Communication with low-cost hearing protectors: hear, see and believe

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ABSTRACT

The effect of hearing protectors on oral communication is highly situational dependent. Subjectively, listening without any hearing protection is most often preferred. Specialized communication equipment could improve communication, but for most common exposure conditions low-cost alternatives are needed.
Musician earplugs aim to reduce high frequency attenuation. This could not only improve music perception, but also speech perception.
Oral communication has been evaluated by sixty participants both quantitatively and qualitatively. Six different listening conditions are evaluated: four different types of premolded musician earplugs, one conventional foam earplug and without any hearing protection. Communication has been evaluated with and without lip-reading.
Without visual information (no lip-reading), scores in the condition without earplugs are higher than scores obtained with conventional earplugs, and also higher compared to two types of musician earplugs included in this study. Lip-reading has a very strong effect on speech perception, clearly reducing the differences in speech perception between the six different test conditions. Participants perceive speech perception with the conventional earplug systematically as more difficult, and the condition without earplugs as more easy.

INTRODUCTION

Fearing interference with communication is one of the most prominent reasons not to wear hearing protection [1]. Hearing protection might indeed affect speech perception, but the net effect is not easy to predict, as it depends on the interaction between protector's attenuation, background noise, task at hand, and user characteristics [2-4].

Active hearing protectors have been developed to improve communication and environmental awareness. However, these devices are considerable more expensive than standard protectors. As an alternative, the attenuation of passive protectors could be altered so that it is less in the frequency range important for speech perception, between 500 Hz and 4000 Hz.

Musician earplugs have been designed to offer a perceptually undisturbed listening experience to music at safe exposure levels. Most of these earplugs aim for a spectrally flat attenuation with less attenuation in the mid- and higher frequencies [5].

In most real-life communication situation, speaker and listener are exposed to the same background noise, and both are wearing hearing protection. In general, speakers will adapt their speech to the background noise to enhance successful communication [6]. The level of the speech is changed (the original Lombard effect) together with the spectral and temporal characteristics. If speakers wear standard passive protectors, the adaptation appears to be less pronounced due to the earplug's attenuation and the occlusion effect, both altering the perception of background noise [7].

Less attenuation in the frequency range important for speech means that also background noise in this region will be less attenuated. This is likely to affect the way speakers adapt to the background noise, as both the level and the spectral of the background noise influence the vocal change [6].

This project assesses the effect of four musician earplugs and one standard earplug on speech perception in an experimental set-up where both speaker and listener wear the same earplug and are exposed to the same background noise (music). Speech intelligibility is assessed with and without visual (lip-reading) information, as visual cues can improve speech recognition.

MATERIALS AND METHODS

Participants

In total sixty participants conducted the experiment, 22 men and 38 woman. They were between 18 and 29 years old, the average age of the male participants was 23 year (standard deviation: 2.5) and 21 year for the female participants (standard deviation: 1.7).

None of the participants reported any problems with attention and focusing, and all had Dutch as their mother tongue. This is of importance as speech intelligibility testings were conducted in Dutch.

Prior to testing, the hearing of the participants was tested using tonal audiometry (Hughson-Westlake method). The pure-tone average for the frequencies 1000 Hz, 2000 Hz and 4000 Hz had to be 25 dB HL or better.

All participants signed an informed consent.

Hearing protection

Five premolded earplugs have been tested, four so-called musician earplugs and one standard foam earplug. All applied with the EN 352-2 regulation.

Price ranged between 0.35 euro and 27.99 euro. The hearing protectors were given to the participants in their original packaging, without further comments on price or usage. They had to fit the earplugs themselves without any feedback or intervention by the experimenter.

The attenuation of the five earplugs as reported by the manufacturer is depicted in Figure 1.

Speech intelligibility test material

Two standardized Dutch word sets routinely used for speech audiometry were used for speech intelligibility testing, the NVA and the Brugse lijst. Both sets consist of monosyllabic words (consonant-vocal-consonant), 12 lists of 17 worths for the NVA and 12 lists of 12 words for the Brugse lijst. Per test condition (see measurement protocol), one complete list was presented.

A word score was used to measure the speech intelligibility, per correctly understood word one point was given. The final score for the whole list is the percentage of words that were understood correctly.

