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Room acoustic design of voice booths in open plan offices

Araújo, Rânnely¹

Harmonia Acústica

Avenida Mofarrej, 1200 - São Paulo, Brazil

Holtz, Marcos²

Harmonia Acústica

Avenida Mofarrej, 1200 - São Paulo, Brazil

Borin, Marcel³

Harmonia Acústica

Avenida Mofarrej, 1200 - São Paulo, Brazil

Monteiro, Carolina⁴

Harmonia Acústica

Avenida Mofarrej, 1200 - São Paulo, Brazil

ABSTRACT

Considering high noise levels in open plan offices and workers' lack of concentration, small enclosed rooms – so called voice booths - are being widely used in order to provide privacy and to be used as an online and offline meeting spot for one or two people. This type of usage demands a high-quality acoustic field and due to its reduced volumes, this characteristic is still unknown.

A previous study has shown the usage increase of voice booths in Brazil and presented modal distribution analysis, coloration frequencies analysis, results of measurements in situ and subjective tests performed in 24 existing voice booths. Even though it was possible to conclude that reverberation time combined to modal analysis could be the most effective parameter to evaluate the acoustic of voice booths, the main goal of the study was still not achieved.

So, the first purpose of this study is to validate the measurement method presented previously. And its second goal is to expand the studies in this field in order to determine parameters or guidelines for the acoustic design of voice booths.

Keywords: Voice Booths, Open Plan, Privacy, Acoustic Treatment, Human Voice

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¹ ranny.araujo@harmoniaacustica.com.br

² marcos@harmoniaacustica.com.br

³ marcel.borin@harmoniaacustica.com.br

⁴ carolina.monteiro@harmoniaacustica.com.br

1. INTRODUCTION

Even though open plan offices are starting to show themselves as unproductive and noisy spaces for workers, companies throughout the world are still amply using this type of configuration. Aiming the increase of worker density, collaboration between coworkers and layout flexibility, employers do not acknowledge the fact that the lack of privacy and concentration caused by the high levels of noise decrease the productivity and, consequently, the profit [1]–[4].

In Brazil, it's becoming common to design enclosed spaces to grant employees privacy and concentration moments. These spaces are usually rooms so small that fit only one person and sometimes two. Because of that, they are being called voice booths.

The usage increase of voice booths in Brazil is noticeable through Harmonia Acústica's acoustic consultancy work, which showed that between 200 office building designs in the past 4 years, approximately 70% of them counted with voice booths.

These booths are being widely used as spaces for people who need quieter areas to work whether it's for personal higher concentration, for the usage for small meetings of two people (private conversation) or for video/phone calls.

As the name 'booth' suggests, these rooms are genuinely small. The ones used in Brazil usually have less than 15 cubic meters. The small dimensions are frequently equivalent to audible low frequencies wavelengths and many times they are the cause for sound effects that are not favorable for the types of usage that involve the human voice as phone/video calls or even regular meetings between two people. In these cases, the intelligibility and quality of the human voice needs to be high, but most of times, in order to achieve that it's necessary to design the acoustic field inside the booths.

Since most of the studies made in the small rooms' acoustics field considered only small studios that have volumes between 30 and 120 cubic meters [5] it's necessary to study what actually happens in booths that have volumes that have a much smaller volume.

2. OBJECTIVE

This study aims to achieve favorable parameters for the acoustic design of voice booths through comparison analysis between objective measurements and subjective tests.

3. STUDY CASE

Measurements were performed in a 4.80 cubic meters voice booth (1.43 m x 0.98 m x 3.48 m) located in São Paulo, Brazil. In figures 1 and 2 are presented a floor plan and a picture of the voice booth analyzed, respectively.

The studied room's construction system is composed of masonry in the back wall, composite wall for the other walls, wood door and concrete slabs (floor and ceiling). There were no absorbent acoustic linings in the voice booth.

