MAINTAINING SPEECH INTELLIGIBILITY IN COMMUNICATION HEADSETS EQUIPPED WITH ACTIVE NOISE CONTROL

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1. INTRODUCTION

The primary requirement for a communication headset is to maintain speech intelligibility under all conditions of use. For headsets equipped with active noise reduction (ANR), the performance of the control system may influence the communication signal reaching the ear. Conversely, the communication signal may perturb the operation of the ANR system. The potential for interaction between the communication and control signals would appear to depend primarily on the control structure.

The intelligibility of speech reproduced at the ear of persons wearing a headset equipped with ANR has been reported in several studies. The influence of the control structure on the speech intelligibility, however, has not been frequently investigated [1,2].

In this paper, the performance of two circumaural headsets is compared, one employing feedback control with a fixed filter and analog signal processing, an approach commonly used in commercial devices, and one employing adaptive digital feed-forward control. Both devices attempt to control low-frequency noise, as the passive attenuation of the earmuff substantially reduces noise at frequencies above 500 Hz. The headset with the feedback control system was chosen to match, as close as possible, the ANR of the headset with the feed-forward control system.

2. METHODS

2.1 Sound Fields and Measurements

The passive, and total, noise reductions of the headsets were measured when they were worn by a human subject, or by a manikin (Bruel & Kjaer head and torso simulator, HATS). In the former case, a miniature microphone recorded the sound pressure under the earmuff when the control system was, and was not, operating. A separate measurement of passive noise reduction was performed with a miniature microphone positioned in the concha (i.e., headset doffed and donned). In the latter case, the built-in microphone within the external ear simulator of HATS was used to record the sound pressure. The measurements were conducted in a reverberation room using band-limited white noise.

2.2 Speech Transmission Index

The influence of ANR on speech intelligibility was determined using the Speech Transmission Index (STI), which is a figure of merit for a communication link that varies from zero (no intelligibility) to unity (ideal intelligibility). The A-weighted sound level at the ear produced by the STI signal fed to the earphone was set to 70 dB. A noise spectrum shaped to approximate that of the long-term average of speech was established at the subject position within the reverberation room, and the sound level adjusted to produce a range of STI values. In each case, a miniature microphone within the volume enclosed by the earmuff was used to record the combination of the STI test signal and the confounding noise both with, and without, active control. For all measurements, the A-weighted sound level of the noise was adjusted to be the same for both headsets when the ANR was not operating.

3. RESULTS

3.1 Passive and Total Noise Reduction

The differences between the passive, and between the total, noise reductions of the two headsets are shown as a function of frequency in Fig. 1. The results are plotted for the headset with the feed-forward control system – headset with the feedback control system. The passive attenuation of the headset with the feed-forward control system can be seen to exceed that of the other headset at frequencies from 200 to 1500 Hz, and at frequencies above 3.5 kHz, while the opposite was observed at other frequencies. The difference in the total noise reduction shows the same pattern at mid and high frequencies, but displays a different pattern at frequencies below 1 kHz, reflecting the contributions of the active control systems. The similarity between the two curves in Fig. 1 at frequencies below 200 Hz implies that the ANR of the two control systems is similar at these frequencies. At frequencies from 200 to 400 Hz, the ANR of the feedback system can be seen to exceed that of the feed-forward system. The extent to which the control systems fulfilled the selection criterion may thus be deduced from the similarities and differences between the two curves in Fig 1 at frequencies below 1 kHz.

