TOWARDS ADJUSTABLE LOUDNESS COMPENSATION IN HEARING PROTECTORS FOR MUSICIANS

Elliot Drees[*1,3], **Eugénie Segers**[†1], **Caroline Traube**[‡2,3], **and Jérémie Voix**[§1,3]
[1]ÉTS – École de technologie supérieure, Université du Québec, Montréal (QC)
[2]Faculté de musique, Université de Montréal, Montréal (QC)
[3]CIRMMT – Center for Interdisciplinary Research in Music, Media and Technology

1 Introduction

Working in a noisy environment is, in certain cases, unavoidable. To prevent noise-induced hearing loss (NIHL), wearing hearing protection devices (HPDs) is something necessary. However, due to the certain barriers to their use, HPDs are not always worn [1]. In this article, we will be focusing on the acoustic comfort of hearing protectors, which depends on two factors: the isolation effect on external sounds and the occlusion effect on internal sounds [2]. This paper solely focuses on the isolation effect, which corresponds to the unnatural sensation of being isolated from a given sound environment and can be caused by wearing HPDs that do not compensate for psychoacoustical factors and therefore alter the wearer's auditory perception.

Musicians belong to a population particularly affected NIHL [3]. High fidelity active HPDs are now available on the market and seemingly have better acceptance compared to passive protection [4], as they gives more flexibility in filtering and equalisation. For this project, we wish to investigate the integration in active HPDs of loudness compensation algorithms [5] [6] to minimize the isolation effect. For this purpose, two experiments were conducted to assess the effectiveness of various loudness compensators in the context of hearing protection, with a dBA level constraint.

2 Method

2.1 Participants

For both experiments, participants needed to have some significant experience with music, either as amateur musicians, professional musicians, or experience with mixing or recording. A pre-study questionnaire allowed to assess their eligibility. Those with an ear surgery history, current ear infection, physical hypersensitivity of the ear canal, or a hearing loss of more than 25 dBHL hearing loss were excluded from the study. Additionally, an otoscopic examination was performed to verify that the ear was not blocked.

For the first experiment, 21 participated, with one abandoning. For the second experiment, 17 participated, with one being excluded for being over the hearing level threshold. Each participant was offered ETY-Plugs ER20 (Etymotic Research, Elk Grove Village, IL, USA) as compensation. The research project was submitted to and approved by the ÉTS research ethics committee (reference H20210503).

*edrees@critias.ca
†esegers@critias.ca
‡caroline.traube@umontreal.ca
§jeremie.voix@etsmtl.ca

2.2 Design, materials and procedure

Both experiments controlled identical parameters, however, the participant's control over them varied. In both cases, the participant had to listen to samples with varying sound pressure levels: a reference sound at 80 dB, to be compared in timbre with other versions of this sound at a lower level (70 dB or 60 dB), processed by different loudness compensators.

The sample sets was composed of 5 musical excerpts and 1 speech in noise excerpt, all of 10 second duration, in 24 bit/48 kHz lossless format. The musical excerpts are: (1) Peer Gynt, Suite No. 1 Op. 46, Morning Mood, (2) Pink Floyd, Breathe In The Air, (3) Nile Rodgers/Daft punk, Get Lucky, (4) Sylvain Barou/Kevin's Reel, The Session, (5) Paolo Fresu, I Was an American Boy.

Although the computer used for the experiment varied, both experiments used an OCTA-CAPTURE (Roland, Hosoecho Nakagawa, Japan) as a sound source. For experiment 1, the samples were played on a Beridynamic DT 770 (Heilbronn, Germany) headphones while experiment 2 used Shure SE 215 earphones (Niles, Illinois, U.S.) to be closer to the type of HPDs musician use in a rehearsal or stage performance situation.

Experiment 1: Four filtering conditions were tested: (1) Adaptative Loudness Compensation [5], (2) Approximate Spectral Balance Compensation [5], (3) Moore & Glasberg based compensation (developed in-house), and (4) no filtering at all. For each excerpt, the original reference sound at 80 dB was presented with four versions of this sound at a lower level. To collect the participants' ratings on each loudness compensation algorithm in this subtle timbre comparison task, a listening test was designed on the basis of the Multiple Stimulus with Hidden Reference and Anchor (MUSHRA) protocol using an existing framework [7]. The experiment consisted in 3 parts with 8 timbre evaluations each, the first part being a training phase. Open questions were also included to inquire about the participant's confidence.

