A case study on Irrelevant Speech Effect assessment at open plan offices using Equivalent Modulation

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Summary

The emergence of recent standards for open plan offices has led to the development of new metrics to measure noise annoyance and decrease in performance at workplaces. The main existent models deal with the ambient noise as a single number (L_{Aeq}) and as a stationary signal. However, they are not completely effective, once the speech levels in an office fluctuates during the day. Chevret et al. (2017) has recently developed a method to assess the Irrelevant Speech Effect (ISE), which is called Equivalent Modulation (M_{eq}), that is based on the depth of modulation of the signal. In this paper, in situ measurements were conducted together with a questionnaire and performance test experiment aiming to correlate the effectiveness of M_{eq} in representing the Irrelevant Speech Effect.

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1. Introduction

The Open Plan office concept has succeeded in the main objective of its existence: improvement of communication between colleagues and work teams, and therefore facilitating the project work. Moreover, space saving contributes to the cost reduction of a company, since the partitionless office layout enables a higher density of employees at the same area. This large concentration of workers leads to many dissatisfactions over the workplace, including lack of privacy, and noise disturbance mainly due to intelligible speech coming from other workstations, which deteriorates the worker performance [1].
Continuous noises such as those generated by air conditioning systems are generally considered less annoying, once we can get used more easily to them [2]. Studies have shown that one of the most disturbing noise sources at work environment is the conversation speech on the phone or between colleagues. Hence, the Speech Transmission Index (STI) is highly connected to the annoyance and work performance. According to studies [1] a high intelligibility may cause a decrease in productivity of almost 10%, while STI values below 0.5 sharply lower this effect until there is no more performance reduction at very low STI values. The STI calculation relies on the background noise, hence a single number quantity of equivalent sound pressure level (L_{Aeq}) is commonly used in the model, assuming a stationary noise level. Unfortunately, in many open plan offices the background noise is not constant, the large amount of collective work and phone calls in the same environment lead to many transient noises and fluctuations on the sound pressure level. The number of voices in the room also impacts on the employee performance and concentration. One or two voices usually affects more dramatically in the tasks, while the raise of voices number commonly helps in concentration if compared to a lower number [3].
Some approaches have been made in order to characterize the workplace acoustic quality using indices based on modulation of ambient noise, which takes into account the sound pressure level of the conversations in the environment. Schlittmeier [4] has shown that the ISE can be described by the Psychoacoustic descriptor known as Fluctuation Strength (F_s), once developed by Zwicker [5]. The results for this parameter depend directly on the

intensity of the presented noise, hence higher noise levels tend to result in greater Fluctuation Strength (F_s).

Recently Kostallari et al. [6] have developed a new and simpler method to assess the ISE, which is called Equivalent Modulation (M_{eq}). This indicator can be determined by calculating the depth of modulation from a signal by subtracting L_{Aeq} from the L_{A90} index. The STI and M_{eq} are proportional descriptors and they tend to increase with each other as shown in Figure 1.

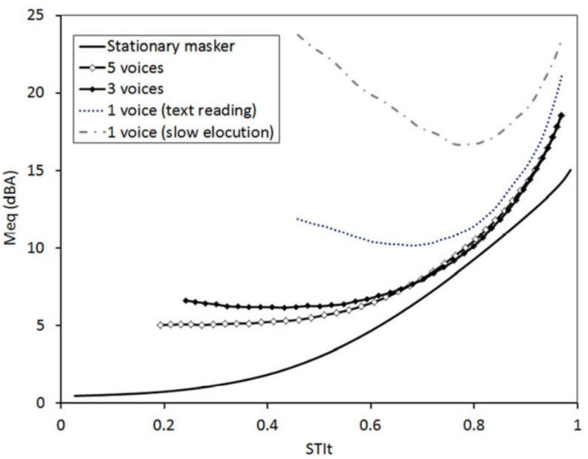

Figure 1. Relationship between M_{eq} and STI suggested by Kostallari et al. [6]

2. Objective

This paper investigates the validity of the Equivalent Modulation (M_{eq}) to assess the Irrelevant Speech Effect in open plan offices. It is presented a pilot case study held in two distinct open plan offices in Brazil, where the noise levels during activity were measured and correlated with questionnaires. In addition, a laboratory study was carried out to support the research.

3. Methodology

This study is divided in three parts: a general objective characterization of the acoustic quality from the two offices under study, acoustic monitoring of ambient noise during activity and a laboratory test.

The offices under study will be named Office 1 and Office 2, and their layout are shown in figures 2 and 3, respectively. The first office is composed by 16 workstations in a 42 m² area, meanwhile the second one is formed by 11 workstations in a 36 m² area.

