On the Use of Wide Dynamic Range Compression and Other Algorithms to Improve Hearing Protection of Workers with Hearing Impairment: A Preliminary Study on Speech Intelligibility.

Solenn Ollivier*[1], Hugues Nélisse†[2], and Jérémie Voix‡[1]
[1]ÉTS, Université du Québec, Montréal (QC)
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)

In Canada, noise-exposed workers are more likely to experience hearing difficulties. This population, who either works or have worked in noisy environment, represents 43% of Canadians [1]. While workers with hearing loss in such environment stand as a substantial part of workers in need of hearing protection, hearing conservationists have not yet come to an agreement on the safest and most efficient way to protect their residual hearing. Common practices of those workers include wearing hearing aids, either turned off or on underneath earmuffs. Hardly any research have explored the potential benefits or dangers of such practice [2].

One solution, based on Leroux et al.' recommendation, is to develop a device for suitable research that incorporates features from both hearing aid devices and Hearing Protection Devices (HPDs). Such device requires the implementation of different signal processing algorithms. One algorithm, popular in hearing aids, is multichannel wide dynamic range compression (WDRC) which allows to amplify while protecting. Different parameters can be used to adjust the amplification/protection to a person's specific needs. Despite numerous research for daily-life applications, the effect of WDRC on speech intelligibility in typical workplace noise has barely been explored. Moreover, research has shown that the use of different WDRC parameters impact speech intelligibility in many ways depending on several factors, including the noise environment and use of WDRC in combination with other algorithms (e.g. noise reduction).

This research first introduces the algorithms to be implemented in the platform for research. Then, a proposed methodology to explore their potential benefits on speech intelligibility in a typical factory noise is presented.

1 Hearing device algorithms

Modulation Based Digital Noise Reduction (MBDNR)
A noise reduction algorithm is used to improve the signal-to-noise ratio (SNR) before compression, thus to increase comfort and speech intelligibility. In this study, the algorithm is adapted from Lezzoum et al.' MBDNR algorithm [3]. After filtering the signal into subbands, the signal envelope is extracted and, based on its modulation frequency, a gain is applied to attenuate the noisy portion of the signal.

WDRC and gain prescription
Wide dynamic range compression is used to decrease the amplitude of a signal using a certain compression ratio (CR) when a defined compression threshold (CT) is reached. Two key constants are used to smooth the signal: the attack time (AT) and the release time (RT). Below the CT, a gain can be applied to the signal. In hearing aids, the gains are usually prescribed by prescription algorithms that typically use hearing loss profile of the wearer. Here the gain computation is based on NAL-RP prescription [4]. The obtained target gains are applied at 65 dB SPL [5]. The compression threshold is chosen as $CT = 50$ dB SPL. To ensure there is no amplification above a certain input level, an anchor point is defined such that $A_{in} = A_{out} = 90$ dB SPL. The CR and gain below threshold can then be computed. As the aforementioned levels are overall levels, the corresponding band-levels were computed using speech-shaped noise processed through the multiband filter. The influence of different time constants on speech intelligibility vary in different noise environments. The AT is often short, below 10 ms, to protect from a sudden increase of loud sounds, although such AT may induce distortions. Longer RT have been reported to be more beneficial in noise for individuals with hearing impairment. In this research, the influence of different AT and RT will be assessed using three AT/RT combinations presented in table 1. WDRC can be applied in different frequency bands to adapt to the user's HTs in different frequency regions. Five-channel WDRC allows for a good individualization of amplification without increasing too much algorithm complexity and latency. The cut-off frequencies [450;900;1800;3600] Hz are chosen such that each band contains the same proportion, approximately 20%, of band importance function for short text passages according to the Speech Intelligibility Index standard (ANSI/ASA S3.5).

Compression Limiting
A compression limiting algorithm is finally used at the output to protect from very loud noise. Thus, more aggressive parameters are used: $CT_{lim} = 90$ dB SPL, $CR_{lim} = 10$, $AT_{lim}/RT_{lim} = 5/50$ ms.

2 Proposed methodology

Participants
Participants' eligibility and hearing thresholds (HTs) were assessed through otoscopic examination and pure tone audiometry. Their pure tone audiogram enabled to classify the participants in 2 groups: the No Hearing Loss (NHL) group and the Hearing Loss (HL) group for participants with mild to moderate hearing loss. All participants were adults and either native speakers of English or French (including French Canadian).

Hardware
The Auditory Research Platform Virtuose (ARPV) is used

*sollivier@critias.ca
†hugues.nelisse@irsst.qc.ca
‡jeremie.voix@etsmtl.ca

as a soundcard connected to a computer. It consists in two earplugs, each with an outer-ear microphone, an in-ear microphone (IEM) and an in-ear loudspeaker (IELS). In this experiment only the IEM and IELS were used.

