significant (p<0.05).

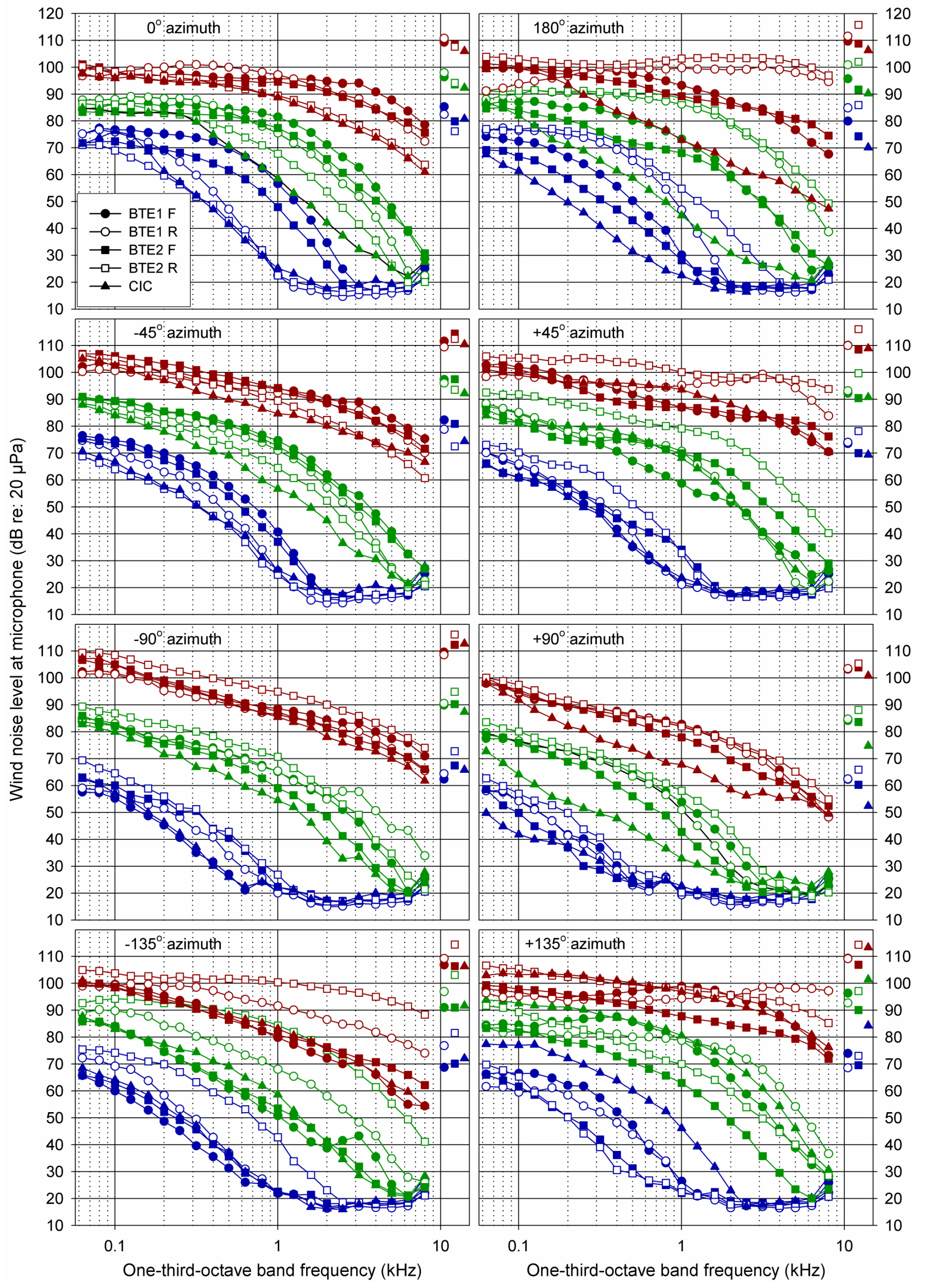

Figure 2. Long-term-average, wind-noise level in each one-third-octave band and across all bands (right of 10kHz). Blue = 3 m/s, Green = 6 m/s, Red = 12 m/s.

Results – Wind Detection

Figure 3 compares the ability of the wind-detection equations to discriminate between wind and white noise (mean values are shown). An ANOVA for the Eq. 6.2 and 6.2a data showed all factors were significant: Equation (F[1,95]=18.4, p<0.001), Azimuth (F[7,95]=11.7, p<0.001), Speed (F[2,95]=12.5, p<0.001) and BTE (F[1,95]=80.1, p<0.001). An ANOVA for the Eq. 6.3 data showed that the factors Speed (F[2,47]=35.5, p<0.001) and BTE (F[1,47]=10.8, p<0.01) were significant, while Azimuth (F[7,47]=1.3, p=0.277) was not significant.