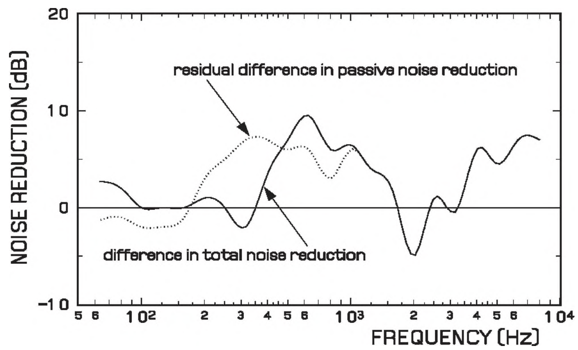

Figure 1: Difference between passive, and total, noise reduction

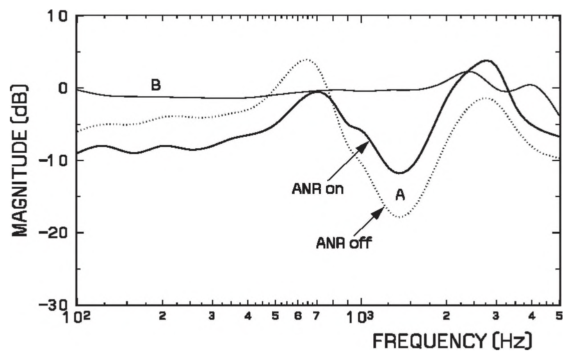

Figure 2: Frequency response of sound reproduction sub-systems

3.2 Speech Reproduction

The frequency responses of the speech reproduction sub-systems are shown in Fig. 2. The results were obtained when the headsets were mounted on HATS with cushions sealed. It can be seen from Fig. 2 that the speech reproduction sub-system of the headset with the feed-forward control system possessed little dependence on frequency from 100 to 4000 Hz (curve B). In contrast, the frequency response of the speech reproduction sub-system of the headset with the feedback control system displayed large frequency-dependent variations in amplitude (curves A, dashed line). Similar, but not identical, variations were observed when this control system was operating (curves B, continuous line). There was no change in sound reproduction by the other headset when its control system was operating. It should be noted that the earphone selected for a feedback control system is usually a compromise between the need to maintain stability of the feedback loop and for communication fidelity: frequency-dependent amplification of the communication signal may also be employed.

3.3 Speech Transmission Index

The STIs of the two headsets for various speech-to-noise (S/N) ratios at the ear are shown in Table 1. It can be seen from the Table that the different S/N ratios produced a range of STI values, as expected, with the largest STI values being obtained with no interfering noise, and the smallest values with the most intense noise (S/N = 2.5 dB). While the STI recorded in noise by the feed-forward control system was greater than that recorded by the feedback system (viz: 0.69 versus 0.55, and 0.85 versus 0.73), it can be seen from the Table that the increase in STI with active control was much greater for the headset with feedback control than for the other headset.

4. DISCUSSION

In a feedback ANR system, the microphone providing the input to the controller is positioned at the ear, under the earmuff, and so senses both the residual noise and the reproduced speech sounds. The controller will attempt to null this "error" signal, i.e., cancel both noise *and* speech. While there are strategies to mitigate the cancellation of speech, it will always occur with this control structure. In contrast, the error signal does not provide the input to a feed-forward controller – the input is taken from a reference microphone outside the earmuff, and so does not contain speech unless there is a substantial air leak in the seal between the earmuff and the head. Thus, the control signal does not perturb the speech reproduced by a circumaural headset with a feed-forward control structure, resulting in improved STI in noise. The disproportionate increase in the STI of the headset with the feedback control system when the ANR system was operating suggests that there may be a factor other than the S/N ratio to consider, as this would be approximately the same for both headsets. Reference to Fig. 2 shows that the frequency response of sound reproduction changed when this controller was operating, presumably as a consequence of the speech component of the error signal, to the benefit of speech intelligibility.

5. REFERENCES

1. A. J. Brammer, R. B. Crabtree, D. R. Peterson and M. G. Cherniack, "Intelligibility in active communication headsets," *Proc ICBEN 2003*, edited by R. de Jong, T. Houtgast, E. A. M. Franssen and W. F. Hofman, pp. 58-64, 2003.

2. A. J. Brammer, R. B. Crabtree, D. R. Peterson, M. G. Cherniack, and S. Gullapalli, "Active headsets: Influence of control structure on communication signals and noise reduction," (to appear).

Table 1: Mean STI for various speech-to-noise (S/N) ratios, for two control structures (from Ref. 2)

Control Structure	Speech Transmission Index		
	S/N=2.5 dB	S/N=8.5 dB	No Noise
fixed-filter, feedback, ANR off	0.42	0.6	0.98
fixed-filter, feedback, ANR on	0.55	0.73	0.97
adaptive filter, feed-forward, ANR off	0.67	0.83	0.99
adaptive filter, feed-forward, ANR on	0.69	0.85	0.98