Speech intelligibility test and software
Speech intelligibility was assessed through measuring differences in speech reception thresholds (SRTs) using a variation of the Hearing in Noise Test (HINT). The HINT consists in presenting a list of sentences mixed with noise with varying SNR to the participant. The participant is asked repeat each sentence. If the repeated sentence matches the original one, the SNR of the next presented stimuli is lower, otherwise the SNR is higher. Once the list of sentences is over, the SRT is obtained. The stimuli used are standardized list of sentences [6, 7], mixed with a factory noise. The **Matlab Speech Test Environment (MSTE)** [8] was used to automate the HINT. This Matlab platform developed by Ellaham et al. at University of Ottawa enables to perform the HINT procedure while allowing to simulate hearing devices. The experimenter inputs the participant's information including HTs. Then test paradigms can be chosen, including the simulation of a hearing device. If simulation of a hearing device is chosen, the stimuli are processed through the implemented algorithm before being played by the IELS. For each subject the HINT was administered for the 5 conditions presented in in table 1. In the table "whole" refers to the combination of the three aforementioned algorithm, and "WDRC" to WDRC only. The order of testing between conditions was randomized and organized in a double-blinded study.

Table 1: Different testing conditions

Condition	Simulated device	WDRC AT/RT (ms)
1	None: unaided	/
2A	Whole	10/800
2B	Whole	100/800
2C	Whole	10/1,500
3	WDRC	10/800

Response time and clarity ratings
Response time is a measure of the benefit of amplification by being indicative of listening effort [9]. The response time is defined as the time between the end of the presented stimuli and the start of the sentence repeated by the participant and was computed for each sentence in the post-processing phase. To assess user preference, five sentences mixed with noise at a fixed SNR and processed for each condition were then presented to the participant who repeated the sentence and rated its clarity on a scale from 1 to 5 (1 being very unclear and 5 being very clear).

Test procedure
After their HTs were obtained, the participants performed the five HINT tests in a semi-anechoic room. The participants wore both ARPV earplugs which were connected to the computer, the IELS playing the stimuli of the automated HINT using MSTE. After repeating a sentence, its understanding was rated by the experimenter on MSTE until an SRT value was achieved. The participants were then presented noisy speech mixtures, had to repeat the sentence and rate its clarity. The whole experiment was both audio and video recorded to later compute the response times, and evaluate the corresponding presentation SNR, for each sentence.

3 Conclusions

The impact of different hearing device configurations with WDRC on speech intelligibility in workplace noise are explored. Differences in SRTs and assessment of listening effort are evaluated to select the best configuration. The selected algorithms will then be implemented on the ARPV, as an embedded platform, allowing further research in more realistic working conditions.

Acknowledgments

The authors would like to acknowledge the financial support received from the IRSST, from the ÉTS-EERS Industrial research chair in in-ear technologies, sponsored by EERS Global Technologies Inc, and from Fonds de Recherche du Québec - Nature et Technologies for the Merit-Based Scolarship for Foreign students. They would also like to thank Valentin Pintat for his assistance with the prototyping of the experimental prototypes and Prof. Christian Giguère for providing knowledge and expertise.

References

[1] Pamela Ramage-Morin and Marc Gosselin. Canadians vulnerable to workplace noise. *Health reports*, 29:9–17, August 2018.

[2] Tony Leroux, Chantal Laroche, Christian Giguère, and Jérémie Voix. Hearing Aid Use in Noisy Workplaces. *Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Studies and Research Projects*, page 117, 2018.

[3] Narimene Lezzoum, Ghyslain Gagnon, and Jérémie Voix. Noise reduction of speech signals using time-varying and multi-band adaptive gain control for smart digital hearing protectors. *Applied Acoustics*, 109:37–43, August 2016.

[4] Denis Byrne, Aaron Parkinson, and Philip Newall. Hearing Aid Gain and Frequency Response Requirements for the Severely/Profoundly Hearing Impaired:. *Ear and Hearing*, 11(1):40–49, February 1990.

[5] Harvey Dillon. *Hearing Aids*. Thieme, Sydney, 2 edition edition, June 2012.

[6] Michael Nilsson, Sigfrid Soli, and Jean Sullivan. Development of the Hearing In Noise Test (HINT) for the measurement of speech reception thresholds in quiet and in noise. *The Journal of the Acoustical Society of America*, 95:1085–99, March 1994.

[7] Véronique Vaillancourt, Chantal Laroche, Chantal Mayer, Cynthia Basque, Madeleine Nali, Alice Eriks-Brophy, Sigfrid Soli, and Christian Giguère. Adaptation of the HINT (hearing in noise test) for adult Canadian Francophone populations. *International journal of audiology*, 44:358–69, July 2005.

[8] Nicolas N. Ellaham, Christian Giguère, and Wail Gueaieb. A new research environment for speech testing using hearing-device processing algorithms. *Canadian Acoustics*, 42(3), August 2014. Number: 3.

[9] Rolph Houben, Maaike van Doorn-Bierman, and Wouter A. Dreschler. Using response time to speech as a measure for listening effort. *International Journal of Audiology*, 52(11):753–761, November 2013. Publisher: Taylor & Francis _eprint: https://doi.org/10.3109/14992027.2013.832415.