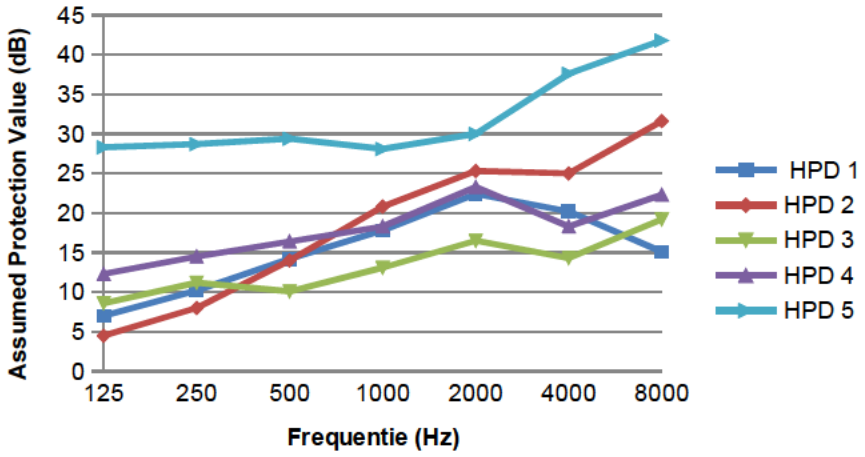

Figure 1: Assumed protection value of the five earplugs as a function

Background noise

As most of the earplugs included in this study are designed to be used in music, music fragments have been chosen as background noise. A contemporary clubbing music compilation made by a professional DJ has been played in a loop for the whole test duration. The original fragment was 15 minutes long. The music was purely instrumental without any lyrics.

The LAeq level was 81.2 dB(A), measured at the participants' position (without the participants being present) using a Svantek type 959 sonometer.

Questionnaire

After each listening condition, participants had to subjectively rate speech intelligibility on a 5-point scale between two opposites: hard to understand speed and easy to understand speech.

Test setup

Speaker and listener were facing each other and seated at one meter and a half from each other. Around the participants five small loudspeakers were placed (ADAM Active Studio Monitor, Type S1X) one meter and half high. Diagonally two subwoofers (ADAM Active Studio Monitor, Type Sub8) were put on the ground. Black stage-play curtains were hung on the walls and in front of the windows to make the room less reverberant.

In-between the participants a screen was placed of 20 by 50 cm so that the participants could not see each other when seated. On the screen, a webcam (Logitech, type C270) was mounted filming the speaker's face and lip movements. In front of the listener, a computer screen was placed, streaming the webcam images in the conditions with audio and visual information, but not in the audio only conditions. Measurements with a Head and Torso Simulator revealed that the screen did attenuate the signal coming from the speaker's side. As expected, attenuation was most prominent for higher frequencies, about 11 dB. It should be stressed that the screen was always present, during all test conditions.

Protocol

Participants have been invited in pairs. Grouping of the participants was done as randomly as possible to prevent that being familiar (or not) with a person's accent and voice would influence the test results. Each participant both acted as speaker and as listener over the course of the experiment.

Speech perception was tested for six earplug-conditions; four different musician earplugs, one standard foam earplug, and without hearing protection. The order of the six earplug-conditions was randomized across participants.

Each of the six test conditions was done twice, once with visual information (presented via the webcam) and once with audio information only. In addition, the whole test sequence of twelve (two times six) conditions was done twice so that each participant completed the test sequence as listener and as speaker.

Statistical analysis

The effect of attenuation on obtained word score was assessed with mixed model linear regression. Two different models were made for the word scores, one for the scores obtained with only audio information, and one for the scores obtained when visual information (lip-reading) was present as well.

In each model, the variable participant has been added as a random factor to account for the fact that each participant had completed the different test conditions. The variable earplug-condition was added as a fixed model to assess whether different types of earplugs or not wearing any earplug at all influenced the speech intelligibility.

Model assumptions were checked using residual QQ-plots, Shapiro-Wilk test and Kolmogorow-Smirnov test. Tukey post-hoc testing was carried out to evaluate pairwise differences.

RESULTS

Quantitative speech intelligibility

The word scores obtained for the different earplug conditions (musician earplugs, standard earplug, no earplug) are depicted in Figure 2 and Figure 3, respectively for the conditions with audio information only, and for the conditions with visual information as well.

When speech was presented without visual information, the earplug condition significantly influenced the obtained word scores ($p<0.01$). Post-hoc testing revealed that two earplugs had especially a lower score than the condition without any earplugs: the foam earplug 5 ($p<0.01$), and earplug 1, a musician earplug ($p<0.001$). Another musician earplug, earplug 2, also

differed significantly from the condition without earplugs ($p<0.05$). All other pairwise comparisons where clearly not significant with $p>0.1$.

