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NOISE ANNOYANCE IN OPEN-PLAN OFFICES: A STUDY OF THE INFLUENCE OF MILD HEARING LOSS

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ABSTRACT

Open-plan offices are the most common office layout in tertiary sector. Despite a noise level (50-60 dBA) below the regulations, occupants of these offices complain about noise. Among the various noise sources, co-worker's voices and conversations seem to be the most annoying one, as employee surveys have shown. Moreover, not all employees working in open-plan offices are young people with normal hearing, they can be older (up to 60 yrs.) and have any level of hearing loss. So, the purpose of this study is to investigate the effects of mild hearing loss (onset of presbycusis) on performance in an open-plan office – particularly under the influence of the speech (the Irrelevant Sound Effect). An analysis of the decrease in performance in the accomplishment of a cognitive task regarding the speech intelligibility level was performed with normal-hearing people under two hearing-conditions: with and without a hearing loss simulator. During the task, the subjects were exposed to six sound-conditions: speech- in-noise in five different intelligibility levels (STI from 0.35 to 0.75) and silence. Afterwards, a subjective intelligibility measurement was performed to compare the signals' intelligibility level for each hearing-condition.

Keywords: *Open-plan Office, Hearing Loss, Irrelevant Sound Effect, Room Acoustics.*

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1. INTRODUCTION

Although being substantially below regulatory constraints and typically lower than 60 dBA [1], noise in open-plan offices does appear to be a source of weariness for work officers. In a survey conducted by Bodin Danielsson and Bodin [2], 58% of employees classified noise as the main source of discomfort in this office layout.
Noise-related discomfort can lead to fatigue, occupational illnesses, accidents at work and, above all, decline in productivity due to distractions [3-5].
Actually, distractions by noise are a recurring problem. In a report by Workfront [6], 38% of office workers declared that loud talkers are the most annoying coworkers. Also, in an experimental investigation, Mark, Gudith and Klocke [7] found that after just 20 minutes of distractions, participants reported considerably increased levels of stress, frustration, workload, effort, and pressure.
Veitch et al [8] observed that acoustic satisfaction in offices rises as subjectively assessed speech intelligibility falls. The observation can be explained by the fact that noise impairs the Working Memory (WM) through an interference-by-process phenomenon [9].
This paradigm is supported by Hongisto [5], who proposed, in 2005, his first model founded on the principles of the Irrelevant Sound Effect to describe the decrease in performance (DP) as a function of the level of intelligibility of a speech. Since then, the DP for normal-hearing people became a current subject and intensely addressed by science since the last two decades [10].
There are, however, few studies that explore this issue specifically with a focus on those who have hearing loss.
Nonetheless, presbycusis is one of the most common chronic conditions of aging [11], being estimated that over 65% of persons aged more than 60 yrs. experience some

degree of hearing loss [12]. In addition to this information, it should be considered the population aging phenomenon [13] and the work-life forced extension [13-14].
So, if people are required to work longer, hearing impairments such as presbycusis are facts that must be considered when adapting workstations. Following the latter, the purpose of this study is to determine if the influence of the speech intelligibility on a task involving WM is similar for normal-hearing people and people with mild hearing loss.

2. METHODS AND MATERIALS

The DP was measured by means of a serial recall test. In this type of test, the participant is presented, visually, to different random series of numbers from 1 to 9, without repetitions, that is, nine orders of numbers to memorize. At the end of each series, the participant must type, through a virtual keyboard, the numbers according to the order in which they were presented.
During the test, the subjects wore headphones. Sometimes there was speech, sometimes silence, and participants were advised not to pay attention to what they heared. In this case, the noise was modulated into five levels of intelligibility based on the Speech Transmission Index (STI) scale; 0.35, 0.45, 0.55, 0.65 and 0.75. The choice of intelligibility levels was based on Hongisto's model for DP. These values cover from just after the first inflection point to the beginning of the stability range of his model.
Speech stimuli were created mixing excerpts from an audiobook with LTASS modulated white noise at different values of signal-to-noise ratio (SNR).
The main objective of the test was to compare the DP of people with normal hearing to that of people with hearing loss, but not fitted with hearing aids. However, given the difficulty in finding a large number of people with mild hearing loss due to age (onset of presbycusis) and with a similar hearing loss profile, it was decided at first to use a hearing loss simulator normal hearing people to simulate the possible results from the hearing-impaired group. The idea is also to verify next the reliability of the simulator results comparing them to the results of a hearing-impaired group.
For the experiment, a hearing loss simulator developed by Grimault et al [15] was used. This simulator is based on an inverse, compressive Gammachirp (GC) filterbank that is able to temporarily "handicap" normal hearing participants.
As for the choice of the hearing loss profile to be simulated, it was chosen the standard audiogram N2, Fig 1, from Bisgaard, Vlaming and Dahlquist [16]. This profile is typical for a person with presbycusis, but who does not necessarily need to wear a hearing aid. The profile to be simulated was adapted according to the audiogram of each participant, in order to consistently maintain the same level of simulated hearing loss for all subjects.

