# Less wind noise with M&RIE leads to better sound quality

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## ABSTRACT

Wind noise in hearing aids is a common issue for users that can lead to decreased satisfaction. Wind noise tends to be most problematic in hearing aids that place the microphones above and behind the ear of the wearer, such as Behind-the-Ear (BTE) and the Receiver-in-the-Ear (RIE) styles. This is due to the microphones' location at the site of greatest turbulent airflow that is the cause of wind noise in hearing aids. The unique Microphone-and-Receiver-in-the-Ear (M&RIE) is a receiver option for ReSound RIE hearing aids that is based on our Organic Hearing principle of taking inspiration from the way we naturally hear and use our hearing. The M&RIE incorporates a microphone in the receiver module - which the user wears in their ear canal - thereby preserving individual spectral cues for spatial hearing. The ear canal microphone location also provides natural protection against wind noise. In this experiment, listeners rated sound quality of recordings made on a manikin in a wind tunnel with traditional microphone placement and the M&RIE. Sound quality was best for M&RIE regardless of direction of the wind, or whether a digital wind noise reduction feature was included. Results indicated 33% better sound quality ratings for M&RIE compared to traditional microphone placement.

Wind noise is a challenge to many users of hearing aids. Wind noise can be problematic outdoors, such as when walking in the wind, or when running or biking, but it can also be a challenge when moving around indoors, causing a flow of air around the head of the hearing aid user.[1] Wind noise in hearing aids can mask speech partly or entirely. It can even overload the hearing aid preamplifier,[2,3] causing very poor sound quality. Survey data showed that 22% of hearing aid users were to some degree dissatisfied with their hearing aids when used in windy conditions, 20% were neither satisfied nor dissatisfied, and 58% were to some degree satisfied. This data suggested that wind noise annoyance may be the second largest hearing aid user complaint relating to sound quality and signal processing, exceeded only by hearing in noise.[4] Dissatisfaction with hearing aids due to wind noise may reduce the number of listening situations where users find it relevant to wear their hearing aids. There is a link between how applicable users find their hearing aids in different listening situations and their overall hearing aid satisfaction. There is a risk that the user will not be satisfied with hearing aids unless they are found to be helpful in at least 70% of the listening situations found to be important to the user.[5] This makes wind noise reduction in hearing aids important to increase hearing aid satisfaction.

Wind noise in the hearing aids' output is caused by the turbulence that is generated around the microphone ports, when an air flow gets sufficiently strong and/or encounters a sufficiently large obstacle. That is, wind noise is caused by turbulent air flows - not the sound of the air flow itself. As explained by Kates,[2] when an air flow is weak, it moves in separate layers, but higher wind speeds and obstacles can cause air flow to become turbulent; the layers are mixed, creating eddies and random pressure fluctuations around the obstacle. Generally, the larger the obstacle and the stronger the wind, the more turbulence will be generated. In the case where the obstacle is the head and pinna of a hearing aid user, the pressure variations will push and pull the microphone diaphragm of the hearing aid, and that movement will be converted into electrical variations that can later be found in the hearing aid output– better known as wind noise.

Generally, wind noise has most of its energy in the low frequency area of the spectrum, but spreads to higher frequencies with increasing wind velocity and decreasing size of obstacle.[2] The level of wind noise increases with wind velocity[3,6-14] and varies depending on what direction the flow comes from relative to the hearing aid microphone ports.[2,10,11]

There are two broad approaches to reducing wind noise. One is via signal processing, where a detection algorithm recognizes that wind noise is present and reduces gain in order to minimize degrading effects on sound quality. While this approach can potentially improve listening comfort, it cannot eliminate the wind noise. Another approach is to protect the microphones' ports from turbulent air flow.[15] While some protection mechanisms involve special screens or covers for the microphone inlets,[16] the position of the microphone also impacts wind noise occurrence. It is advantageous to place the microphone in an area where turbulence is minimal depending on wind speed and direction. It has been shown that wind noise can be worse when the microphone is placed behind the pinna as is typical with BTE and RIE style hearing aids than if the microphone is located within the pinna.[2,3]

