ADAPTIVE RANGE OPTIMISATION FOR TELEPHONY

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ADRO® is a sound processing strategy implemented in a headset amplifier with acoustic shock protection for call centres. An initial experiment established the feasibility of maintaining high intelligibility of speech in ambient noise levels up to 75 dBA without amplifying speech to uncomfortable levels. In another experiment, ten normally hearing listeners compared the ADRO device with a device used in many Australian call centres. In background noise, the ADRO device provided higher speech intelligibility scores on the Phonetically Balanced Monosyllable word test than the comparison device, and was preferred in 95% of cases. These results suggest the possibility of improving communication and working conditions in call centres and other noisy environments.

1. INTRODUCTION

Headsets have developed rapidly over the last decade, and are now commonly used in call centre environments to improve comfort and productivity of the user. However, an increase of reported incidents of acoustic shock injury, which results from loud unexpected sounds, has also been noted with headset use [13]. Therefore, output limiting has become a priority. Two sets of guidelines have been developed for this reason, the Australian Communications Industry Forum G616: 2004 [1] and the Telstra TP TT404B51 [16]. Devices have been developed to protect against acoustic shock injury [e.g. 7, 8] and improve the occupational safety of call centre operators by meeting these guidelines. While acoustic shock protection is essential, sound quality, speech intelligibility in background noise and listener comfort should not have to be compromised.

Sound processing is critical in call centre environments, where background noise levels are typically between 55 and 66 dBA and the main source is general conversation between callers and co-workers [14]. Perception in speech or speech-like background noise has been shown to be the most difficult listening environment over other types of noise [11], probably due to the noise carrying a meaningful content (information masking). The negative effects of background noise on various cognitive tasks include loss of efficiency in working memory capacity [15], slower reaction times and reduced accuracy [9], and a greater degree of perceived effort for speech perception [11]. The perceived effort to understand printed text is also increased [11], indicating that the influence of speech-like background noise is detrimental to a wide range of cognitive tasks. A distorted speech signal will exacerbate the problems associated with speech perception in noise. Thus, a clear speech signal is fundamental to successful and efficient communication in call centre environments, which could also lead to improved customer satisfaction.

A digital signal processing scheme, Adaptive Dynamic Range Optimisation (ADRO), has been modified to meet the need for acoustic shock protection while providing optimised speech intelligibility at the same time. It uses statistical analysis to optimise sound in independent narrow frequency channels and a set of fuzzy logic rules to place the output signal within the comfortable and audible range of the listener [2]. The ADRO processing results in an optimized frequency response, signal dynamic range, and overall signal-to-noise ratio. The adaptation rate is also optimized so that ADRO provides linear processing on a moderate time scale, compared with most nonlinear processing schemes. ADRO has shown benefits in cochlear implants and in comparison with wide dynamic range compression hearing aids [4, 12]. ADRO has been specially adapted for telephony applications [3]. ADRO assesses the ambient noise level using the headset microphone and adjusts the output level and frequency response for the received signal based on this information.

This paper reports two experiments. The first experiment explored the feasibility of using ADRO processing in a headset amplifier for call centres. Loudness perception and speech intelligibility were assessed, with and without ADRO processing. The second experiment was a blind comparison between the ADRO device and a device currently used in many Australian call centres. Speech intelligibility and subjective preferences were evaluated.

2. FEASIBILITY OF ADRO FOR TELEPHONY

All testing was carried out in an audiometric test booth, with dimensions 2.7 m x 2.45 m x 2.1 m, and a reverberation time of 0.22 seconds. The setup of the room is shown diagrammatically in Figure 1. Input speech material was filtered according to the send filter specification in ITU P.48 as shown in Figure 2 [10].