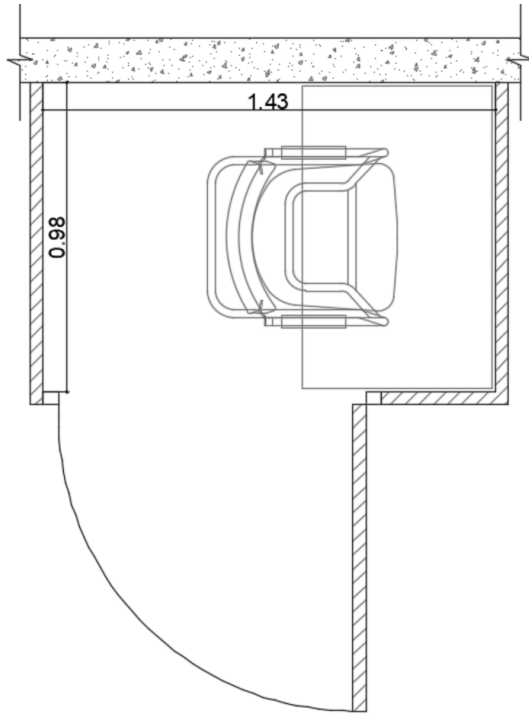


Fig. 1 – Voice booth's floor plan
Dimensions indicated in meters



Fig. 2 - Photo of the voice booth

4. METHODOLOGY

The methodology used in this investigation was divided into 2 parts: field measurements of 10 different scenarios of the voice booth that contained different setups of absorbent acoustic linings, and for the second part subjective tests of 4 of these scenarios. Table 1 presents the setups analyzed in this study:

Table 1 – Voice booth's investigated setups

SETUP	MATERIALS		
	FLOOR	SUSPENDED CEILING	WALLS
A	concrete	gypsum board	composite wall
B	carpet	gypsum board	composite wall
C	concrete	acoustic fiberglass	composite wall
D	carpet	acoustic fiberglass	composite wall
E	carpet	acoustic fiberglass	acoustic lining on 1 wall
F	carpet	acoustic fiberglass	acoustic lining on 2 walls
G	carpet	acoustic fiberglass	acoustic lining on 3 walls
H	carpet	gypsum board	acoustic lining on 1 wall
I	carpet	gypsum board	acoustic lining on 2 walls
J	carpet	gypsum board	acoustic lining on 3 walls

The acoustic suspended ceiling used in this study was made of fiberglass with better performance on medium and high frequencies and it was used with 100% of the ceiling area coverage, its equivalent area of absorption by unit (m^2 Sabin) is presented on Figure 3.

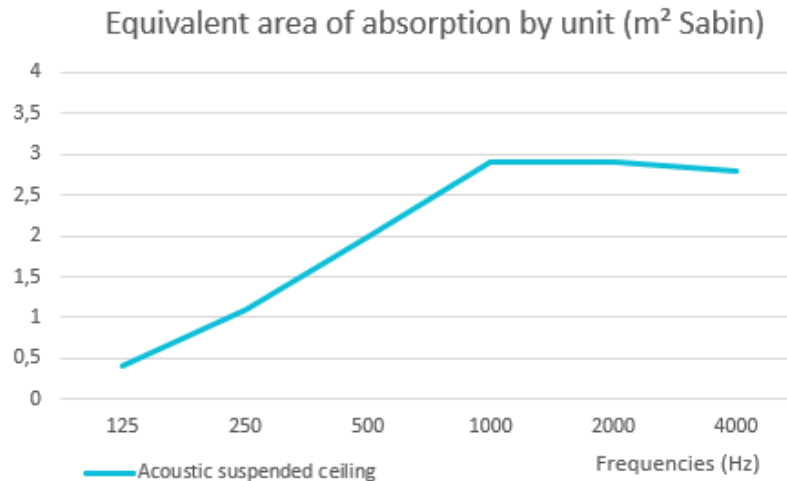


Fig. 3 – Acoustic suspend ceiling absorption graph

On the walls, acoustic panels with NRC=0,70 that are commonly used in office spaces in Brazil were utilized in modules of 0,96 m² on 1, 2 or 3 walls.