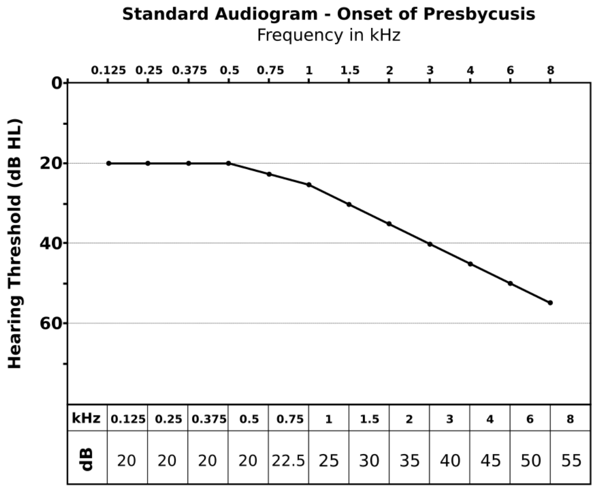

Figure 1. The standard audiogram that represents the onset of presbycusis. 0dB HL represents the hearing threshold for people with normal hearing.

Thus, a group of people with normal hearing was recruited and this group performed the test twice: once with original signals (Leq: 56 dBA) and another with modeled speech to simulate the sound perception of mild hearing loss.
Participants performed the two serial recall sessions on different days and alternately (50% performed the first session with the simulator and 50% with the original signals), but always the two sessions at the same time of day, as a way to maintain the same state of metabolic functions in each session, according to personal circadian rhythm.
Participants performed 20 series per condition (6 conditions; 5 speeches and silence), making a total of 120 series per hearing-condition. There was no repetition of excerpts from the audiobook. Conditions were presented randomly and a condition was never followed by another stimulus of the same condition.
Soon after the analysis of the first DP results with and without simulator, a question was posed about the level of subjective intelligibility of the signals, both the original and the simulated ones. It was possible that a large part of the results of the experiment could be explained by an evident difference in intelligibility between the signals. Therefore,

subjective measures of speech intelligibility were carried out for both original and hearing loss simulated signals.
The speech audiometry was chosen as the intelligibility measuring method for this stage. Participants heard a recording of a list of phonetically balanced sentences in French. Combescure [17] and Fournier [18] lists were chosen for this task. Both of them are standard lists of meaningful French sentences commonly used in speech audiometry. Sentences are spoken at different levels of intelligibility, and participants were asked to repeat those words.
The objective was to verify how clearly the participants could understand and distinguish different words when they heard them spoken at each level of intelligibility. At each repetition, the number of words correctly repeated was noted. The intelligibility levels were defined based on a mixture of the original signals with LTASS modulated white noise at five SNR values, the same ones used in the noise modulation in the serial recall test (-4.5, -1.5, 1.5, 4.5 and 7.5 dB). Also, the sound pressure levels were equivalent to those from the serial recall test, as well as the simulator used to simulate hearing loss.
Participants listened to 15 sentences per condition, making a total of 75 series per hearing-condition. They performed both hearing-conditions at the same session, but conditions were mixed.
Both experiments were performed in a sound-attenuating booth and stimuli were delivered over Sennheiser HD650 headphones to the participants.

2.1 Participants

Thirty-nine (seventeen females) participants were recruited for the serial recall test (M = 21 yrs.; SD = 1; range = 20-23), and twenty-four (eight females) for the speech audiometry (M = 21 yrs.; SD= 1; range = 19-24). All participants were native French speakers and they were recruited among INSA Lyon students.
Their normal hearing sensitivity were assessed by a pure-tone air-conduction audiometry using a Piston PDD-401 Clinical Audiometer, under Eolys Piston XP software, with 3M PELTOR Optime II headphones, following the procedure recommended by ISO 8253-1:2010.

3. RESULTS AND DISCUSSION

After each session, subject's serial recall results were grouped in order to compute the performance in silence (Po) and the performance in each noise condition (Pn) and then the DP per condition, Eqn. 1.

$$DP\ (\%) = 100\ .\ \frac{P_o - P_n}{P_o} \tag{1}$$

The DPs of each hearing-condition are presented in Tab. 1 and Fig 2. The normal hearing-condition is noted by NHP and the hearing loss simulated condition by SIM.

Table 1. Mean values of groups' decrease in performance in the serial recall test.