## M&RIE INSPIRED BY ORGANIC HEARING

The human external ear helps our hearing by its acoustic effects, but also offers protection of the delicate structures of the middle and inner ear. As discussed, wind noise is an unfortunate technical side effect of hearing aid microphone exposure to the turbulent airflow that can occur around the obstacles presented by the head and pinna. Inspired by our Organic Hearing philosophy, ReSound designed a solution for RIE hearing aids that places the location of sound pick-up where it naturally belongs – in the ear canal. The M&RIE receiver unit contains a microphone ensuring that the individual filtering of the sound provided by the hearing aid wearer's pinna is preserved, which adds to the user's perception of depth and direction in the listening environment.[17] In addition, the placement of the microphone in the ear canal provides protection from turbulent airflow and therefore wind noise. A measured reduction in wind noise of 15 dB compared to microphone placement behind-the-ear has been reported.[18]


Figure 1. ReSound ONE with M&RIE showing the position of the microphones. The ear canal microphone offers natural protection from wind noise.

Such a large difference in acoustically measured wind noise can be expected to be clearly audible and may also be associated with subjective preferences. This investigation looked into the effect of M&RIE on subjective wind noise annoyance compared to the traditional microphone placement behind the ear with and without digital wind noise reduction.

## METHODS

### Design

The test participants were asked to evaluate wind noise recordings that were prerecorded on an acoustic manikin in a wind tunnel. Prerecording the stimuli allows for double blinding and makes it possible to control for wind direction and velocity across hearing aid test conditions. The effect of the microphone placement in wind noise was evaluated based on the test participants' ratings of annoyance.

### Participants

Sixteen adults with hearing threshold levels within normal limits participated. Their ages varied between 23 and 53 years with an average of 38 years (SD = 8.3 years).

#### Hearing Aids and fitting

ReSound ONE RIE-devices with M&RIE-receivers were used in this study. Prior to fitting the hearing aids, a calibration of the DFS Ultra III feedback management system was conducted on the ears of a Knowles Electronics Manikin for Acoustic Research (KEMAR) using closely fitting foam tips from insert phones. The hearing aids were programmed with 15 dB of flat, linear gain utilizing ReSound Smart Fit fitting software. The gain level was chosen to ensure that the recorded sound was indeed amplified sound and not direct sound. The hearing aids were fitted with three different programs: one using the ear canal microphone of the M&RIE module, one with traditional microphone placement on the device and an omnidirectional response (hereafter "omni"), and one with traditional microphone placement on the device, an omnidirectional response, and Wind Guard digital wind noise reduction in its default mode 'Mild' (hereafter "omni + WG"). DFS Ultra III feedback management was active in all programs at the default "Mild" level. Other advanced features were turned off.

### Test conditions

The following conditions were tested:

1. M&RIE
2. Omni
3. Omni + WG

### Wind noise recordings – setup and procedure

All wind noise recordings were made in with an integrated closed-return wind tunnel in the GN Research Laboratory at GN headquarters. The wind tunnel can generate a homogeneous air flow in an area of 0.5 x 0.5 meters, and the wind velocity is optimal at a distance around 0.5 meters away from the exhaust of the tunnel. The tunnel can generate wind of 1-15 m/s within a range of +/-5% in 0.1 m/s increments. The exhaust of the tunnel is elevated from the floor creating a 158 cm space between the floor and the center of the exhaust. The test section of the tunnel is acoustically treated with acoustic panels and carpeted floors. For this investigation, the wind tunnel was adjusted to generate wind of 5 m/s. This wind velocity corresponds to a gentle breeze on the Beaufort Wind Scale. A gentle breeze makes leaves, small twigs and flags move.

| | |
|---|---|
| **Hearing aid conditions** | 1) M&RIE<br>2) Omni<br>3) Omni + WG |
| **Wind velocity** | 5 m/s |
| **Wind incidence angles** | 0° azimuth<br>135° azimuth<br>270° azimuth |
| **Speech signal** | "Northwind and the sun" presented from 90° azimuth (S90) at about 65 dB SPL. |

Table 1. Overview of test conditions, wind velocity, wind incidence angle, and speech signal.

The recordings were made on a KEMAR (GRAS 45CB Acoustic Test Fixture), placed centrally in the air flow with its ears 0.5 meter away from the exhaust and 160 cm above the floor. The KEMAR was placed on an electric turntable that was adjusted to create the three different wind incidence angles (see Figure 2). The angles were chosen to spread out any potential microphone placement-related advantages: a wind angle incidence of 0° should theoretically be disadvantageous for all conditions; 135° should be more advantageous for Omni and Omni + WG; and 270° should be advantageous for M&RIE. A loudspeaker (Genelec 6010A Studio Monitor) was placed 0.5 meters from, and in the same height as the KEMAR's right ear (S90). This loudspeaker was intended to represent a male conversational partner telling a story. This speech signal was not added to test speech recognition, but to give the test participants a reference when rating the wind noise annoyance.

