ADAPTIVE WIND NOISE ATTENUATION ALGORITHM: SUBJECTIVE ANNOYANCE AND SPEECH-IN-WIND PERFORMANCE

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INTRODUCTION

Wind noise is created at a hearing aid microphone when the flow of the air is obstructed as it moves past the hearing aid. The obstructions cause turbulence which results in air pressure fluctuations at the microphone membrane. These changes in air pressure are perceived as wind noise. Wind noise can overload the microphone preamplifier resulting in audible distortion and drowning out the acoustic signals that are transduced by the hearing aid microphone. Wind noise can limit the optimal use of the hearing aids outdoors and may negatively impact participation in normal activities.

One approach to reduce the negative effects of wind noise is to utilize digital signal processing algorithms. Acoustic signals measured at the two microphones of a dual microphone hearing aid are typically highly correlated for far field signals. A special characteristic of wind noise is that its correlation with itself as measured at two points decreases rapidly with distance. This property can be utilized to reduce the amount of wind noise in hearing aids.

The current study evaluated the effect of the new wind noise attenuation algorithm using a single-blinded repeated-measures design. First, listeners' subjective impressions on wind noise annoyance was measured with and without the algorithm. The listeners' speech-in-wind performance at a wind speed of 5 m/s was measured at several speech levels in a controlled laboratory environment to examine how the attenuation of wind noise affects speech intelligibility.

ALGORITHM

In the detection stage the algorithm uses correlation of signals at the two microphones, the frequency spectrum, and the energy level of the input signal to determine presence or absence of wind noise. For the input to be classified as wind noise, inputs at the two microphones must be uncorrelated, its spectrum must be primarily in the low frequencies and its intensity level has to be higher than 40 dB SPL.

In the attenuation stage a least mean squares (LMS) algorithm is used to reduce wind noise. The two signals y_1 and y_2 entering the hearing aids are the sums of the acoustic signals x_1 and x_2 and the wind noise s_1 and s_2. Assuming far field model for the acoustic sounds, the desired acoustic signals s_1 and s_2 picked up by the two microphones are highly correlated within the bandwidth of interest, whereas the wind noise signals w_1 and w_2 are highly uncorrelated.

Adaptive filter H(z) alters one of the microphone inputs. The filter coefficients are recursively calculated in an attempt to minimize the mean squared difference u between the signals y_1 and y_2. Adaptive filter can only predict the part of the signal y_2 that is correlated with y_1 (i.e. the desired signal). Because the two wind signals w_1 and w_2 are uncorrelated, they are left out of the predictor output. The wind noise reduction algorithm works for frequency bands up to 3.2 kHz.

