Wind noise variability of different hearing aid designs and ear geometries

Simon Köhler[1], Eleftheria Georganti[1]
[1] *Sonova AG, 8712 Stäfa, Schweiz, Email: simon.koehler@sonova.com*

Introduction

Hearing aids are often exposed to air flow, particularly when using the devices outdoors. With the head and hearing aid itself obstructing this air flow, turbulences and corresponding pressure variations occur, which results in disturbing wind noise at the hearing aid microphones. In addition to commonly used wind noise reduction algorithms, which can create artifacts and compromise the target signal (e.g. speech), an inherent low wind noise sensitivity of the hearing aid itself is desirable. In this research, the influence of different hearing aid designs on resulting wind noise levels is investigated. This is done for multiple ear geometries in order to account for the effect of morphological differences across human subjects.

Hearing aid designs

Three different BTE (Behind-The-Ear) and three different ITE (In-The-Ear) hearing aid designs were compared. Each device has two microphones (front and back). An exemplary view of a BTE positioned behind the ear is given in Figure 1. The housing size and microphone position was the same for all BTEs, but the housing shape and orientation/geometry of the microphone openings was slightly modified. The ITE designs do not differ in inlet geometry, but in shell style and insertion depth. The different shell styles are shown in Figure 2. The Full-Shell (FS) design fills out the whole concha, while the In-The-Canal (ITC) and Mini-Canal (MC) designs fill out only parts of the concha. Due to the different concha and ear canal geometries, the ITE devices had to be built for each ear individually.

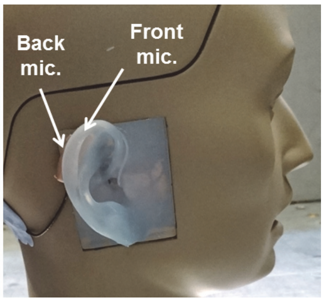

Figure 1: Exemplary view of a BTE positioned behind an artificial head's ear.

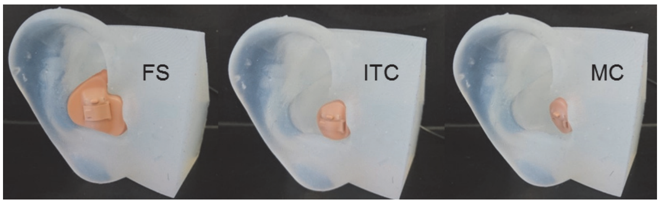

Figure 2: Silicone ear with three different ITE shell styles.

Variation of ear geometries

For varying the ear geometry, a set of eight generic ear shape models was created. This was done by adjusting the most relevant morphological features of a 3D statistical shape model of the human external ear, built upon a large data set of scanned ears. The resulting ear shape models are shown in Figure 3. These eight geometries are expected to represent the natural variability across adult human subjects. They were silicone molded and attached to a customized artificial head (G.R.A.S. KEMAR).

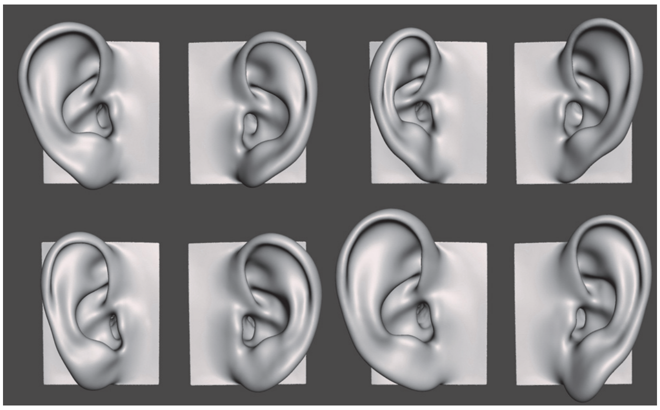

Figure 3: Generic ear shape models.