The hearing aids were mounted in the KEMAR ears using closely fitting foam tips from insert phones. The output of the hearing aids into the KEMAR ears (GRAS RA0045-S7 Ear Simulators) was recorded via a Brüel & Kjær NEXUS Conditioning Amplifier and an RME Fireface UCX sound card using Audacity 2.4.2 software adjusted to make 32-bit stereo recordings with a 44.1 kHz sampling frequency. Each recording was approximately 24 seconds long. A total of 9 stimuli recordings were made. The recordings were saved as 24-bit WAV-files and each cut to the same length of 22.2 seconds.

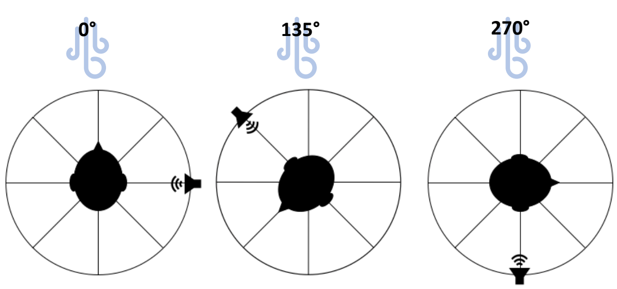



Figure 2. Illustrations of how the KEMAR was rotated relatively to the exhaust of the wind tunnel to create the three incidence angles. The loudspeaker was always placed at 90° azimuth.

For the purpose of acoustic analysis and calibration of sound levels, an additional 11 recordings were made: 9 recordings of the wind noise without speech and two recordings of a 1 kHz-tone 94 dB SPL calibration tone from a Brüel & Kjær Sound Calibrator Type 4231 (one for each ear).

### Subjective rating of wind noise annoyance – setup and procedure

For the subjective ratings, listening tests were conducted utilizing the web-based system SenseLabOnline (version 4.1.1; FORCE Technology, Brøndby, Denmark;[19]). The listening experiment included three subtests corresponding to the three tested incidence angles. Within each subtest, participants were presented with three recordings made according to the three test conditions. Both subtests and recordings within each subtest were double-blinded and randomized in a full-factorial randomized block design.

All data collection took place in a quiet hearing aid fitting room. The test stimuli were presented via Beyerdynamic DT990 PRO circumaural headphones. The test participants were instructed to carefully listen to all recordings within each subtest and afterwards rate the level of wind noise annoyance on a 7-point Likert-type scale that had been adapted from Korhonen et al[13]. The points of the scale were defined as follows: (1) not noticeable (and thus not annoying); (2) slightly noticeable, but not annoying; (3) somewhat noticeable, but not annoying; (4) slightly annoying; (5) somewhat annoying; (6) very annoying; and (7) extremely annoying. The presentation level was initially calibrated to the actual level recorded in the wind tunnel, but informal testing proved that it was too loud for normal-hearing listeners. The level was therefore lowered by 15 dB (equal to the 15 dB flat gain that was programmed in the initial fitting of the devices). The recordings were also compensated for the HATS ear couplers (ERP-DRP) and headphone frequency response.

## RESULTS

### Acoustic results

The Z-weighted equivalent continuous sound levels were calculated between 22 and 22050 Hz using the recordings of the calibration tone as a reference. One-third octave spectra were similarly calculated using 24th order 1/3-octave filters. All sound levels are specified in dB(Z).

Overall wind noise levels in dB(Z) for all conditions and incidence angles can be found in Table 2. It should be highlighted that these levels are wind noise levels measured at the output of the hearing aids, i.e. with 15 dB flat linear gain, but without the speech signal. For all incidence angles and left and right devices combined, M&RIE-levels varied from 72 to 86 dB(Z), Omni varied from 78 to 96 dB(Z)and Omni+WG varied from 78 to 92 dB(Z). Looking at maximum levels, Omni generated the most wind noise followed by Omni+WG, and finally M&RIE.