	DP (%)[1]				
STI	**0.35**	**0.45**	**0.55**	**0.65**	**0.75**
NHP	5.94 (8.09)	6.42 (9.76)	6.93 (8.86)	7.53 (11.78)	11.13 (9.58)
SIM	3.40 (6.72)	4.55 (7.65)	6.36 (9.23)	7.91 (8.78)	5.79 (8.85)

Note: [1]Mean (SD).

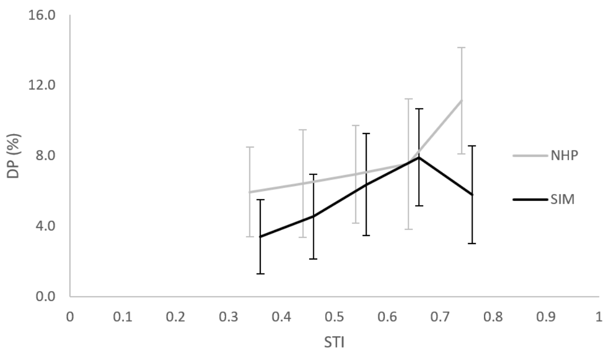

Figure 2. Comparison of DP's groups. Mean values are presented with their corresponding confidence intervals (95%).

The differences in DP between the hearing-conditions are very small, not even exceeding 5% and a repeated measures ANOVA confirm they are not statistically significant [$F_{(1, 38)}$ = 2.435, p = 0.127]. But, STI effect is significant [$F_{(4, 152)}$ = 5.166, p < 0.001]. And no interaction between hearing-conditions and STI values was found [$F_{(4, 152)}$ = 2.228, p = 0.068].
Nonetheless, a pairwise T.test (Bonferroni's correction) shows there is only a significant difference between DPs of STI 0.75-0.35 and 0.75-0.45 (p<0.05) for the normal-hearing-condition.
Also, a pairwise T-test was computed to assess whether the difference in performance between the silent condition and the other noise conditions is significant. Regardless of the hearing-condition and the STI value, all performances in

noise are significant different from the performance in silence (all $p < 0.05$).
In one way or another, the DPs from the SIM condition are globally lower than the DPs from NHP condition. This difference might be explained by a difference of intelligibility between the original and the simulated signals.
Results of the subjective intelligibility measurement are shown in Tab 2 and Fig 3. A sentence was considered intelligible when the subject was able to repeat it completely correctly.

Table 2. Mean values of speech intelligibility for sentences per SNR.

Intelligibility (%)[1]					
STI	**0.35**	**0.45**	**0.55**	**0.65**	**0.75**
NHP	63.33 (20.99)	86.67 (14.45)	93.61 (10.12)	97.50 (4.31)	97.78 (4.68)
SIM	6.10 (7.33)	31.67 (15.26)	53.61 (15.41)	62.50 (14.01)	68.33 (16.36)

Note: [1]Mean (SD).

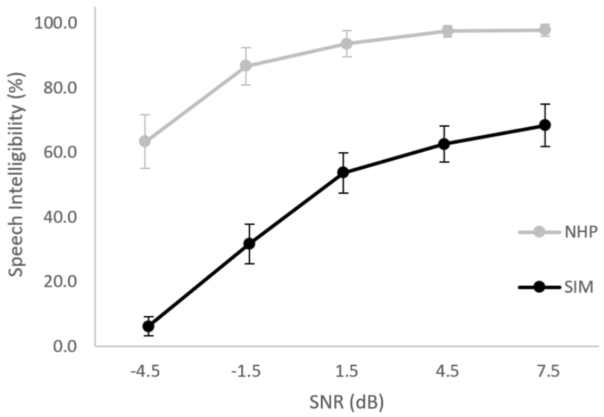

Figure 3. Comparison of DP's groups. Mean values are presented with their corresponding confidence intervals (95%).

A repeated measures ANOVA confirm the signals are significantly different [$F_{(1, 23)} = 749.238$, $p < 0.001$], as well as differences between SNR values [$F_{(4, 92)} = 206.231$, $p < 0.001$], and an interaction between the type of signal and values of SNR [$F_{(4, 92)} = 2.435$, $p < 0.001$].
However, a pairwise T.test (Bonferroni's correction) shows the subjective intelligibility level of the original signals at 1.5, 4.5 and 7.5 dB of SNR are statistically equivalent ($p > 0.05$). It also shows the subjective intelligibility level of the simulated signal at 7.5 dB of SNR is statistically equivalent to the one of the original signals at -4.5 dB of SNR ($p < 0.05$).

4. CONCLUSION

Performances of both of hearing-conditions were impaired by speech. General results show a less important decrease in performance in the condition with simulator, but the difference is not statistically significant. The substantial difference of intelligibility between signals might explain the difference of decrease in performance.
Globally, the performances of both hearing-conditions were impaired by noise.

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