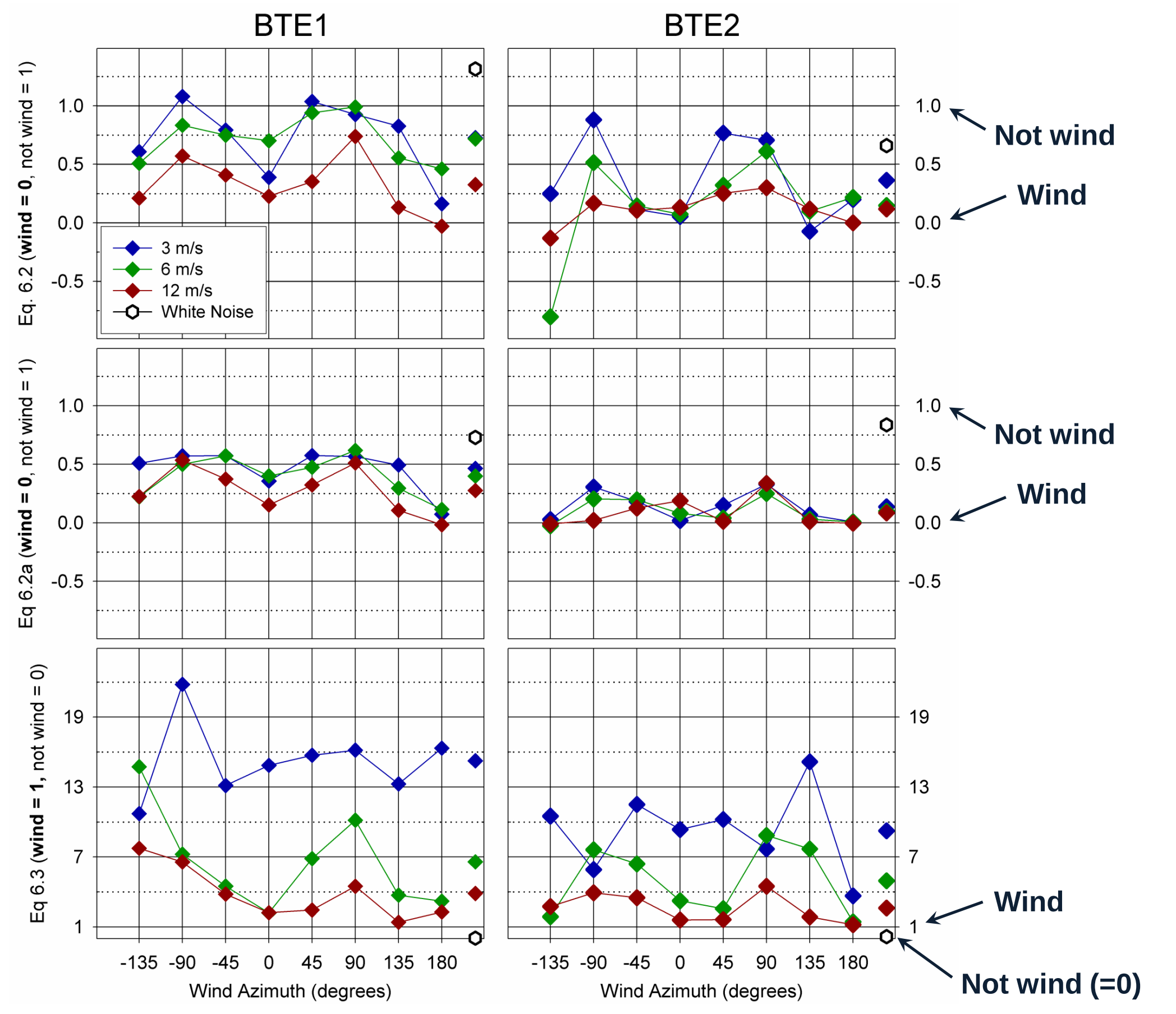

Figure 3. Mean values calculated with wind-detection equations 6.2, 6.2a and 6.3 for each wind speed and azimuth (single coloured points for all azimuths). The white symbols are for white noise recorded in an anechoic test box.

Conclusions

This study led to the following main conclusions:

- Wind noise saturated the hearing-aid microphones at a wind speed of 12 m/s.
- At 12 m/s, wind noise levels at the hearing-aid input can reach approximately 115 dB SPL.
- At most tested azimuths, wind noise tended to be lower at the front than the rear BTE microphone, although this varied with wind speed and BTE shell design. Adaptive switching to the quietest omni-directional microphone would be preferable in wind.
- Wind noise levels for the CIC microphone tended to be comparable to the BTE microphones, except most notably at 90 and 135 where levels at the CIC tended to be lowest and greatest, respectively.
- For the unmatched microphones and BTE shells used in this study, wind-detection Eq 6.3 tended to be more reliable than Eqs. 6.2 and 6.2a averaged across both devices.

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