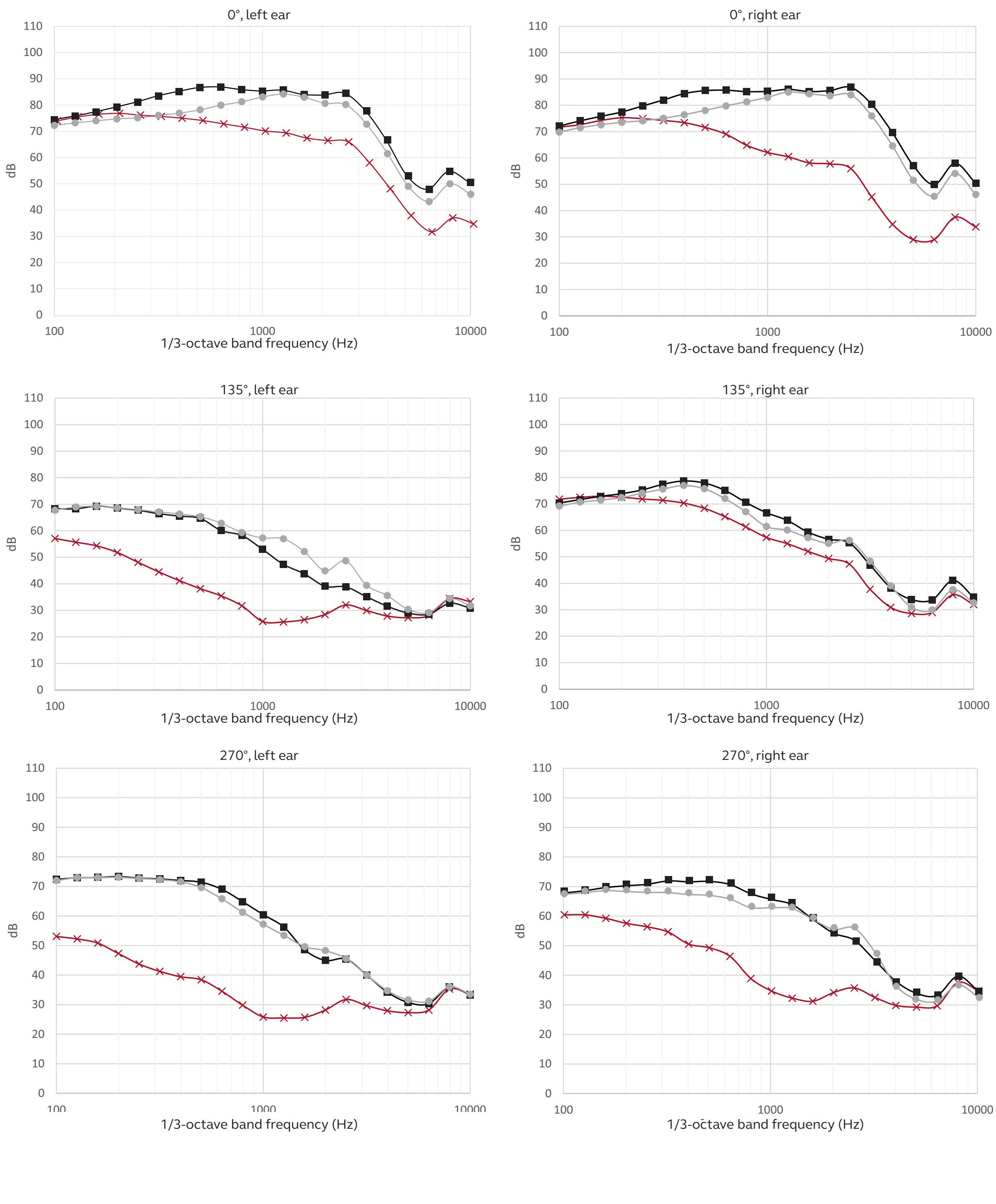
For all tested conditions, 0° azimuth was the incidence angle that produced the most wind noise, but whether 135° or 270° generated the second-most depended on what side the device was placed.

| OVERALL WIND NOISE LEVELS (dB(Z)) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0° | | 135° | | 270° | | |
| **Condition** | Left | Right | Left | Right | Left | Right | Average |
| **M&RIE** | 86 | 84 | 72 | 82 | 73 | 73 | 78.3 |
| **Omni** | 96 | 96 | 78 | 86 | 83 | 82 | 86.8 |
| **Omni + WG** | 92 | 92 | 78 | 84 | 83 | 80 | 84.8 |
| **Average** | 91 | 90.5 | 74.3 | 84 | 77.5 | 78.8 | |

Table 2. Overall wind noise levels in dB(Z) (22-22050 Hz) measured at the output of right and left hearing aid with the four conditions: M&RIE, Omni and Omni+WG at angles 0°, 135° and 270° azimuth. Measured in 5 m/s wind speed.