Experiment 2: The participant listened to three version of a same sample, the reference at 80 dB, an attenuated at 70 dB and a filtered version at 70 dB. they had control over the parameters of the filter during each adjustment task. The user interface was made from scratch using Python language and Tkinter library. Filters more similar to the ones used in audio mastering were used this time: (1) a loudness filter using the equal-loudness contours, (2) a low-high filter, and (3) an 8-band EQ. An additional dBA constraint was added on top of these filters. The participant's task was to adjust the filter to make the timbre of the lower-level sound match the timbre of the reference sound at 80 dB. The adjusted filter parameters were recorded and saved. As a training phase, 3 adjustment tasks were presented, then 3 filtering methods were evaluated in a random sequential order with 3 samples being evaluated 3 times for each filter. Additionally, participants had to rate each filter on a 5-point Likert scale in terms of ease of use, quality, and their desire to use such a filter in a protector.

All testing was done in silent rooms to mitigate the impact of external sounds: either a semi anechoic room within CIRMMT, or a laboratory at the U. of Montreal's Faculty of Music, or an audiometric booth at CRITIAS. Additionally, to reduce participants fatigue, several breaks were imposed during the experiment.

3 Results

In both experiments, participants overwhelmingly shared the desire to be able to adjust HPDs, with all participants in experiment 1, and 14 out of the 16 participants for experiment 2 expressing the need for HPD adjustment, the remaining two expressing uncertainty about it.

Experiment 1: The original sample was always preferred with a higher median compared to the other compensators. When considering *t*-tests between the distributions of the original sample and the other compensators (c) in the context of the sound pressure level (l) and compensator interaction $l \cdot c$, statistically significant difference were found for the MGCL: $p = 3.32 \cdot 10^{-6}$ at $l = 70$ dB and $p = 3.32 \cdot 10^{-6}$ at $l = 70$ dB, and for the ALC at $l = 70$ dB: $p = 9.28 \cdot 10^{-3}$.

Experiment 2: Although the results are preliminary, the Likert scale testing in figure 1 shows that the low high setting is preferred when it comes to all three categories, with the 8-band filter being the less intuitive.

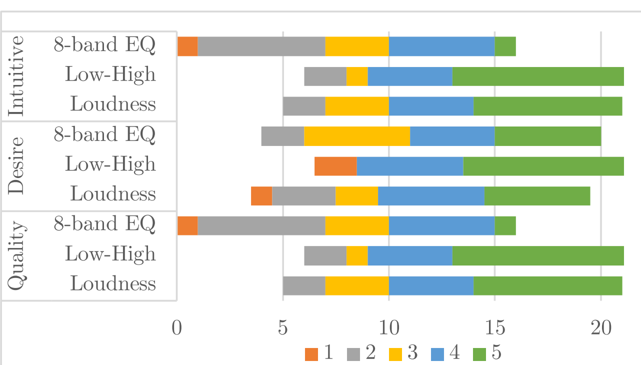

Figure 1: Diverging stack bars representing the responses to the Likert rating question for experiment 2. Intuitiveness, quality and desire to be used are grouped for ease of comparison.

4 Discussion

These two studies evaluated the use of loudness compensation in the use of HPDs as well as possible control schemes to adjust their frequency response.

Although loudness compensators in the literature had been tested on human subjects, the results in our first study does not favor existing loudness compensator. A hypothesis explaining this result is that loudness compensators increase the overall level of the sound by affecting the lower and higher frequency, making the timbre more similar. This effect could be mitigated by our dBA constraint.

In experiment 2, participants preferred simple control schemes (loudness, low-high) over more complete and complex ones (8-band). This can be explained by the need for simple controls while adjusting hearing protector in a live setting.

In both experiments, ideal HPD conditions were simulated by varying the volume of predetermined sounds. Additional studies focused on HPD adjustment in live situations are necessary.

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