As for the carpet that was used on 8 of the setups, was also a regular carpet that is used on most of Brazilian office building. However, its acoustic properties are not high as the ceiling and wall linings, carpet's sound absorption coefficient is around $\alpha_w=0.10$.

4.1 Field Measurements / Procedures

- Reverberation Time (RT)

In order to evaluate the energy decay of the booth, the reverberation time (RT) was measured *in-situ* for each one of the setups presented in Table 1. These measurements followed the procedure from the standard ISO 3382-2:2012 [6].

- 1/3 Octave Band Frequency Response of the room

The 1/3 octave band frequency response of the room was also measured for all the previously presented setups using the sound power level of the pink noise from 50Hz to 20kHz characterized according to ISO 3745:2012 [7] and emitted from an omnidirectional sound source positioned in one of the room corners. The measurement followed the methodology for voice booths presented by Monteiro and Borin [8].

- Recordings

In order to develop the subjective test, inputs of the different voice booth setups were necessary. Therefore, a head simulator was used as the receiver to obtain binaural signal files. And instead of an omnidirectional source, a speaker with certain directivity was used as a sound source for the recordings of each setup in order to simulate a sound and videoconference system in the room.

The audio files used in this procedure were obtained from an anechoic recording of a human voice reproducing a real conversation.



Fig. 4 – Head simulator inside the voice booth

4.2 Subjective Tests

For the purpose of obtaining results which are more correlated to the human perception of the acoustic field inside the voice booth, 38 subjects were tested on a listening test to verify their opinion of the different scenarios created with the booth.

The listening test was built with the recordings acquired with the head simulator for each one of the setups, but they were presented to the subjects in a pairwise comparison test between setups A, D, E and G. These scenarios were considered the ones that had considerable differences between each other to be noticeable by the subjects.

Subsequently, subjects were separated into 2 groups that were asked to listen to the stimuli in different orders with headphones and, for each pair of audios, answer which one was the most pleasant voice for a booth. The pairs of audios presented to each group is presented in Table 2.

Table 2 – Listing of the setups order and combinations presented to both groups of subjects for the subjective test

PRESENTED ORDER	SETUPS COMBINATION	
	GROUP 1	GROUP 2
1 st	Setup A vs Setup D	Setup G vs Setup E
2 nd	Setup D vs Setup A	Setup E vs Setup G
3 rd	Setup A vs Setup E	Setup G vs Setup D
4 th	Setup E vs Setup A	Setup D vs Setup G
5 th	Setup A vs Setup G	Setup E vs Setup D
6 th	Setup G vs Setup A	Setup D vs Setup E

7 th	Setup D vs Setup E	Setup G vs Setup A
8 th	Setup E vs Setup D	Setup A vs Setup G
9 th	Setup D vs Setup G	Setup E vs Setup A
10 th	Setup G vs Setup D	Setup A vs Setup E
11 th	Setup E vs Setup G	Setup D vs Setup A
12 th	Setup G vs Setup E	Setup A vs Setup D

5. RESULTS AND DISCUSSION

All the measurements performed in the booth have a wide frequency range – between 50 Hz and 5 kHz. However, since the main usage of the voice booths are meetings (in person or by call / videoconference), it is important to limit the studied frequency range to the characteristic voice spectrum. According to ANSI S 3.5-1997 (R 2017) [9] there is a representative range for both male and female speech voice spectrum – between 100 Hz and 2 kHz. Therefore, all results shown hereafter will be analyzed in the range presented by this American standard.

5.1 Subjective Tests

The results of the subjective tests are shown in Table 3 and it is possible to notice a close win of setup E against setup G (39 votes for E against 37 for G). But if the other pairs are also taken into account into the favorite setup analysis, setup E wins in all comparisons that it was presented to the subjects (E vs G / E vs D / E vs A), against two wins of setup G (G vs D / G vs A) and only one win of setup D (D vs A).