Figure 3 shows 1/3-octave spectra for left and right devices' output measured with the three conditions in 5 m/s wind from three different angles. Crosses, squares and circles represent M&RIE, Omni and Omni+WG, respectively. The spectra show that Omni and Omni+WG behave relatively alike apart from the low frequency difference as a result of WG; mostly when the wind noise was at 0° azimuth. M&RIE has lower levels across the spectrum for all wind noise incidence angles.

Figure 3. Right and left hearing aid output measured in dB(Z) in 1/3-octave bands for 5 m/s wind presented from 0°(top), 135° (middle) and 270° (bottom) azimuth with the three conditions: M&RIE (crosses), Omni (squares) and Omni+WG (circles).



## Subjective results

Owing to the non-normality of these ordinal data, the non-parametric Mann-Whitney U-test and Spearman's rank-order correlation were used for statistical analysis of the subjective results. Mann-Whitney U-tests have been Bonferroni-corrected to counteract the problem of multiple comparisons, implying that the alpha-level for statistical significance was adjusted to .008. Statistical analysis includes all ratings.

Figure 4 displays median ratings and statistically significant differences between the tested conditions. Median ratings of wind noise annoyance ranged across angles between 2-4 with M&RIE, between 4.5 and 7 with Omni, and between 5 and 6 with Omni+ WG. Wind from 0° generally caused the highest subjective ratings followed by 135° and 270° azimuth.

M&RIE was at all tested angles rated significantly better than Omni (0°: $p < 0.0001$; 135°: $p < 0.001$; 270°: $p < 0.0001$) and Omni +WG (0°: $p < 0.001$; 135°: $p < 0.001$; 270°: $p < 0.0001$). There were no significant differences between Omni and Omni with WG (0°: $p < 0.02$; 135°: $p < 0.3$; 270°: $p < 0.2$)

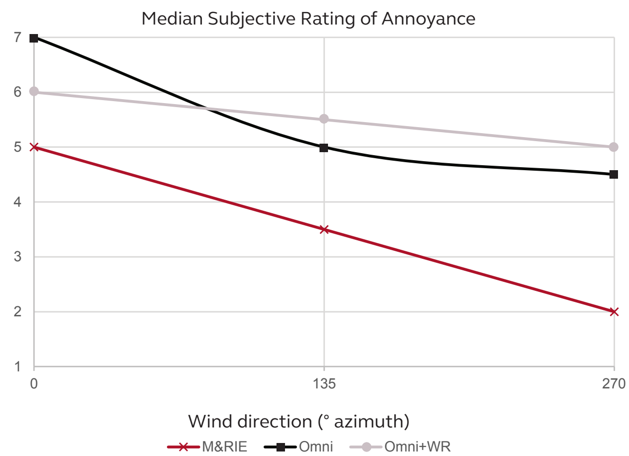



Figure 4. Median subjective ratings of annoyance with the three conditions M&RIE, Omni and Omni+WG in 5 m/s wind from 0°, 135° and 270° azimuth. Lower ratings are better. M&RIE was rated significantly better than Omni and Omni+WG at all azimuths. The differences in ratings between Omni and Omni+WG were not significant.

## Correlation between wind noise level and subjective ratings

Figure 5 displays a scatterplot and trendline for average wind noise levels between left and right devices and conditions together with median subjective ratings. The Spearman's rank-order correlation showed a strong correlation between wind noise levels and the subjective ratings ($r_s(10) = 0.9$, $p < .0001$), indicating that higher levels induced higher subjective ratings.

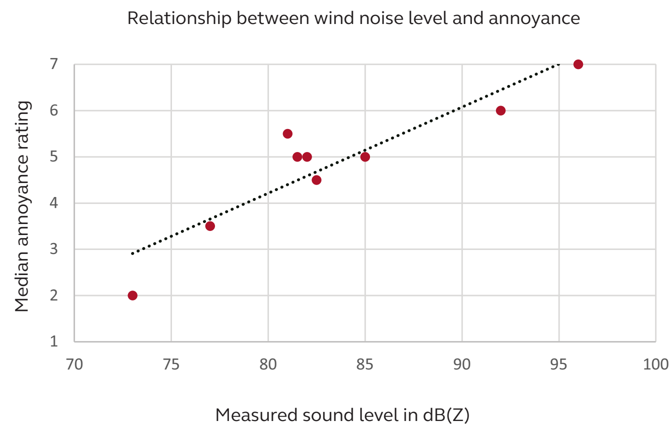



Figure 5. Scatterplot and trendline for average wind noise levels between left and right devices and conditions together with median subjective ratings. Lower ratings are better.