Four normally hearing adults ranging in age from 21 to 30 years were recruited for the experiment. Participants were tested prior to the experiment to ensure that they had normal hearing bilaterally (pure tone thresholds $\leq$ 25 dB HL at octave intervals from 250-4000 Hz). Participants sat in the middle of the room with 4 speakers as noise sources at 1 metre from the listener's head. The noise was the National Acoustics Laboratory Restaurant Noise recording with a long term spectrum similar to the Hoth spectrum recommended by IEEE 269-2002 as shown in Figure 3. Tests were performed in quiet and with noise levels of 55, 65, and 75 dBA (diffuse free field as measured at head location of participant). The input speech material to the headset was female City University of New York (CUNY) sentences [5] at a

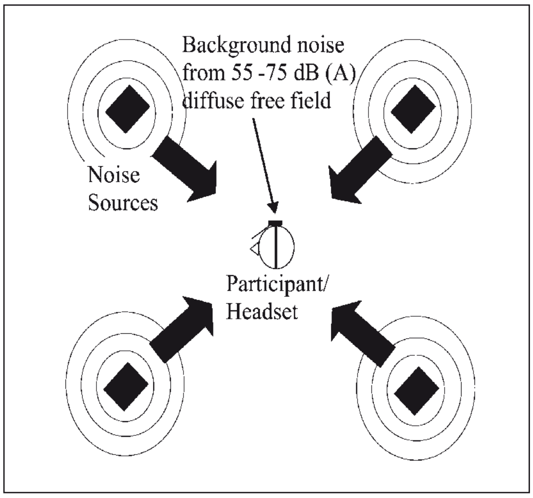

FIGURE 1 General test setup in the audiometric test booth used in the current study

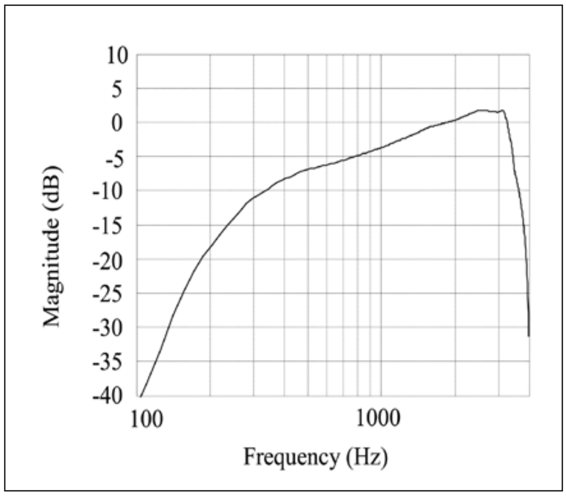

FIGURE 2 ITU Recommendation P.48 IRS send filter magnitude response [10] used for the input material in the current study

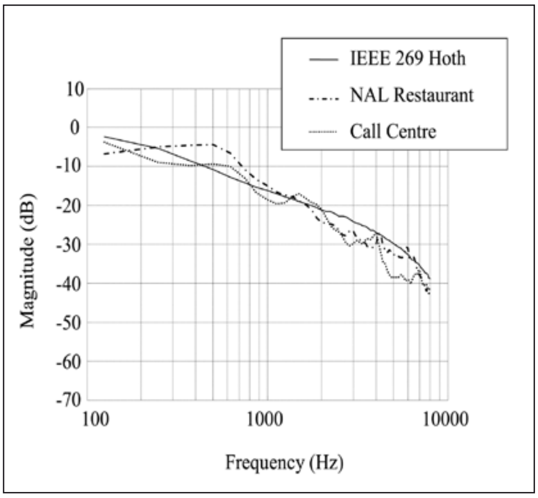

FIGURE 3 Ambient noise spectra showing IEEE 269 Hoth, NAL restaurant, and simulated call centre noise as used in the current study