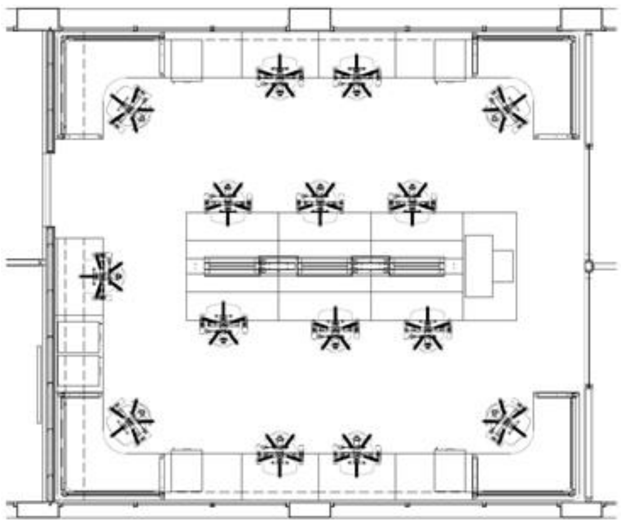

Figure 2. Layout of the Office 1

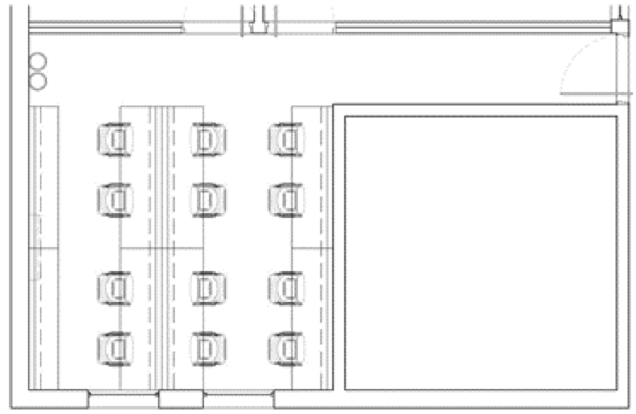

Figure 3. Layout of the Office 2

3.1. Measurements of the workplace

Firstly, measurements of room acoustics were conducted in the offices, so the general acoustic quality of the ambient is properly characterized and allows to be considered in the results discussion.

The approach considered the main existing descriptors used to evaluate the acoustic quality of this type of environment: reverberation time (T_{30}), spatial decay rate of speech ($D_{2,S}$), distraction distance (r_D) and A-weighted sound pressure level of speech at a distance of 4 m ($L_{p,A,S,4m}$) as described in ABNT NBR ISO 3382-3 [7] and NF S 31-199 [8]. A questionnaire was applied to the users to correlate the objective measurements with their responses. This study is further discussed in the paper “Development and application of questionnaires to assess acoustic environment in open plan offices” presented on this same conference.

3.2. Ambient noise during activity

The second part consists on the measurement of the ambient noise of the occupied site in order to obtain the L_{Aeq} and L_{A90} during activity. This procedure was carried out a few times, each at a different day, and a questionnaire was applied afterwards on a pilot study to correlate users' perception of the day with the M_{eq} objective measurement.

3.3. Laboratory test

The third part resides in a serial recall cognitive test carried out in laboratory as performed by Hongisto [9]. It is a classic task which the user had to recall a sequence of numbers presented on the screen. The digits from 1 to 9 are randomly shown at the rate of 1 per second, with an inter-digit interval of 1 second. After the sequence presentation the subject is asked to recall the digits on a 3 x 3 array on the screen. There was also the option of clicking "I don't remember" if a certain number in the position could not be recalled. The test interface is shown in Figure 4.

Figure 4. Interface used in the laboratory test (in portuguese).

In this test, three signals with different M_{eq} were played at the background in random order, each one was presented with 5 sequences, in a total of 15 sequences, and an extra one at the beginning which was discarded. The test signals were presented by headphones and their levels were adjusted to the same equivalent sound pressure level. The signals are primarily comprised of 2 main target voices, which content are daily phone conversations, and some murmuring voices are added at the background to form a characteristic cooperative tasks office. Different depth modulations were achieved by adjusting the signal levels of the test, which resulted in three signals with distinct M_{eq} values: 6 dB, 9 dB and 12 dB. The choice of the integration time has significant effect on the results, since the L_{A90} relies on it. There is not much discussion in the literature about this effect on the results yet. A "fast" (125 ms) mode of integration time was adopted in this study.

4. Results and discussion

The results of the 3 parts are presented in this section.