When visual information was present, the difference between the earplug-conditions substantially reduced. Earplug-condition had only a marginally significant effect on word score anymore ($p=0.03$). Post-hoc testing revealed that again especially for the foam earplug 5 and for the musician earplug 2 scores were lower compared to the open ear condition, but the difference appeared to be limited ($p=0.03$ for both conditions).

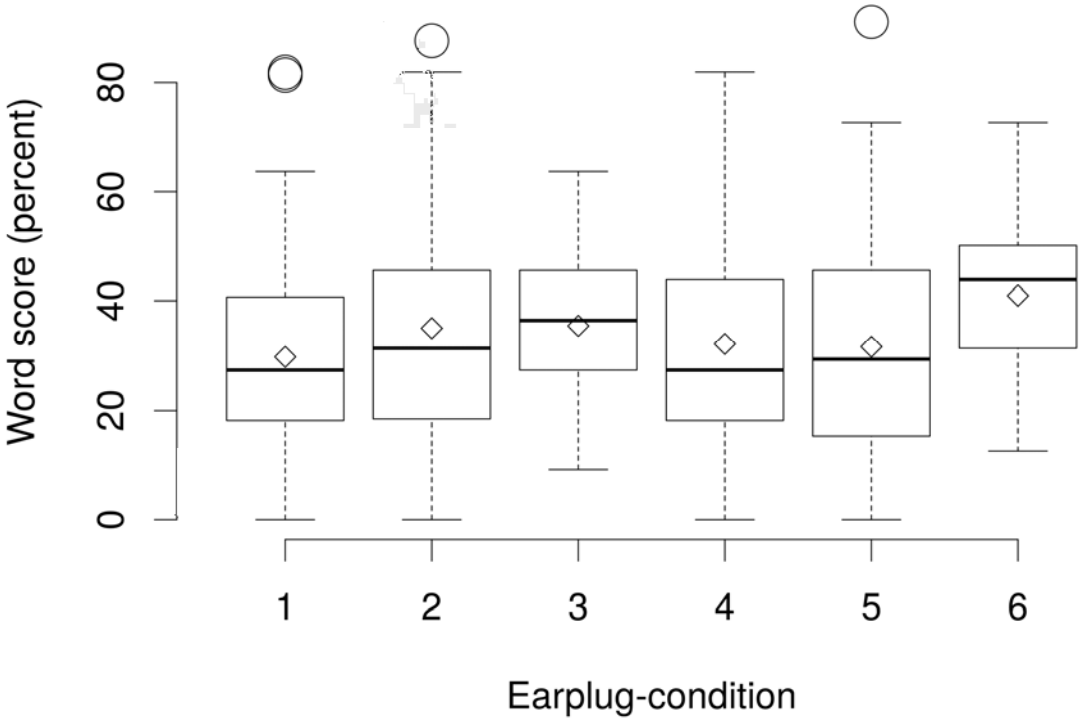

Figure 2: Box plot of word score with audio information only obtained for the four musician earplugs (1 to 4), the standard foam earplug (5) and the open ear condition (6). Diamond depicts the mean value .

Subjective speech intelligibility

Speech intelligibility was scored subjectively after each test condition on a 5-point scale between hard to understand and easy to understand. The different earplug conditions have been scored significantly different (Pearson's chi-squared test on count data, $p<0.001$). Scoring was more in favorable for the condition without hearing protection, whereas the condition with the standard foam earplug 5 was clearly rated less good.