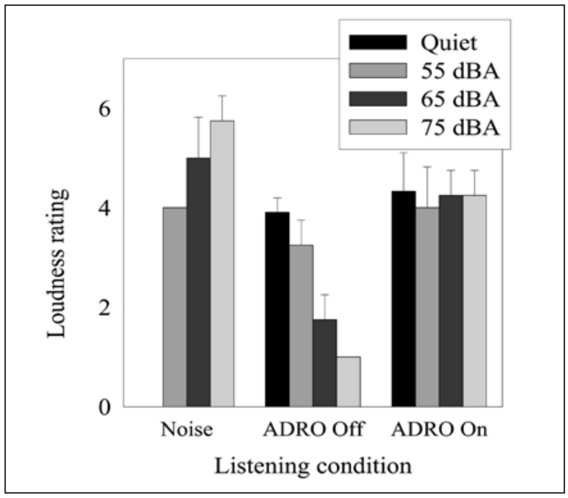

FIGURE 4 Loudness ratings averaged across subjects

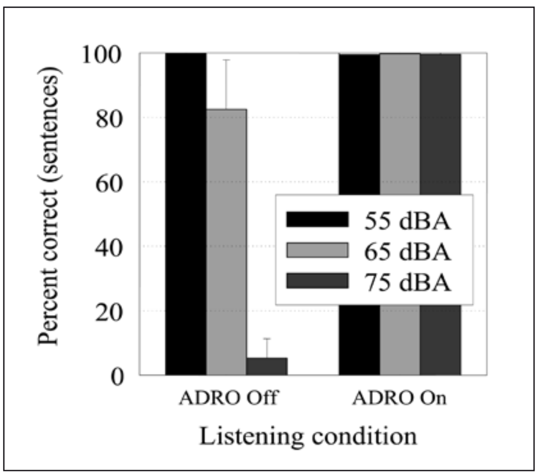

FIGURE 5 Speech intelligibility scores in percent correct for City University of New York sentences in various levels of noise for ADRO-ON and ADRO-OFF conditions

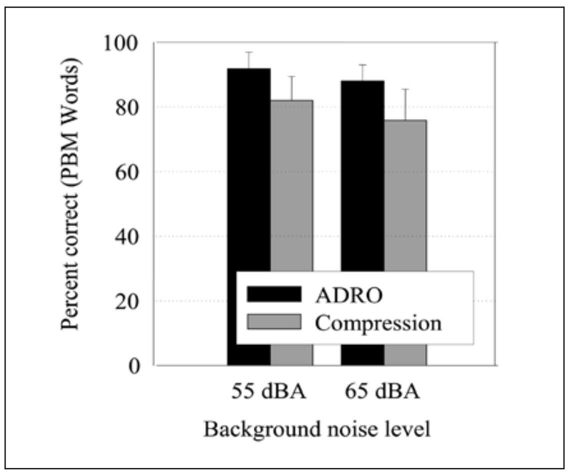

FIGURE 6 Speech intelligibility scores for Phonetically Balanced Monosyllable words in 55 and 65 dBA of pseudo call centre background chatter

nominal input level to produce 73 dB SPL RMS at the eardrum reference position on a Brüel & Kjær head and torso simulator (Ear Simulator IEC711 ITU-T Type 3.3) for both ADRO-ON and ADRO-OFF conditions and did not change throughout the experiment. In the ADRO-OFF condition, the headset amplifier operated as a linear amplifier with flat frequency response and no ambient noise adjustment.

Participants placed the Plantronics Supra Monaural H51-TT3 headset comfortably on their right ear for testing. Initially, loudness ratings were taken according to a 7 point loudness scale (Appendix) with 0 being inaudible and 7 being uncomfortably loud [6]. The CUNY sentences were presented through the headset with background noise from the speakers at four levels (off, 55, 65, and 75 dBA). Participants were asked to give loudness ratings for the background noise alone and for speech in the ADRO-ON and OFF conditions in each level of noise.

Secondly, CUNY sentences were presented through the headset with background noise levels of 55, 65, and 75 dBA to evaluate speech intelligibility. One list containing 10 sentences was presented for each noise level in both ADRO conditions (ON and OFF), so a total of 6 lists were presented. Scores were calculated by counting the number of words correct for each list. The order of presentation of noise levels and ADRO conditions, and the assignment of CUNY sentence lists were randomized across participants.

Loudness Ratings

The loudness ratings averaged across participants are shown in Figure 4. The loudness ratings for noise range from Comfortable to Loud but OK. Without ADRO processing, the perceived loudness of speech decreased as noise level increased. With ADRO processing on, speech was maintained at a constant and comfortable loudness, regardless of the level of noise.

