ANALYSIS OF THE ACOUSTIC BEHAVIOR OF PEOPLE IN A RESTAURANT
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Abstract
This article presents a study of the acoustic soundscape in a populated restaurant with good acoustic comfort. Besides the investigation of the correlation between the number of people present and the sound pressure level they produce, we compare sound spectra between quiet and noisy periods. Also temporal modulations of the overall sound pressure level are analysed.

Keywords: behaviour, people, restaurant, pressure, modulations.

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1 Introduction

It is well known that in noisy environments, the vocal effort of people tends to increase with increasing noise level. Different studies were performed in relation to this topic. Lazarus created a system of assessment of verbal communication based on signal to noise ratio (*SNR*) and defined levels of vocal effort [5] [6], which belong to important aspects to this respect. Nijs et al. studied the effect of room absorption on human vocal output in multitalker situations [7].

It has also been observed that people tend to interrupt their conversation for a while, once a certain noise level is exceeded, or after a strong impulsive sound has occurred. Several researchers have focused on the study of similar effects in eating establishments.

Besides the fluctuation of noise levels in talking crowds of people caused by these acoustic effects (exceeded noise level and impulsive sound), also spontaneous fluctuations of noise levels in crowds with a constant number of people have been studied or suggested to be studied [8] [10].

This article focuses on the analysis of noise levels in a restaurant in Bratislava (Club SvF Shupitoo) from different points of view. The main aim is to understand the influence of the Lombard effect in a room with good acoustic conditions, and to verify the possible dependence of fluctuations of noise level and spectral content on the steady state sound pressure level. The latter is done by comparing “quiet periods” with “noisy periods”.

2 Description of restaurant space Club SvF Shupitoo

The operating hours of Club SvF Shupitoo are from 8:00 a.m. to 5:00 p.m. Both breakfast and lunch are served. In the evenings there is no activity unless a reservation is made for larger group.

The dining room has a shoebox shape, with a basic volume of 525 m^3 and a floor area of 150 m^2. The height of the room is 3,5 m. The overall area of interior surfaces is 486 m^2. The floor is constructed out of red marble tiles on concrete slabs. The walls are covered by gypsum plasterboards.

Part of the walls is used as a blackboard for menus or other writings with chalk. The ceiling consists of suspended perforated metal plates with perforation of approximately 4 × 4 mm. Fibreboard are placed on metal plates. Complex construction is hanged 2 m below reinforced concrete slab.

One wall contains windows along its full length, from 0.9 m above the floor till the ceiling. The total surface area of windows is 40,5 m^2. The restaurant has a capacity of 18 tables, with about 80 seating places. Figure 1 - up shows a photo of the interior. Figure 1 - down shows reverberation time values for 6 octave bands between 125 – 4000 Hz. Results of reverberation time (T_{30}, T_{20}) achieve acceptable values in frequency range of human speech for satisfactory verbal communication [2].

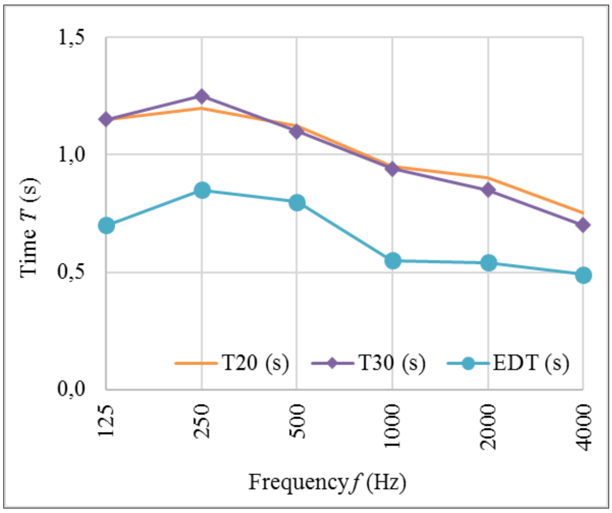

Figure 1 – Interior of the restaurant (up), values of reverberation time (down).

3 Experimental details

Several acoustic measurements were performed. The first experiment consisted of noise level monitoring with two Omni-directional Behringer ECM 8000 microphones, which were connected to an external sound card (Tascam US 122 MKII) and a laptop with noise monitoring software. Two positions of microphones were used.

The height of each receiver was 2.0 m above the floor. The evolution number of present people was registered on the basis of low - resolution time lapse photography at a 1 frame – per - minute frequency. The noise level and the amount of people were synchronously registered over 5 hours' periods, during the opening hours of restaurant.