# DISCUSSION

Participants in this study rated the wind noise significantly less annoying for the M&RIE condition compared to both Omni and Omni +WG at all tested wind directions. The ratings for M&RIE were at least 2 scaling units better than Omni at most incidence angles. Assuming participants used the rating scale in a linear fashion, this amounts to an approximately 33% improvement in subjective rating of wind noise with M&RIE compared to the traditional microphone placement conditions. No significant difference on the ratings between Omni and Omni with Wind Guard was found. Unsurprisingly, there was a strong correlation between measured level of wind noise and rating of annoyance with higher levels receiving worse ratings. This is consistent with a similar study, which also found that the level of wind noise annoyance is driven by the overall level of wind noise in the hearing aid's output.[13]

It was also found that the overall measured wind noise level with M&RIE was approximately 9 dB less than either Omni or Omni+WG. While this is somewhat less than the previously reported 15 dB reduction in wind noise with M&RIE, the difference in results is due to methodological differences in the two studies; the earlier study measured only the right ear but at more angles of wind noise incidence, used high and low pass filtering to limit the measurement results to the hearing aid bandwidth, and used a different duration of the exposure to the wind noise. All of these differences likely contributed to the difference in results. However, both studies were consistent in finding that M&RIE resulted in vastly lower wind noise.

It would seem reasonable to compare the results of this study with others that compared Completely-in-the-Canal (CIC) microphone placement with Behind-the-Ear (BTE) placement. Indeed, Zakis[3] found that a CIC device on average across 8 incidence angles produced less wind noise than two difference BTE devices. Regardless, one should be careful in comparing results since previous studies have shown that different models of the same form factor can generate very different levels of wind noise.[14,16] Also, the results from this investigation suggest that the M&RIE-placement may be even better protected by the tragus than CIC microphone placement. For example, other studies have found that 135° is the wind direction that causes the most turbulence around the CIC placement. At this specific direction, the CIC placement was reported in other studies to generate even higher levels than BTE-devices.[3,11] The current study showed that both wind noise levels and ratings are lower with M&RIE than with Omni at all wind directions – even 135°.

**Digital wind noise reduction with Wind Guard**

Omni +WG produced similar wind noise to Omni at 135° and 270°, and there was no significant difference between subjective ratings at any of the tested wind directions. This was probably due to the chosen wind velocity and the choice of statistical tests. The wind noise reduction with Wind Guard is activated when a wind noise level of >70 dB SPL is detected but since the levels of the wind noise are calculated in dB(Z), it is not possible to either confirm or deny whether the wind noise has reached this level. Still, on the 1/3-octave spectra, it appeared that Wind Guard reduced the wind by 3-5 dB in the frequency range 500-1250 Hz at 135° and 270°, but it was more distinct at 0°. Perhaps the effect would have been the same at 135° and 270° as at 0° if it had been tested with a higher wind velocity. This is also reflected in the subjective results where Omni+WG had a better median rating than Omni at 0° even though it was not statistically significant. Therefore, it can still be said that Omni+WG had a wind reducing effect, noticeable to participants. Surprisingly, Omni+WG had slightly poorer subjective median ratings than the Omni at 135° and 270° even though their average overall wind noise levels were almost the same. This might be explained by the few decibels that Wind Guard reduced the wind noise; the speech signal may also have been lowered slightly, causing participants to rate the wind noise more annoying. Although the speech signal was included to give the test participants a reference when rating the wind noise annoyance, it is hard to know exactly how and if the speech signal affected the participants' ratings. It cannot be ruled out that some participants might have based their ratings on how affected their perception of the speech was.

In view of the significantly better ratings for the M&RIE, there is strong evidence that it is more effective to physically protect the microphone against turbulence than to reduce the wind noise by signal processing after it has entered the system, at least for relatively low wind speeds. Whether the findings would be the same for higher wind velocities is a topic worthy of further investigation.