Table 3 – Listing of the subjective tests results

VOTES PER SETUP PAIRWISE COMPARISON				
Setup	A	D	E	G
A	-	71	71	67
D	5	-	49	40
E	5	27	-	37
G	9	36	39	-

The winner setup (E) had carpet as the floor covering, acoustic fiberglass suspended ceiling and only one of its walls with acoustic lining as oppose to 3 walls covered with acoustic lining on the setup G, which was the second most voted scenario.

Since this win was so close between setups E and G, a statistical significance test would be an analysis method necessary in this study in order to conclude if setup E had an actual significant win.

5.2 Reverberation Time (RT)

Figure 5 presents the results obtained by the field measurements of the voice booth setups (A – J) and the four setups used for the subjective test are highlighted in red (A, D, E and G). These results show that the RT is considerably irregular below 100Hz. On the other hand, the reverberation time on the frequency range of the human voice spectrum (100Hz – 2kHz) is controlled, and its behavior correlates to the quantity of absorbent materials for each setup.

Another aspect that it is noticeable is that the reverberation time of both of the most voted setups in the subjective test (E and G) is below 0.5 seconds for all frequency bands, so correspondingly to Monteiro and Borin's conclusion [8], it is possible to adopt $RT \leq 0.5$ seconds as a criteria for the acoustic design of voice booths.

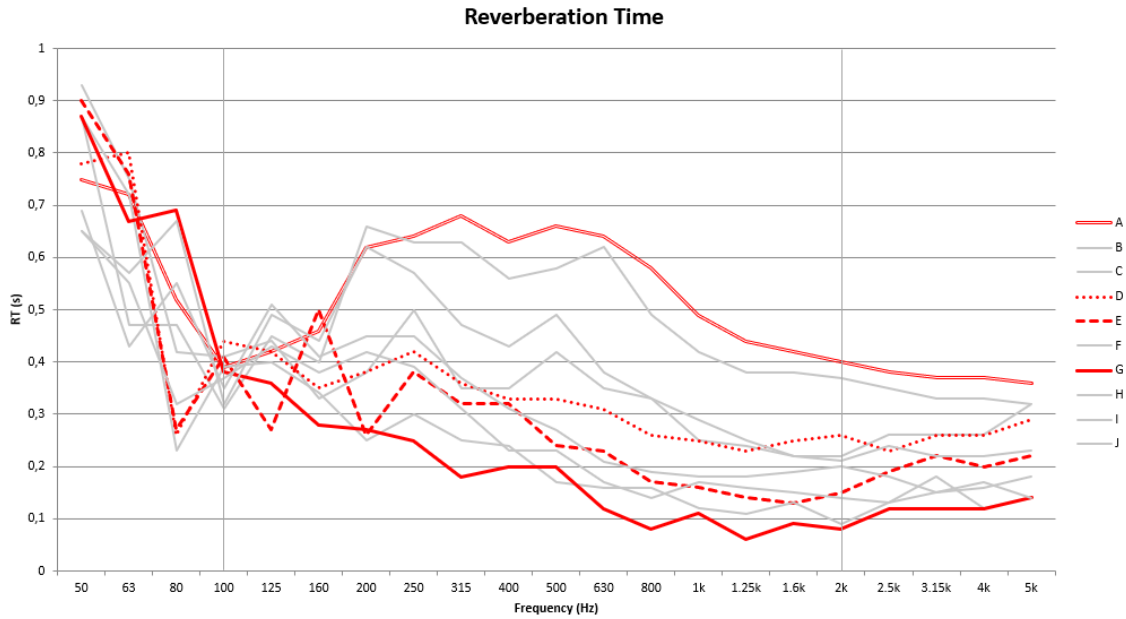


Figure 5 – Reverberation time measured in each one of the voice booth’ setups

5.3 Room Frequency Response

The results obtained with the room frequency response measurements are presented on Figure 6. The graph with the results shows that below the Schroeder Frequency of the studied voice booth (405 Hz – frequency calculated based on the RT of the setup A), the proportions and geometry of the room or the construction characteristics of the involucre material are two of the aspects that are probably interfering on the frequencies behavior. On the other hand, for the frequencies above 405 Hz the absorbent materials start to act, and a more controlled and stable scenario is shown.