The measuring system was calibrated by piston calibrator (94 dB and 1 000 Hz). Values of noise level and frequency spectra were obtained from recording with 32 - bit depth and with sampling frequency 44 100 Hz.

4 Data analysis and discussions

4.1 Sound pressure level trends

The A - weighted sound pressure level in time domain and the number of people present were recorded over 7 full days. Figure 2 and Figure 3 show, for two days of measurements (Monday and Tuesday) that, as expected, the noise level (sampled with 15 sec intervals) roughly follows the changes of the number of people present, with a few exceptions. On day 2, at t = 198 - 214 min, there is a decline of the sound pressure level. Possibly, the amount of people presents at that moment, 40, was so large that the acoustical capacity N_{max} of the room was exceeded. According to the estimate [3]:

$$N_{max} = \frac{V}{20 \times RT}\ , \tag{1}$$

with V the volume in m^3 and RT the reverberation time in seconds in furnished but unoccupied state at mid frequencies (500 - 1000 Hz), the acoustic capacity was 25 - 40 people [3].

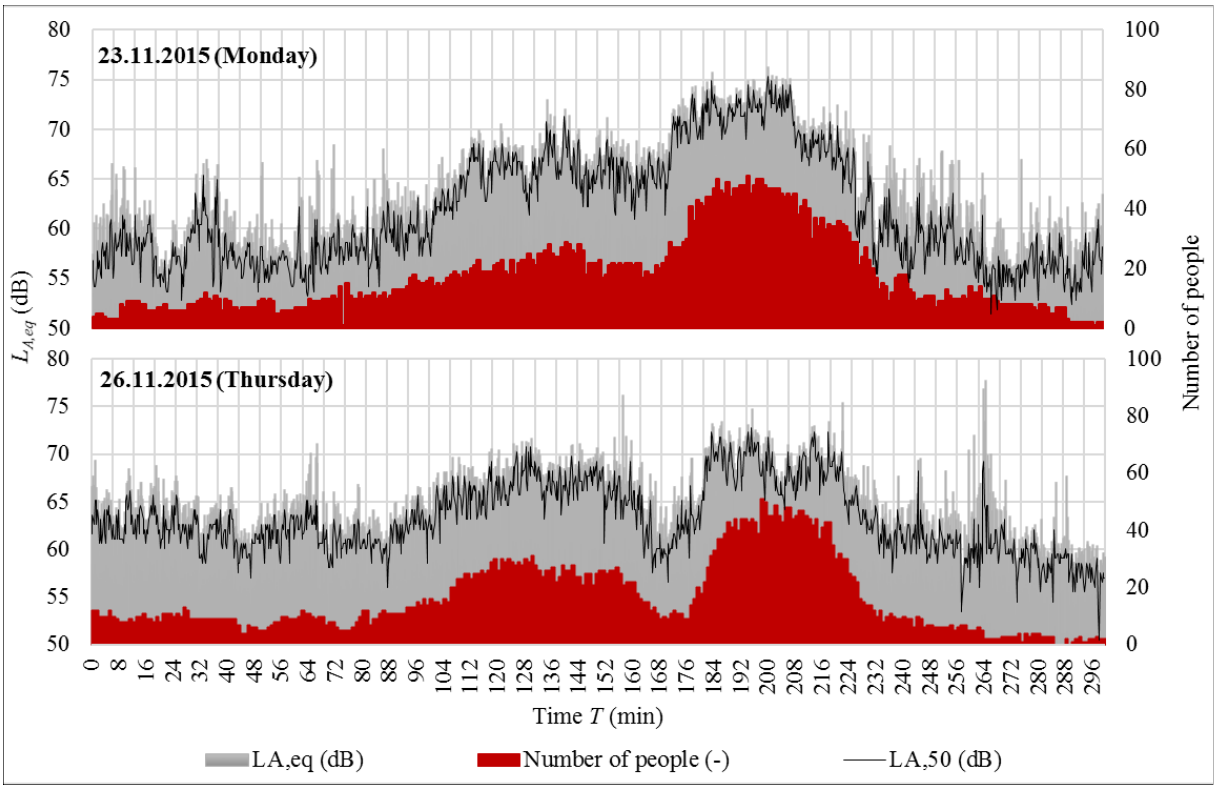

Figure 2 – Typical evolution of the noise level and the number people present.