Speech Intelligibility

The ADRO-OFF results in Figure 5 establish how difficult this task is without any processing. The CUNY sentence scores decreased from 100% in 55 dBA of noise to 5% in 75 dBA of noise. This is consistent with the perceived loudness of the speech which decreased from comfortable but slightly soft to very soft as shown in Figure 4. The CUNY sentence scores remained close to 100% in all noise conditions with ADRO-ON, consistent with the constant comfortable loudness ratings. A non-parametric Kruskal-Wallace test was used to assess the statistical significance of the differences between ADRO-ON and ADRO-OFF conditions because of the obvious ceiling effect in the ADRO. The differences were statistically significant for the 65 dBA and 75 dBA conditions ($p<0.05$).

3. BLIND COMPARISON OF DEVICES

In the second experiment, the ADRO device was compared with a headset amplifier commonly used in call centres throughout Australia. The comparison device uses compression and selective filtering to control the loudness of speech and other sounds. For most signals the time constants are in the order of 100 ms. For high level sounds the attack time of the algorithm is much faster, in the order of 5 ms in order to protect the listener against acoustic shock. The comparison device can also adapt two notch filters to remove high-pitched tones in the frequency range from 1 kHz to 4 kHz. The device settings were as shown in Table 1. The settings for the comparison device are those most commonly used in several Australian call centres with the Plantronics H51 headset. They were chosen to maximize speech intelligibility in background noise, within the capability of the comparison device.

The participants for this experiment were eight adults with normal hearing, ranging in age from 25 to 45 years. Participants were tested to ensure that they had pure tone thresholds ≤ 25 dB HL at octave intervals from 250-4000 Hz. The room set up was the same as in the previous experiment as shown in Figure 1. The diffuse noise conditions of a call centre were simulated using 4 speakers as noise sources at 1 metre from the participant's head, with simulated call centre background chatter as the output, according to test methods specified in TT4 [16] and shown in Figure 3. Tests were performed with noise levels of 55 and 65 dBA (diffuse free field as measured at head location without subject). A Plantronics Supra Monaural H51-TT3 headset was used with both headset amplifiers. The input signal to both amplifiers was ITU P.48 IRS Send filtered, 0.3 – 3.4 kHz bandwidth, at -20 dBV RMS [10] as shown in Figure 2. All participants were instructed to place the headset comfortably on their right or left ear for testing, with the microphone two finger-widths from the corner of their mouth. The volume control was set at maximum level on both devices. At this volume setting, the long-term average output level for a sample of speech measured using a Brüel & Kjær head and torso simulator (Ear Simulator IEC711 ITU-T Type 3.3) was equal for the two devices in quiet conditions.

The input speech material for the first part of the experiment was NAL Phonetically Balanced Monosyllable (PBM) Words. Eight PBM word lists equivalent in their performance/intensity (PI) functions were used for speech intelligibility and subjective comparison testing (2 devices x 2 noise levels x 2 lists). Noise levels, list sequence, and starting condition were randomized. The first 5 words were practice items, and the remaining 25 words were test items. The score was the percentage of completely correct whole word answers.

A paired comparison procedure was also used to assess listener preference for the ADRO and compression devices. The listening material consisted of 20 samples of continuous speech (10 male and 10 female voices) heard through the headset in the presence of 55 dBA of simulated call centre background noise. The participants used an A/B switch box to switch as many times as they needed to reach a preference judgment. The order of speech samples and the assignment of processing strategy to switch positions A and B were chosen randomly for each trial and counterbalanced across participants. Each participant compared the two devices once for each voice, making a total of 20 judgments for each participant.

Speech Intelligibility

The speech intelligibility results with PBM words are shown in Figure 6. A two-way analysis of variance showed a significant difference between processors ($F(1, 60) = 38.24$, $p<0.001$) and between noise levels ($F(1, 60) = 7.9$, $p<0.01$). The interaction between processor and noise level was not significant ($p=0.485$). The error rates for the PBM word test for ADRO were 9% and 12 % in 55 and 65 dBA noise levels respectively. This is in accord with the TT4 guideline [10] which specifies a 10% or less error rate in 55 dBA background noise.