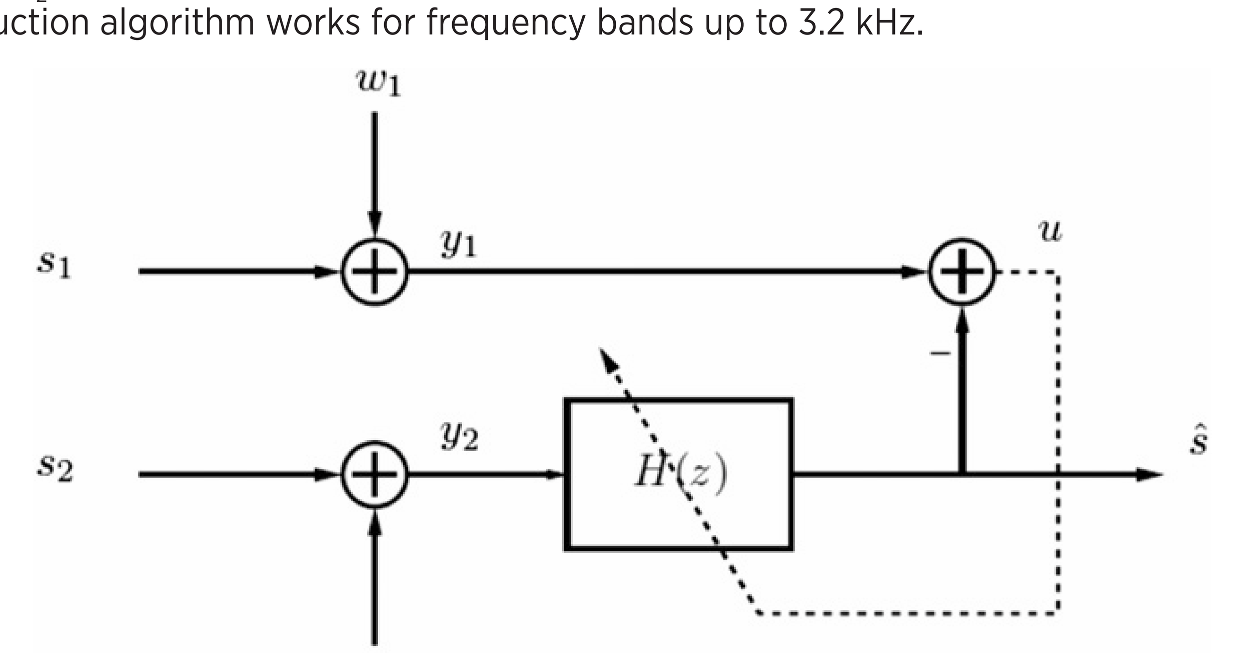

Figure 1. Block diagram displaying the adaptive filtering used to reduce wind noise in the study hearing aid.

SUBJECTS

- N = 15
- PTA_{right} = 42.3 dB HL (SD = 10.0 dB)
- PTA_{left} = 42.5 dB HL (SD = 7.3 dB)
- Mean age = 70.1 yrs (SD = 13.8 yrs)
- Average hearing aid experience 9.5 yrs (SD = 7.8 yrs)
- Own aid: 9 RIC, 3 ITE, 3 no aid
- (Additional nine participants in rating test with same HL configuration)

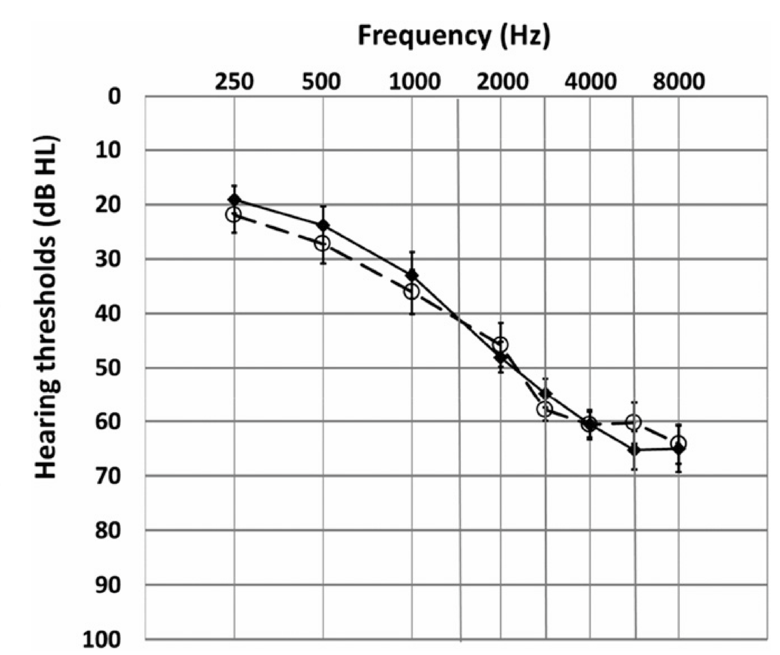

Figure 2: Averaged audiometric thresholds for left (solid) and right (dashed) ears. Error bars indicate ±1SD.