## Conclusion

These results support that M&RIE is an effective solution to wind noise, and is superior to a signal processing based approach for relatively low wind speeds. Therefore M&RIE can potentially contribute to greater satisfaction in windy listening environments and general satisfaction among hearing aid users.

## SUMMARY

This study looked into the effect of M&RIE on subjective wind noise annoyance compared to omnidirectionality with and without the digital wind noise reduction algorithm Wind Guard. Sixteen normal-hearing participants evaluated wind noise recordings in relation to annoyance. The stimuli had been pre-recorded on an acoustic manikin in a wind tunnel at a wind velocity of 5 m/s at incidence angles 0°, 135° and 270° azimuth. The results showed that M&RIE reduced subjective wind noise annoyance compared to Omni and Omni with Wind Guard at all tested angles. There were no statistically significant differences between Omni and Omni with Wind Guard. Wind Guard did not reduce the wind noise enough for test participants to rate it less annoying than with Omnidirectionality at the tested velocity. In conclusion, M&RIE is effective in reducing subjective wind noise annoyance compared to Omnidirectionality and digital wind noise reduction with Wind Guard.

## REFERENCES


1. Launer S, Zakis JA, Moore BCJ. Hearing Aid Signal Processing. In: Popelka GR, Moore BCJ, Fay RR, Popper AN, editors. Hearing Aids. Cham: Springer International Publishing; 2016. p. 93-130.

2. Kates JM. Digital hearing aids. San Diego: Plural Publishing; 2008.

3. Zakis JA. Wind noise at microphones within and across hearing aids at wind speeds below and above microphone saturation. The Journal of the Acoustical Society of America. 2011;129(6):3897-907.

4. Kochkin S. MarkeTrak VIII: Consumer satisfaction with hearing aids is slowly increasing. The Hearing Journal. 2010;63(1):19-30-2.

5. Kochkin S. Increasing hearing aid adoption through multiple environmental listening utility. The Hearing Journal. 2007;60(11):28-31.

6. Chung K. Wind noise in hearing aids: I. Effect of wide dynamic range compression and modulation-based noise reduction. International Journal of Audiology. 2012;51(1):16-28.

7. Chung K. Wind noise in hearing aids: II. Effect of microphone directivity. International Journal of Audiology. 2012;51(1):29-42.

8. Chung K. Comparisons of spectral characteristics of wind noise between omnidirectional and directional microphones. The Journal of the Acoustical Society of America. 2012;131(6):4508-17.

9. Chung K. Effects of venting on wind noise levels measured at the eardrum. Ear and Hearing. 2013;34(4):470-81.

10. Chung K, Mongeau L, McKibben N. Wind noise in hearing aids with directional and omnidirectional microphones : Polar characteristics of behind-the-ear hearing aids. The Journal of the Acoustical Society of America. 2009;125(4):2243-59.

11. Chung K, McKibben N, Mongeau L. Wind noise in hearing aids with directional and omnidirectional microphones: Polar characteristics of custom-made hearing aids. The Journal of the Acoustical Society of America. 2010;127(4):2529-42.

12. Jackson IR, Kendrick P, Cox TJ, Fazenda BM, Li FF. Perception and automatic detection of wind-induced microphone noise. The Journal of the Acoustical Society of America. 2014;136(3):1176-86.

13. Korhonen P, Kuk F, Seper E, Mørkebjerg M, Roikjer M. Evaluation of a wind noise attenuation algorithm on subjective annoyance and speech-in-wind performance. Journal of the American Academy of Audiology. 2017;28(1):46-57.

14. Zakis JA, Hawkins DJ. Wind noise within and across behind-the-ear and miniature behind-the-ear hearing aids. The Journal of the Acoustical Society of America. 2015;138(4):2291-300.

15. Chung K. Strategies to Reduce Wind Noise Interference on Hearing Devices. The Hearing Journal. 2020;73(7):10,2,3.

16. Grenner J, Abrahamsson U, Jernberg B, Lindblad S. A comparison of wind noise in four hearing instruments. Scandinavian Audiology. 2000;29(3):171-4.

17. Jespersen CT, Kirkwood B, Schindwolf I. M&RIE receiver preferred for sound quality and localisation. ReSound White Paper. 2020.

18. Groth J. An innovative RIE with microphone in the ear lets users “hear with their own ears”. Canadian Audiologist.[7(5).]

19. Jespersen C. Independant study identifies a method for evaluating hearing instrument sound quality. Hearing Reveiw. 2014;21(3):36-40.

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