Measurement setup

A low-noise and low-turbulent wind tunnel at the Fraunhofer IBP in Stuttgart (Germany) was used for generating the air flow, see Figure 4. An artificial head wearing hearing aids was positioned in the air flow. At the head location, the wind tunnel has a cross section of $0.5\,\mathrm{m}^2$. The head was mounted on an automatic turntable for changing the wind direction. Per ear and hearing aid, ten seconds of the front and back microphone signals

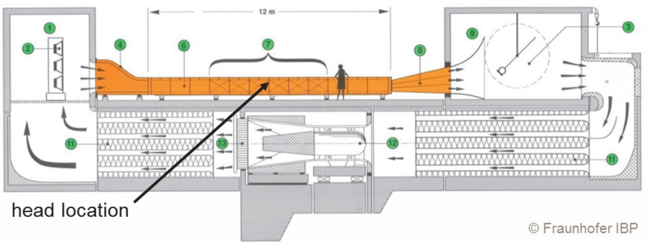

Figure 4: Cross sectional view of the wind tunnel.

were recorded for 24 horizontal wind directions and two different wind speeds (5 and 8 m/s).

Display of results

In the following sections, polar plots are used to display wind noise levels for different horizontal wind direction. Angular values are marked with an *i* or a *c* indicating whether wind is coming from the ipsi-lateral or contra-lateral side. For example, with a hearing aid on the left ear, wind coming from 90° left or 90° right would correspond to 90°i or 90°c, respectively.

Furthermore, levels are always displayed separately for two different wind speeds (5 and 8 m/s) and two different frequency regions (below/above 700 Hz).

Repeatability

Measurement repeatability was tested for two BTE devices on all eight ears (with repositioning of the devices). Exemplary wind noise levels for one single ear with two different BTE devices are shown in Figure 5. Overall, the repeated measurements are in good alignment and deviations are smaller than for two different BTE designs. Nevertheless, especially at higher frequencies, where the absolute levels are lower, differences between two repeated measurements can exceed 5 dB.

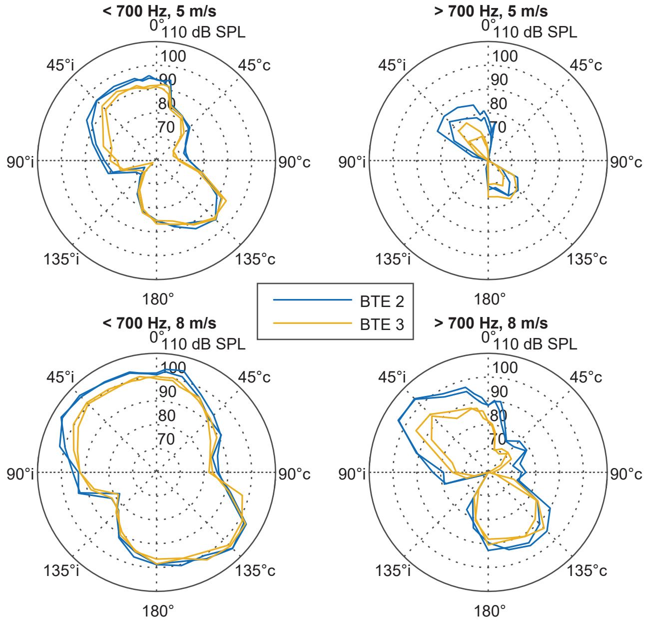

Figure 5: Measured wind noise levels for one single ear with two different BTE devices (front microphone). Results are shown for different wind speeds, wind directions and frequency regions. Same colored lines represent measurement repetitions.

Absolute octave-band level differences between the two measurement repetitions, averaged across the two devices, eight ears and 24 wind directions, are given in Figure 6. Clear trends of increasing level differences with increasing frequency and decreasing wind speed can be observed. Both is probably related to the absolute levels, which typically decrease with increasing frequency and decreasing wind speed. Overall, level differences between repeated measurements are on average in the range of 2 to 3 dB below 500 Hz and in the range of 3 to 5 dB above 500 Hz. Such deviations are much higher compared to typical measurements with purely acoustical excitation. This must be taken into account when comparing wind noise levels for different hearing aid designs.