HEARING INSTRUMENT

Hearing aids used in the study were Widex UNIQUE Fusion440 receiver-in-the-canal (RIC) BTE hearing aids (P-receiver). Hearing aids were programmed using the average hearing loss from all participants and the default frequency-gain setting was used.

Hearing aid features:

15-channel wide dynamic range digital hearing aid. The input limit before saturation is 113 dB SPL.The frequency response of this instrument ranges from 100 Hz to 6400 Hz (ANSI S3.22-2009). The maximum power output (MPO) of this instrument is 121 dB SPL.

Hearing aid settings:

Two hearing aid programs: WNA-ON and WNA-OFF; Digital noise reduction: off; Microphone: omnidirectional; Feedback cancellation: SuperGain; Enviromnetal classifier: off.

STIMULI

All the stimuli were prerecorded using KEMAR (RA0045 Ear Simulator IEC 60318-4 [60711]) in a wind tunnel (G.R.A.S. Sound & Vibration A/S in Holte, Denmark) and presented via insert earphones during the data collection. A loudspeaker (G.R.A.S. 44AA Mouth Simulator) presenting the speech stimuli was placed at 270°. The study hearing aid was coupled to KEMAR's left ear using a fully occluding earmold.

Subjective annoyance rating for wind noise was obtained for wind presented alone without speech. Wind was presented at wind speeds of 4, 5, 6, 7, and 10 m/s from 0° or 290°. The angle of 290° was selected over the 270° (directly to the left) because the 290° angle was rated to result in more wind noise based on an informal listening test carried out during the recordings. Each wind noise sample was 20 seconds in duration.

Objective speech-in-wind identification performance was measured for speech presented from 270° at 60, 65, 70, and 75 dB SPL with the wind originating from 0° at a wind speed of 5 m/s. This wind speed was selected because it occurs frequently in real-life during outdoors and leisure activities.

PROCEDURES

The subjective rating of annoyance was measured using a rating scale from 1 to 7 (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; 7 = extremely annoying). The participants indicated their rating for each sample on a touch screen. Order of presentation across wind speeds and processing conditions were randomized.

Objective speech-in-wind identification performance in the presence of wind was measured using the Widex Office of Research in Clinical Amplification Nonsense Syllable Test (ORCA-NST, Kuk et al, 2010). This is an open-set CVCVC test containing 25 English consonants. A shortened 32-item female version of the test was used in the current study. All test conditions were presented in a counterbalanced order using a single blinded design.

RESULTS

Subjective annoyance

The wind noise was consistently rated as more annoying with WNA-OFF than with WNA-ON regardless of the wind direction. For wind from 0° condition the difference in median ratings between the WNA-ON and WNA-OFF conditions was the greatest at 6 m/s where the rating changed from 7 (extremely annoying) with WNA-OFF to 4 (slightly annoying) with WNA-ON. With WNA-OFF the median rating of 7 (extremely annoying) was reached at a wind speed of 6 m/s whereas the same rating was not reported with WNR-ON. The difference in annoyance ratings between WNA-ON and WNA-OFF was significant for wind speeds 4, 5, 6, and 7 m/s ($p < 0.05$).

For wind from 290° condition the difference between the WNA-ON and WNA-OFF when the wind speed was between 6 and 7 m/s (difference of 1 point) was statistically significant ($p < 0.05$). There was no significant difference in annoyance ratings between WNA-ON and WNA-OFF for wind speeds at 4, 5, and 10 m/s ($p > 0.05$).