4.1. General open plan offices parameters

The open plan offices descriptors will be assessed in this section with the aid of the informative values from the Annex A of the ABNT NBR ISO 3382 [7], and according to the NF S 31-199 [8] requirements. The reverberation time measured in both offices, found in Table I, are suitable for the environment purpose. The results meet the NF S 31-199 recommendations, except for the 125 Hz reverberation time in Office 2, which exceeds the required one in 0,8 seconds.

Table I. Reverberation Time in both offices.

T_{30} (s)		
	Office 1	Office 2
125 Hz	0.42	1.06
250 Hz	0.40	0.86
500 Hz	0.34	0.59
1 kHz	0.29	0.56
2 kHz	0.34	0.54
4 kHz	0.33	0.53
8 kHz	0.25	0.44

The spatial decay rate of speech ($D_{2,S}$), distraction distance (r_D) and A-weighted sound pressure level at 4 m ($L_{p,A,S,4m}$) are indicated in Table II.

Table II. $D_{2,S}$, r_D and $L_{p,A,S,4m}$ of both offices.

Descriptor	Office 1	Office 2
$D_{2,S}$ (dB)	2,5	2,9
r_D (m)	>10	>10
$L_{p,A,S,4m}$ (dB)	54,5	54

The $D_{2,S}$ is considered insufficient in both standards, as well as the 3382-3 indicates a poor performance for r_D and $L_{p,A,S,4m}$.
In general, despite the satisfactory reverberation times, the offices have presented low performance regarding the sound attenuation between workstations, which is aggravated by their proximity and the absence of screens between them. The offices are composed by mixed teams, involving collaborative and concentration work at the same time. Due to this fact, employees are constantly exposed to irrelevant speech that may harm their performance.

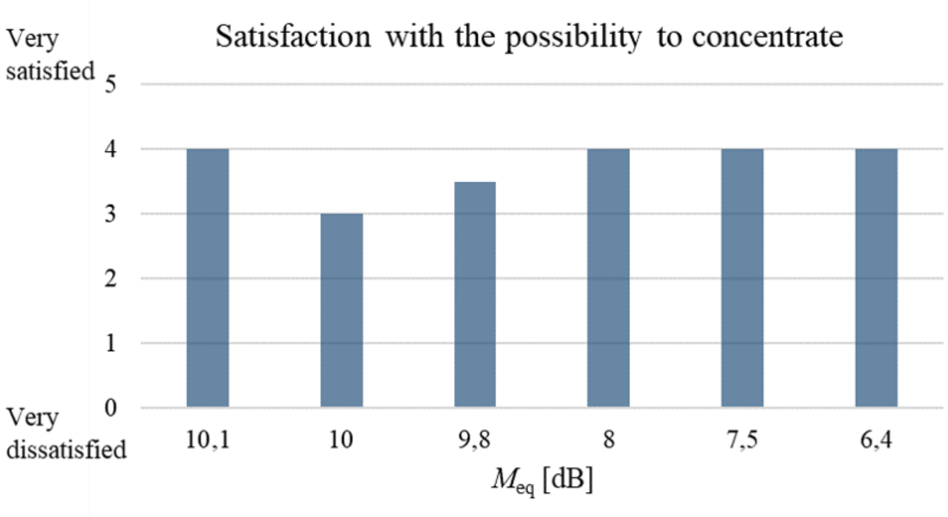

Figure 5. Comparison of the satisfaction with the possibility to concentrate with the M_{eq} from each day.

4.2. Study case of ambient noise during activity

The ambient noise during activity was carried out in both offices during three shifts at different days, and the users' perceptions of the ambient noise were acquired with the aid of a 5-point rating scale questionnaire which comprises four questions:

- How satisfied are you with the possibility of concentration in your workplace during the shift?
- How would you define the noise in your office during the shift?
- How satisfied are you with the office noise during the shift?
- How annoyed were you regarding the noise during the shift?

The M_{eq} measurement in the offices are presented in Table III. The Office 1 has a quite similar objective results in all days, while a larger variation in the results can be observed on Office 2, all of them lower than the earlies.

Table III. M_{eq} measured in both offices.

M_{eq} (dB)		
	Office 1	Office 2
Day 1	10	7,5
Day 2	9,8	8
Day 3	10,1	6,4

Figure 5 assembles all data from three days of the offices, regarding the answers to the question about satisfaction with the possibility to concentrate. The bars represent the median of the users' responses from each day versus the measured M_{eq} of the corresponding day. It is visible that days with lower values of modulation depth comprise 3 out of 4 from the most satisfying days.