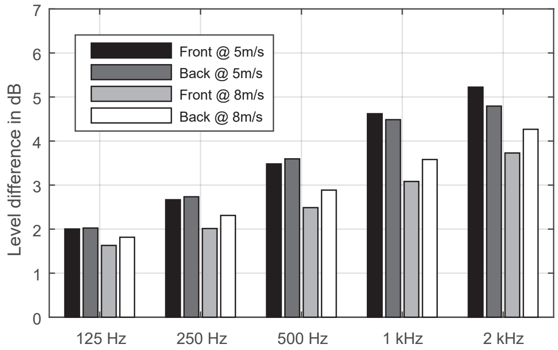

Figure 6: Octave-band level differences between two measurement repetitions for the front and back microphone and for two different wind speeds, averaged across two hearing aids, eight ears and 24 wind directions.

BTE results

Measured wind noise levels at the front microphone of three different BTE designs are shown in Figure 7. A clear trend of increasing levels with increasing wind speed can be seen, especially at frequencies above 700 Hz. The highest levels were measured for wind directions between 0° and 90°i. For these directions and especially at high frequencies, a strong influence of the hearing aid design can be observed. BTE 3 is clearly less sensitive to wind

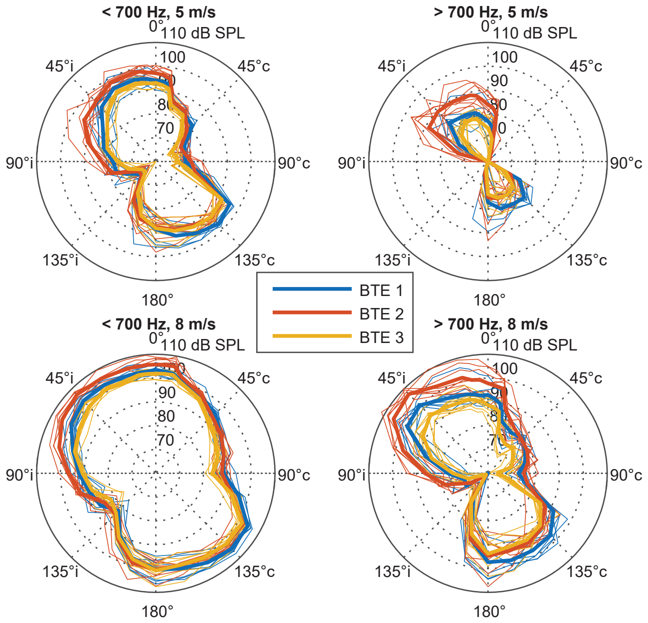

Figure 7: Measured wind noise levels at the **BTE front** microphones for different wind directions, frequency regions and wind speeds (thin/thick lines = individual ears/average).

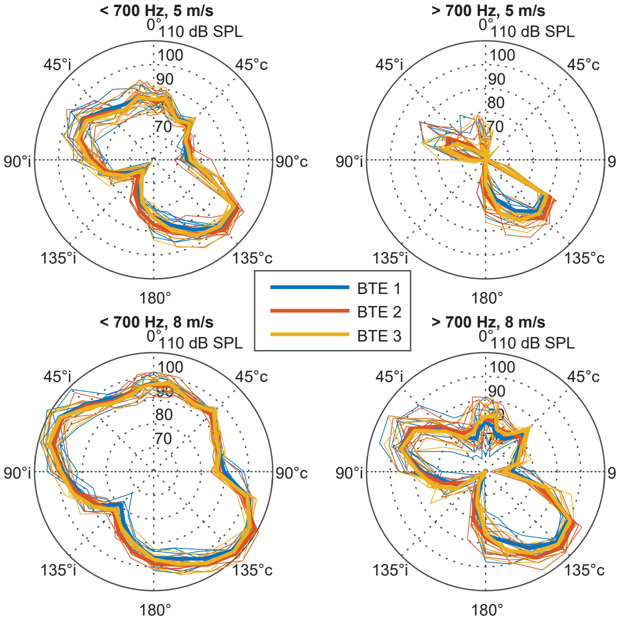

Figure 8: Measured wind noise levels at the **BTE back** microphones for different wind directions, frequency regions and wind speeds (thin/thick lines = individual ears/average).

noise than BTE 1 and BTE 2. Resulting inter-design differences reach up to 20 dB in some cases.