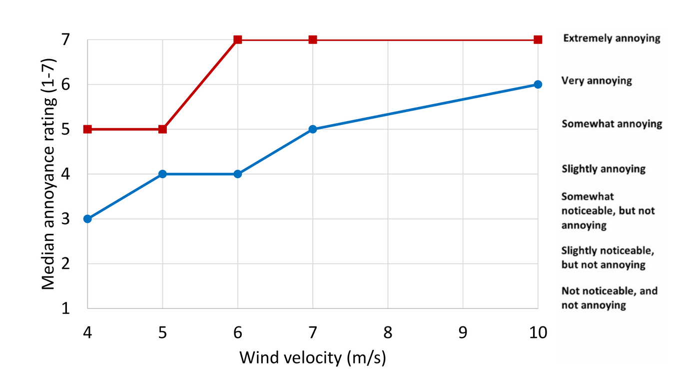

Figure 3. Median listener rating of annoyance wind from the front

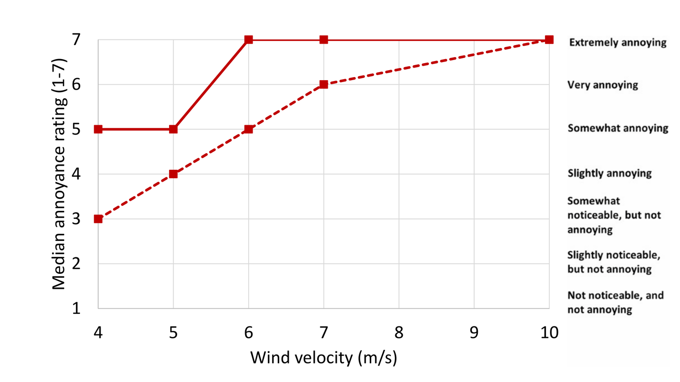

Figure 4. Median listener rating of annoyance WNA-OFF

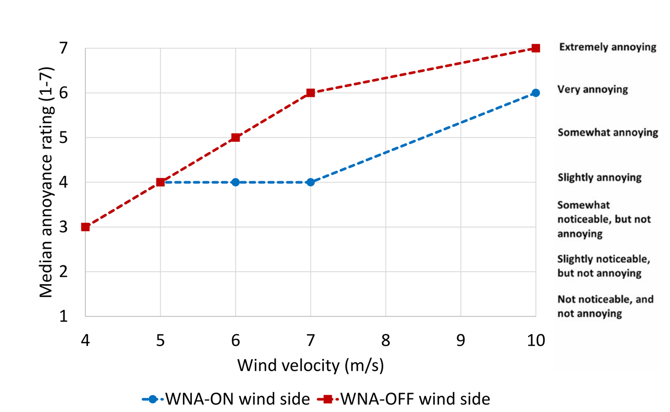

Figure 5. Median listener rating of annoyance wind from the side

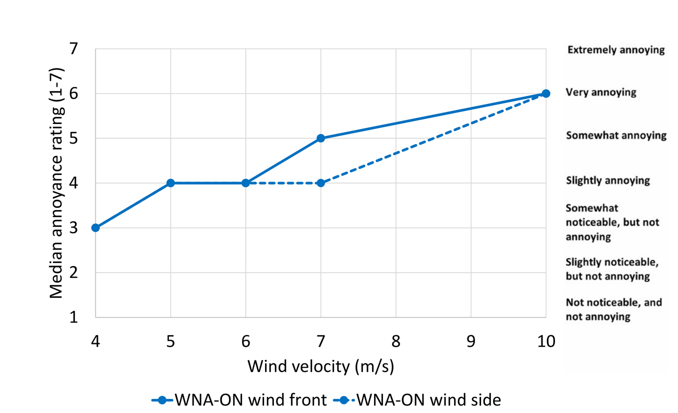

Figure 6. Median listener rating of annoyance WNA-ON

RESULTS (CONT.)

Speech-in-wind performance

At a speech level of 60 and 65 dB SPL, the performance with WNA-OFF was close to zero. Only at higher speech levels (70 and 75 dB SPL) were the participants able to identify some speech with WNA-OFF. With WNA-ON all participants were able to perform above 0% level even when speech was presented at the softest level of 60 dB SPL. The average phoneme identification scores with WNA-ON were 34.4%, 49.6%, 64.4%, and 68.1% for 60, 65, 70, and 75 dB SPL speech levels respectively. The average phoneme identification scores with WNA-OFF were 0%, 1.4%, 31.4%, and 57.8% for 60, 65, 70, and 75 dB SPL speech levels respectively. The difference in performance between WNA-ON and WNA-OFF was statistically significant at all speech levels ($p < 0.01$).