One may wonder to what extent the sound pressure level is caused by talking people and by background noise. Typical background noise levels in the empty restaurant, caused by music and sounds of equipment (refrigerator, cutlery sounds, etc.), were determined to be around 50 - 52 dB(A). This is hardly less than the typical sound pressure level produced by a single person in a quite environment being $L_{P,1person} \cong 54$ dB(A) at 1 m distance [1]. However, the contribution to the total sound pressure level is negligible compared to the total sound level produced by 20 talkers or more.

The time lapses revealed that typically between 1/3 and 1/2 of the present people were simultaneously speaking. For the situation with 40 people present, the maximum sound pressure level can be expected to be produced by half of them. The total sound pressure level at a location in the room, produced by 20 talking people, can be estimated as follows:

$$L_{P,tot} = 10 \times log_{10}\left(\sum_j 10^{\frac{L_{P,direct,j}}{10}} + 10^{\frac{L_{P,diffuse}}{10}}\right), \tag{2}$$

with j counting over talking people. The direct sound pressure level resulting from a talker at a distance r_j from a listening location is given by:

$$L_{P,direct} = 10 \times log_{10}\left(\frac{P_{1\,person}}{4 \times \pi \times r^2 \times I_{ref}}\right), \tag{3}$$

with $P_{1\ person}$ the acoustic power produced by one person in a point source approximation. $I_{ref} = 10^{-12}$ W/m^2 is the reference intensity. The contribution of the diffuse sound field is given by:

$$L_{P,diffuse} = 10 \times log_{10}\left(\frac{4 \times N \times P_{1\,person}}{\alpha_{average} \times S_{tot} \times I_{ref}}\right), \tag{4}$$

with

$$\alpha_{average} \times S_{tot} = \sum_m \alpha_m \times S_m.$$

The index m is counting over all surfaces S_m in the room, with respective acoustic absorption coefficients α_m.In the restaurant under consideration, the hall radius (for which $L_{P,direct,j} = L_{P,diffuse}$) is given by:

$$r_{hall} = \sqrt{\frac{\alpha_{average} \times S_{tot}}{16 \times \pi \times N_S}}, \tag{5}$$

Using the Sabine equation for the reverberation time:

$$RT = \frac{24 \times \ln(10) \times V}{c \times \alpha_{average} \times S_{tot}}, \tag{6}$$

With c (m/s) the speed of sound. Given the reverberation times (Figure 1) (between 0.5 and 1,25), the free room volume V = 486 m3, the distance where the diffuse sound of N_S = 20 talking people equals the direct sound of one talking person can be estimated, via:

$$r_{diffuse=direct} = \sqrt{\frac{24 \times \ln(10) \times V}{16 \times \pi \times N_S \times c \times RT}}, \tag{7}$$

to be less than 30 cm. This infers that in this situation, the signal to noise ratio of a conversation between nearest neighbors (~30 cm) is around 0 dB. Typical sizes of desks in Club SvF Shupitoo are about

90 cm × 90 cm and 90 cm × 160 cm. For conversations across a table in the presence of 20 talkers at other tables, the *SNR* is therefore about - 10 dB or worse. Since the sound field is dominated by diffuse sound, we have:

$$L_{P,tot} \cong L_{P,diffuse} =$$

$$= 10 \times log_{10}\left(\frac{I_{1\,person,1\,m}}{I_{ref}}\right) + 10 \times log_{10}(N_S) + 10 \times log_{10}\left(\frac{16 \times \pi}{\alpha_{average} \times S_{tot}}\right) \cong$$

$$\cong L_{P,1\,person} + 10log_{10}(N_S) + 10 \times log_{10}\left[\frac{16 \times \pi \times c \times RT}{24 \times V \times \ln(10)}\right]. \quad (8)$$

Inserting $L_{P,1\,person} \cong 54$ dB(A) and $N_S = 20$ speakers and reverberation time values between 0,5 and 1,25 s, we obtain $L_{P,tot}$ values between 62 dB(A) and 67 dB(A). In practice, levels as high as 75 dB(A) were observed (Figure 3).

Given the background noise level being less than or equal to 52 dB(A), the high actual level (about 12 dB excess) should be associated with people increasing their vocal effort as a feedback to the increased environmental level, i.e. the Lombard effect [4] [9], with voice power increases of the order of 8 - 12 dB.

4.2 Sound level fluctuations and sound spectrum

Comparing in Figure 3 the spread on the recorded noise levels (grey dots) with the trend line (full red line), the spread of noise levels is clearly reduced as the number of people present is larger, and as the average sound pressure is higher.