Listener preferences

The paired comparison of continuous discourse with 55 dBA simulated call centre background chatter resulted in the majority of participants choosing ADRO in 95% of cases as their preferred listening strategy. The comparison headset was chosen a total of 8 times out of 160 choices. This result was significantly different from chance ($p<0.001$).

4. DISCUSSION

We did not expose the participants in this study to the risk of acoustic shrieks for obvious reasons. A comparison of the device performance from this point of view is more appropriately done by instrumental measurement. The manufacturers of both the ADRO device and the comparison device state that they are G616 compliant and suitable for TT4 compliant operation. The ADRO processing in a headset amplifier with acoustic shock protection maintained good intelligibility and comfortable loudness under adverse listening conditions, while protecting users' hearing with signal limiting. It is likely that the independent optimization of listening level in each frequency channel of the headset contributed to the robustness of the speech intelligibility scores in noise. The typical transfer function of a telephone line (Figure 2) and the typical ambient noise spectrum (Figure 3) slope in opposite directions, resulting in a variation in the effective signal-to-noise ratio for the listener at high and low frequencies. ADRO's frequency shaping of the headset output tends to overcome this problem. The linear operation of ADRO has also been shown to provide improved intelligibility in noise compared to the non-linear operation of compression in hearing aids [4]. In addition, the ambient noise adjustment built into the ADRO amplifier provided an automatic volume control function to keep the signal-to-noise ratio at an adequate level without exceeding the safe output levels built into the device.

In difficult listening situations with 65 and 75 dBA of noise, CUNY sentence scores with ADRO processing on were significantly higher than with ADRO off. There was a ceiling effect for both ADRO on and off conditions in noise at 55 dBA.

The PBM words have less redundant information than the CUNY sentences, and provided a more sensitive intelligibility test. In particular, the acoustic cues for consonant identification are often at a much lower sound level than the vowels, and are easily misheard in background noise.

The PBM word test results indicated that the imposition of safe output levels in both devices had a measurable adverse effect on speech intelligibility under typical noise conditions for device settings that are commonly used in Australian call centres. This limitation of speech intelligibility was observed when the comparison device was set to minimal limiting and maximal volume: the condition likely to provide maximum speech intelligibility in noise. The ADRO device provided significantly greater robustness and halved the error rate relative to the comparison device. This difference is likely to correspond to a measurable difference in the accuracy of call center operators' work and reduced call resolution time.

The ADRO amplifier provided comfortable listening levels in all ambient noise levels up to 75 dBA, and was preferred 95% of the time over the comparison device in a blind paired comparison. These results show that use of the ADRO amplifier is likely to add to the comfort and job satisfaction of call centre operators.

5. ACKNOWLEDGMENTS

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7. APPENDIX

LOUDNESS SCALING INSTRUCTIONS

In this task, we want you to rate the loudness of various sounds according to the scale printed below. You will be presented with three types of sounds; some with a voice talking in quiet, some with a voice talking with noise in the background and some with just the background noise. Please rate the overall level of loudness for the various types of sounds. The quality or clearness of the speech when presented with the noise is not important in this task, just rate the overall loudness of the speech and the noise. The task will be repeated several times.

LOUDNESS RATING CATEGORIES

7. UNCOMFORTABLY LOUD
6. LOUD, BUT OK
5. COMFORTABLE, BUT SLIGHTLY LOUD
4. COMFORTABLE
3. COMFORTABLE, BUT SLIGHTLY SOFT
2. SOFT
1. VERY SOFT
0. INAUDIBLE

TABLE 1 Device settings

	ADRO Processing	Compression Processing
Software Version:	1.10a	1.9
Rx Volume:	Max	Max
Tx Volume:	Mid	Mid
Tx Mute:	Off	Off
Other:	Terminal setting: A	Config menu settings: Rx input gain: mid Tx volume: mid Headset profile: Limiter setting: 1