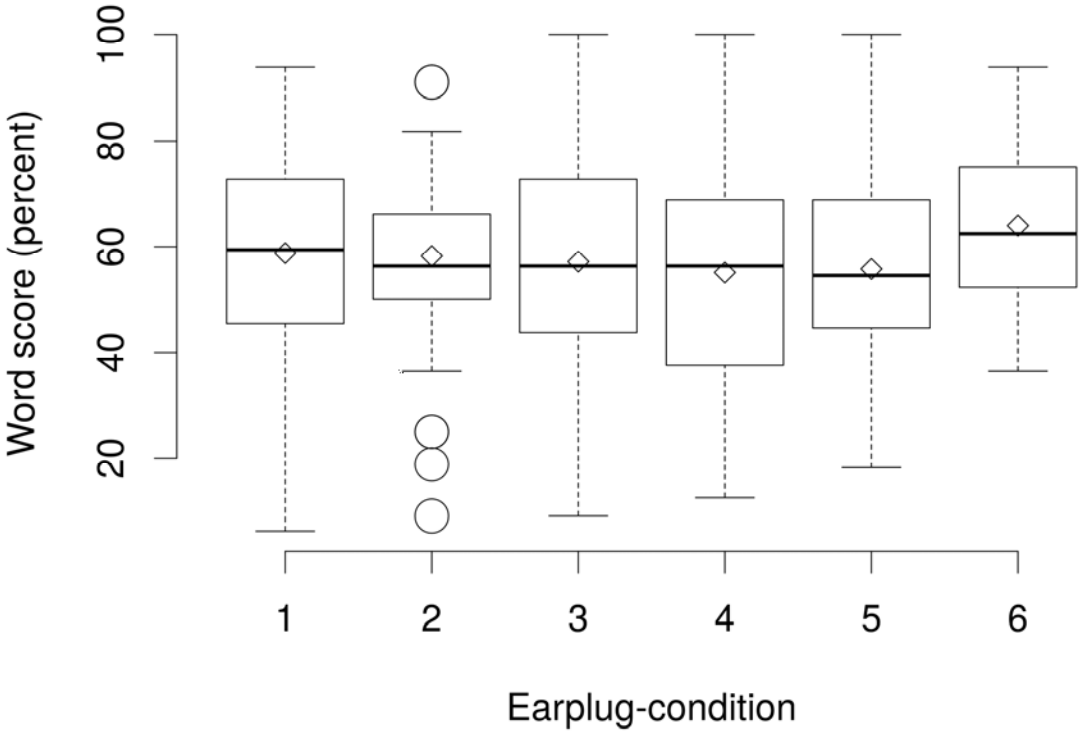

Figure 3: Box plot of word score with audio and visual information only obtained for the four musician earplugs (1 to 4), the standard foam earplug (5) and the open ear condition (6).

DISCUSSION

This study confirms that wearing hearing protection can affect speech intelligibility, but the effect clearly depends on the experimental conditions, in this case whether visual information is present.

The earplug's attenuation is one of the most plausible factors for reduced speech perception. In the test conditions with only audio information, two earplugs that score lower than the open ear condition have indeed the highest attenuation in the frequency range important for speech perception (earplug 2 and 5). Adding visual information appears to alleviate most of the negative effects, as the difference in speech intelligibility with the open ear condition becomes less smaller.

For earplug 1, also a musician earplug, it is somewhat less clear why speech intelligibility is less than for the open ear conditions. The attenuation as reported by the manufacturer is not markedly different from the other musician earplugs. It could be that the attenuation obtained by the individual users is systematically higher (different) than predicted by the manufacturer, but this doesn't explain why the effect is no longer statistically significant once visual information is added. One possible hypothesis that will be explored in follow-up work is that this particular earplug might have altered speech production rather than perception directly.

The other earplugs tested in this study show no significant decline in speech intelligibility score compared to the open ear conditions. Pairwise comparison do not support the hypothesis that they are markedly better than the earplugs who do show a decrease in speech intelligibility, as the difference is not statistically different, but it does suggest that in some particular situations, these protectors might be an alternative worthwhile investigating.

The somewhat larger variation in intelligibility scores makes it harder to detect significant differences. This variation is for sure partly attributable to the way the material has been presented, having a participant reading the material instead of pre-recorded samples or samples presented by the experimenter. However, this approach is closer to reality were the speaker as well as the listener would wear hearing protection. In addition, a “naive” speaker would also not necessarily compensate vocal changes to the fact that he/she is wearing hearing protectors. Hence, the current setup might give a more realistic view on what can actually be gained from improved hearing protection.

As for the subjective rating, it seems that participants had a more clear preference for the open ear conditions and disliked more to communicate with the foam earplug. They do not clearly distinguish between the different musician earplugs, although based on the quantitative speech perception results this could have been expected. A general tendency to dislike the standard foam earplug in every aspect, including sound quality but also for instance comfort, has been found previously [5]. Here, it is assumed that also other factors such as marketing and packaging might be important.

The results from this study by no means advocate for the use of musician earplugs in industry to improve speech perception. The background levels in this study where deliberately kept relatively low to safely include test conditions without hearing protection. In industry where the use of hearing protectors is obligatory, noise levels are much higher and here it is unlikely that the musician earplugs – that are not designed for this kind of exposure – will offer sufficient protection.

This study does emphasize once more the importance of adequate attenuation, adapted to the background noise level, to maintain communication in noise. Previous research has already shown that the performance of the same passive protector in terms of speech intelligibility can greatly vary depending on the background noise level [3].

The results show that even when more advanced communication hearing protectors are not available, other alternatives can be considered to improve communication. It is worthwhile to search for other passive protectors with attenuation levels more adapted to the noise conditions. In addition, the general communication context can be improved, for instance by making sure that visual information can be used as well.

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