Results for the back microphone (see Figure 8), show a similar trend of increasing levels with increasing wind speed. However, inter-design differences are much lower – without indicating any trend. This can be explained by the much more similar microphone inlet designs of the back microphone compared to the front microphone.

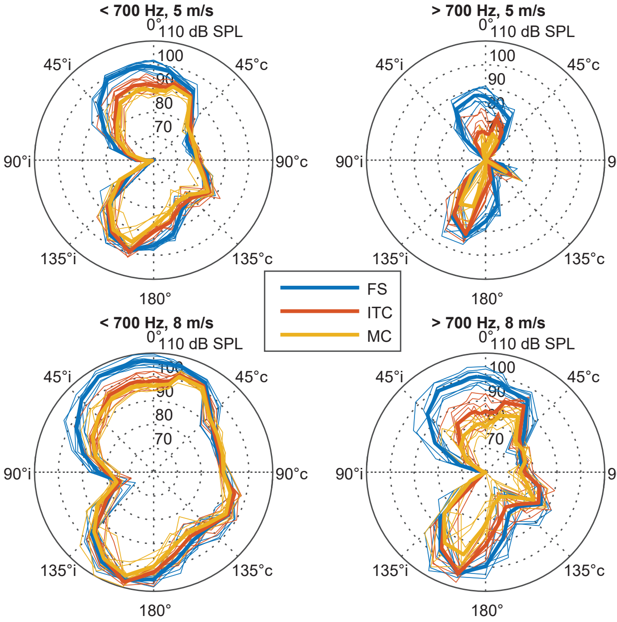

Figure 9: Measured wind noise levels at the **ITE front** microphones for different wind directions, frequency regions and wind speeds (thin/thick lines = individual ears/average).

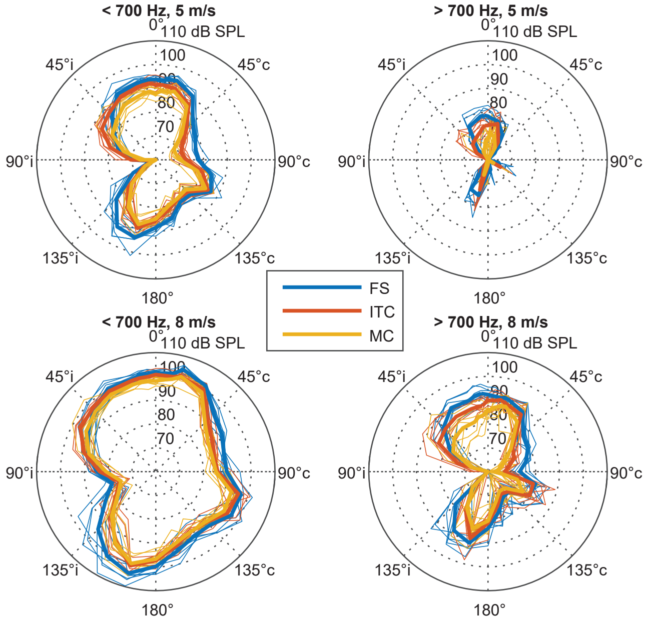

Figure 10: Measured wind noise levels at the **ITE back** microphones for different wind directions, frequency regions and wind speeds (thin/thick lines = individual ears/average).

ITE results

ITE wind noise levels at the front microphone are shown in Figure 9. Especially between 45°i and 15°c, a clear trend of lower levels for microphone locations deeper in the ear can be identified. This can be explained by the fact that the front microphones of the ITC and MC designs are well protected behind the tragus, while for the FS design it is fully exposed to the air flow.

Results for the back microphone (see Figure 10) show much lower inter-design differences, however a slight tendency of lower levels with deeper microphone position is still visible.

BTE vs. ITE

An overall comparison of the different BTE and ITE designs is given in Figure 11. Broadband levels were A-weighted and averaged across all wind directions and ear geometries.

Within the BTE and ITE group, the differences in average levels between the worst and best performing devices are in the range of 5 to 7 dB. The ITE MC shows the best overall performance, while the BTE 2 design results in the worst performance.

Within the ITE group, the clear trend of lower levels with deeper microphone location in the ear canal is again visible. Furthermore, the back ITE microphones perform clearly better than the front microphones. This would suggest to use the back microphone for sound pickup in non-directional working mode and when wind noise is present.