However, only the comparisons between the day 1 from Office 1 with day 2 from Office 2 ($t(11) = 1,795$, $p < 0,05$)) and day 2 from Office 1 with day 2 from Office 2 ($t(13) = 1,770$, $p < 0,05$)) showed significant difference in the t-test result.
In the users' opinions the noisiest days in the offices comprise 3 out of 4 of the lowest M_{eq} measurements days, which results can be verified in Figure 6.

However only the comparison between day 3 from office 1 and day 2 from office 2 showed significant statistical difference between the samples ($t(5) = 2{,}015$, $p < 0{,}05$).
The satisfaction with the noise in the office also follows the ratio of 3 out of 4 of the smallest equivalent modulation values as seen in Figure 7. The exception is that, in this case, no comparisons between days resulted in significant statistical difference according to t-tests performed.

The noise annoyance analysis is slightly more difficult to relate to a conclusion, since the results seem more uniform, except for the lowest M_{eq} value, which led to a less annoying ambient noise compared to the rest as seen in Figure 8.

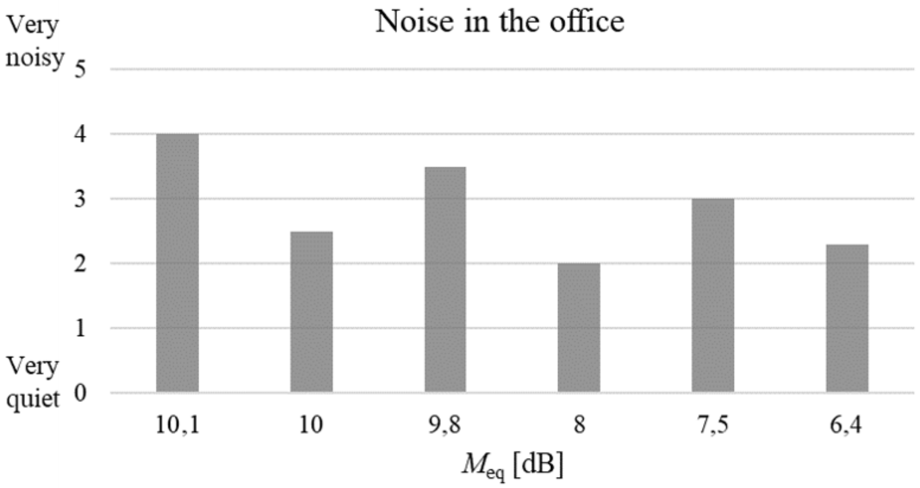

Figure 6. Comparison of the perceived noise in the office with the M_{eq} from each day.

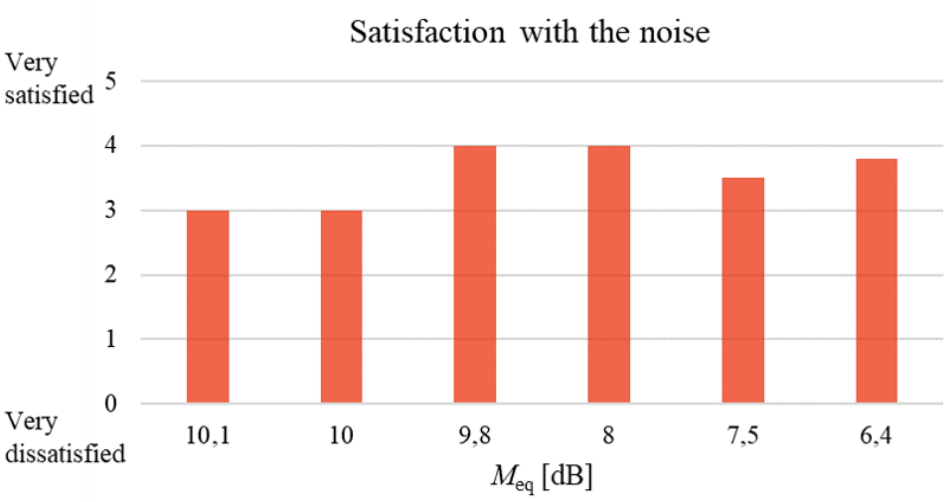

Figure 7. Comparison of satisfaction with the noise in the office with the M_{eq} from each day.