Because the phoneme identification scores were measured at multiple speech levels, we could estimate the SNR benefit that the WNA algorithm provides at a given performance level. For phonemes the SNR benefit when using the WNA feature was 8.39 dB at the 50% speech performance level.

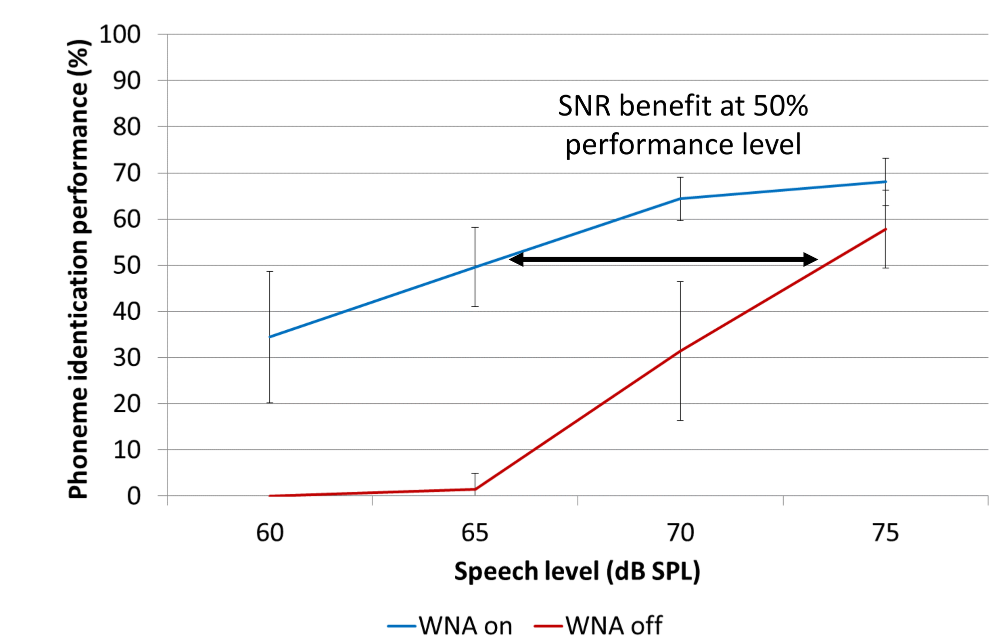

Figure 7. The average phoneme identification performance for WNA-ON and WNA-OFF conditions when speech was presented from 270° at 60, 65, 70, and 75 dB SPL and wind originated from 0° at 5 m/sec speed. The error bars represent ±1SD.

CONCLUSIONS

The current study showed that the LMS based wind noise attenuation algorithm reduced subjective annoyance for wind from the front and side, and improved speech identification performance at a wind speed of 5 m/s. The current wind noise attenuation algorithm could therefore seamlessly expand the range of real-life situations where a hearing aid wearer can listen comfortably. This can promote consistent use of the hearing aid and promote effortless hearing. Because of the potential benefits that this feature may offer, its inclusion in hearing aids as a necessary feature should be considered. The benefits reported were based on adaptive filtering using inputs from the two microphones to derive an estimate of the correlated input signal. Because of the uniqueness of this feature, the results of the current study may not be generalized to other wind noise reduction algorithms that use other strategies.

REFERENCES

American National Standards Institute. (2009) Specification of Hearing Aid Characteristics. ANSI S3.22-2009. New York: American National Standards Institute.

Kochkin S. (2010) MarkeTrak VIII: Consumer satisfaction with hearing aids is slowly increasing. Hear J 63(1):19-27.

Kuk F, Lau C, Korhonen P, Crose B, Peeters H, Keenan D. (2010) Development of the ORCA Nonsense Syllable Test. Ear Hear 31(6):779-795.