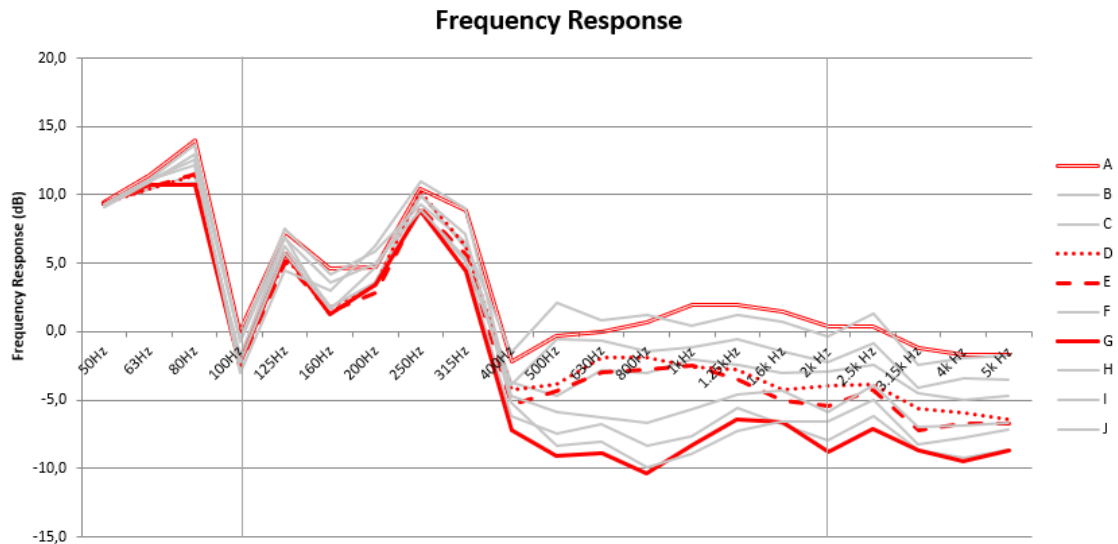


Figure 6 – 1/3rd octave band frequency response of the measured voice booth’s setups

5.4 Modal analysis and Coloration

Besides the analysis presented previously on this paper, the modal analysis of the voice booth and its frequencies of coloration were compared to the results of the field measurements and no correlation was found. Previous studies on this field [10] also did not find a connection between the investigated results and these two parameters.

6. CONCLUSIONS

Considering that two of the most voted setups (E and G) had reverberation time (RT) values below 0.5 seconds for all frequency bands, when the room frequency response for each setup is compared, it is possible to presume that E had more votes because for medium and high frequencies, its acoustic field was less distorted (-5dB) than the setup G (-10 dB). That result indicates that there might be a limit on the quantity of acoustic materials with high absorption on medium and high frequencies to maintain the acoustic comfort inside a voice booth.

So, up to this moment, it is possible to conclude that the descriptive solutions for the acoustic treatment of a voice booth is to use as finishing materials: carpet on the floor, acoustic suspended ceiling and, at least, acoustic lining in one of the walls. Perhaps having more absorbent materials on more walls are also effective but it is not increasing the comfort and effectiveness of the acoustic treatment in a significant level.

7. FURTHER WORK

As further work, it will be necessary to analyze the statistical significance of the subjective tests results in order to deeply understand the difference between the studied setups.

As on this study, it was possible to conclude the acoustic field preference of the voice booth users considering medium and high frequencies, the next step of this investigation needs to study if and how the wall acoustic lining position interferes on the user's experience and, consequently, on the results obtained with this study.

Another aspect that still needs to be considered is the usage of materials with absorption properties focused on the acoustic treatment of low frequencies.

8. ACKNOWLEDGEMENTS

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