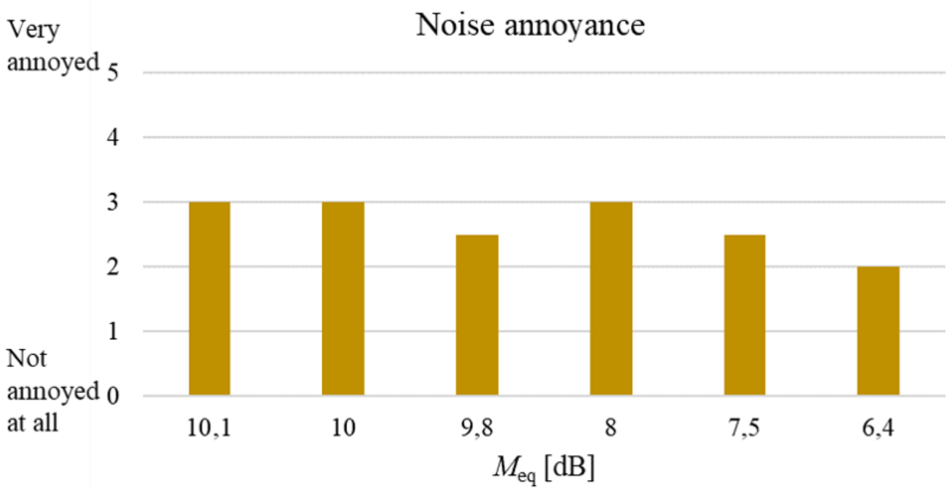

Figure 8. Comparison of the noise annoyance with the M_{eq} from each day.

4.3. Laboratory memory recall test

A dataset of 34 subjects was inquired in the laboratory test. The total of correctly recalled numbers of all dataset subjects separate by signal can be seen in Table IV.

The rate of success is quite similar for each signal, a bar plot represents the percentage of correct numbers recalled (Figure 9). A further investigation is made by comparison of means; however, the t-test shows no significant difference between the signals success rate. The result is $t(33) = (1{,}692, p > 0{,}05)$ between the 6 and 9 dB M_{eq} signals, which are the two groups that differ the most.

Table IV. Total number of successful recalled numbers

M_{eq} [dB]	Total number of success
6	926
9	899
12	923

Therefore, despite the greater number of successes in the 6 dB signal compared to the others, the difference is not significant enough to conclude there is a relation between low M_{eq} and percentage of success.

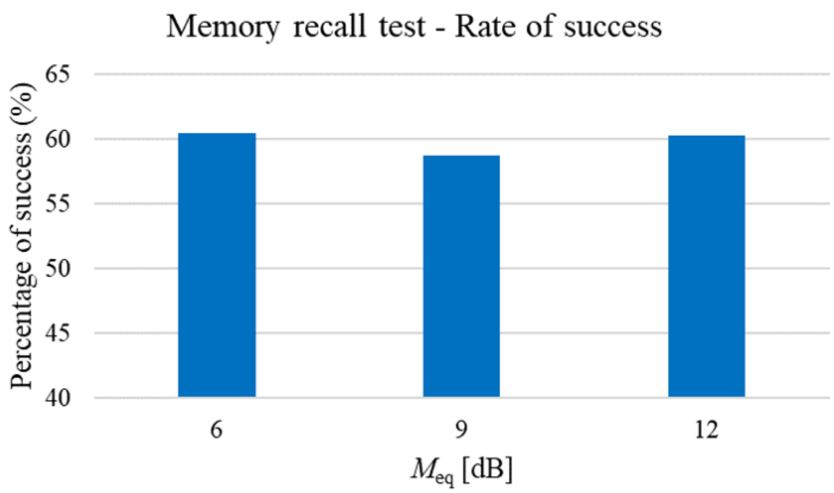

Figure 9. Comparison of the satisfaction with the noise in the office with the M_{eq} from each day

5. Conclusions

It is possible to observe a tendency in the subjects' responses in sensing the Irrelevant Speech Effect while working in days of higher equivalent modulation. The previous condition was not satisfied in every test, nevertheless in most cases 3 out of 4 days with highest M_{eq} subjects were more affected by the ISE. For the noise annoyance topic, it was no observed a minimum behavior pattern in this study, although only in few cases a statistically relevant difference between groups was accomplished.

It is paramount to consider the effect of the offices poor acoustic quality on the subjects' responses, and the possibility of its influence on the perception, as well as possible cultural effects. The reduced number of samples and days of measurements also contributes to the absence of a possible pattern of answers.

For future research, more offices should be assembled to the study in order to obtain a major range of equivalent modulation. An improvement in the laboratory test is suggested for the future embracing signals of different number of voices and masking sounds, since the test has not shown a significant performance difference between groups for this type of test and signals. It is convenient to work on different cognitive tests as well as to further inquire cultural aspects on how open plan offices co-workers are affected by noise.

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