A similar trend of either the front or back microphone performing clearly better cannot be seen for the BTE

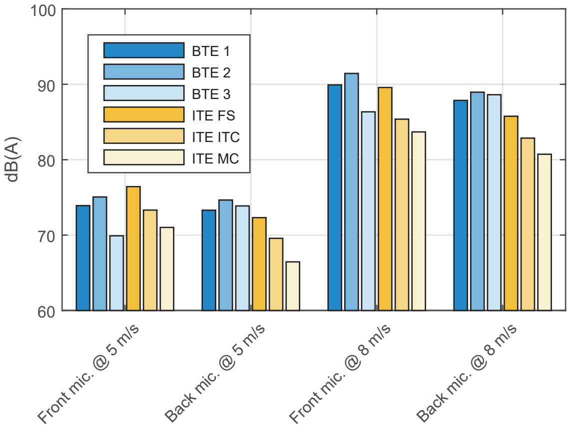

Figure 11: A-weighted broadband levels at the front and back microphones of the six BTE/ITE devices, averaged across all wind directions and ear geometries.

group. Worth noting is that with an improved BTE design (BTE 3), one can achieve a performance which is comparable to the better performing ITE designs.

Influence of ear geometry

Exemplary inter-design level differences, calculated for two BTE design pairs for each ear separately, are shown in Figure 12. When looking at the averaged results, it is quite evident that BTE 2 performs worse than BTE 1 and BTE 3. However, the individual results show a large variation in the range of ±10 dB, which could lead to the conclusion of much higher or almost no inter-design differences when using only one single ear geometry. Therefore, one should always use several ear geometries when assessing wind noise sensitivity of different hearing aid designs.

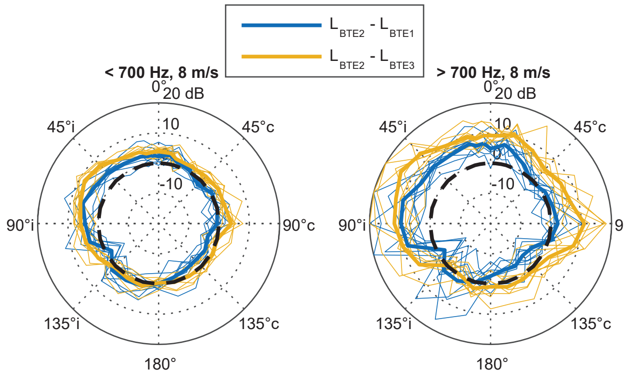

Figure 12: Wind noise level differences for two BTE design pairs at 8 m/s wind speed, calculated for each ear separately (thin/thick lines = individual ears/average). The dashed lines indicate 0 dB.

Conclusions

Wind noise levels were investigated for different hearing aid designs and ear geometries. It was found that both the hearing aid design and the ear geometry can have a large influence on resulting wind noise levels. Differences can easily reach up to 20 dB. Deep ITE devices have the lowest sensitivity to wind noise, while ITE devices filling out the whole concha are more comparable to the BTE devices with higher wind noise sensitivity.

Inter-ear and especially inter-design differences are larger at higher frequencies. This is in good agreement to [1], where it is stated that large obstacles (e.g. the head) are mainly responsible for low frequency wind noise, while smaller structures (e.g. the pinna and the hearing aid design) become more relevant at higher frequencies.

A strong variability of inter-design differences across different ear geometries was found. This suggests to assess wind noise sensitivity on multiple ear geometries.

Outlook

In the future, one could also investigate the influence of other obstacles and structures, e.g. head shapes, glasses, helmets and hair styles. For example, it might be possible to offer hearing aid designs which are more suitable for users having long or short hair. This would allow the end user to select a hearing aid design which is more appropriate for his specific profile.

Acknowledgement

We would like to thank Pierre Guillon (Sonova AG) for providing the generic ear shape models. Furthermore, we thank Fraunhofer IBP Stuttgart for providing the wind tunnel facility.

References

[1] Dillon et al.: Wind noise in hearing aids. Presented at Hearing Aid Amplification for the New Millennium, Sydney, Australia (1999).