The amplitude modulation of crowds above 30 people is about 5 - 10 dB, while the one for smaller crowds is larger than 10 dB.

The green curve in Figure 3 shows the increase of sound pressure level in a diffuse field, assuming a constant sound source 54 dB [1] for every person. The trend line (red) through the measured values (gray dots) becoming increasingly larger than the green curve with increasing number of (talking) people clearly illustrates the Lombard effect.

We have also verified if there are differences in spectral content of the sound depending on the produced sound pressure level. The signals were classified in moderate intensity ‘steady state’ and enhanced intensity ‘noise burst’ fragments, on the basis of the $L_{A,50}$ values.

A comparison was done for different numbers of people present (00 - 10, 11 - 20, 21 - 30, 30 - 41, 41 - 50).

Figure 4 shows a decrease of the difference between $L_{A,eq}$ and $L_{P,N}$ and of the difference between $L_{A,50}$ and $L_{P,N}$ with increasing number of people. This

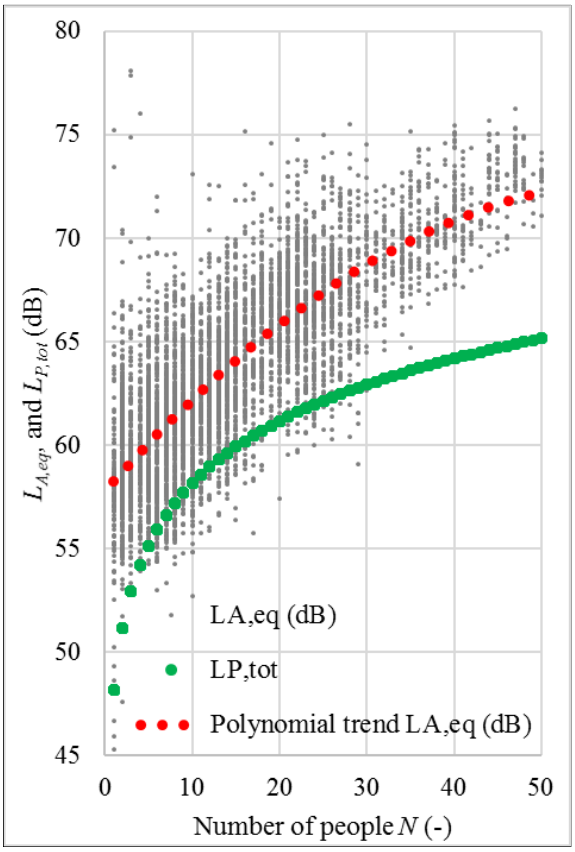

Figure 3 – Dependence of noise level on number of people present.

indicates that, for the given room acoustic parameters, due to physical limitations of the vocal capacity, noise bursts are quenched above 70 - 75dB, limiting Lombard effect induced level enhancements to about 12 dB.

Figure 5 shows that in general, except for a global level difference, noisy and quiet episodes have similar spectral content. The average difference between noisy parts and quiet parts for whole frequency spectrum from 175 Hz to 8 kHz is 3,5 dB. Visual inspection of the noise level evolution showed that for every given number of people present in the room, the highest sound pressure levels were about 3,5 dB larger than the lowest ones. This infers that background noise levels reductions and enhancements tend to trigger (re-) starts or interruptions of conversations, in line with observations by Lazarus [5] [6].

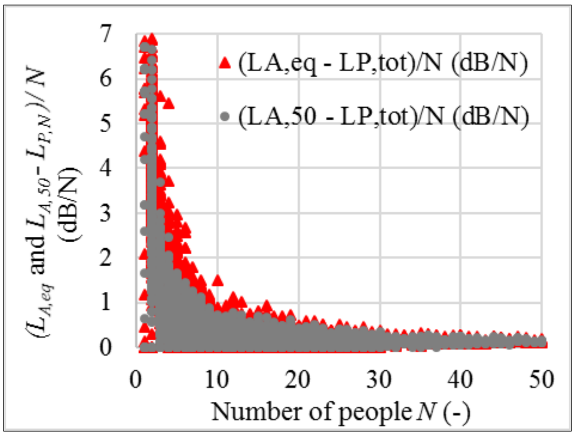

Figure 4 – Difference $L_{A,eq}$ (dB) - $L_{P,tot}$ (dB) (red triangles) and $L_{A,50}$ (dB) - $L_{P,tot}$ (dB) (black dots) versus number of people present.

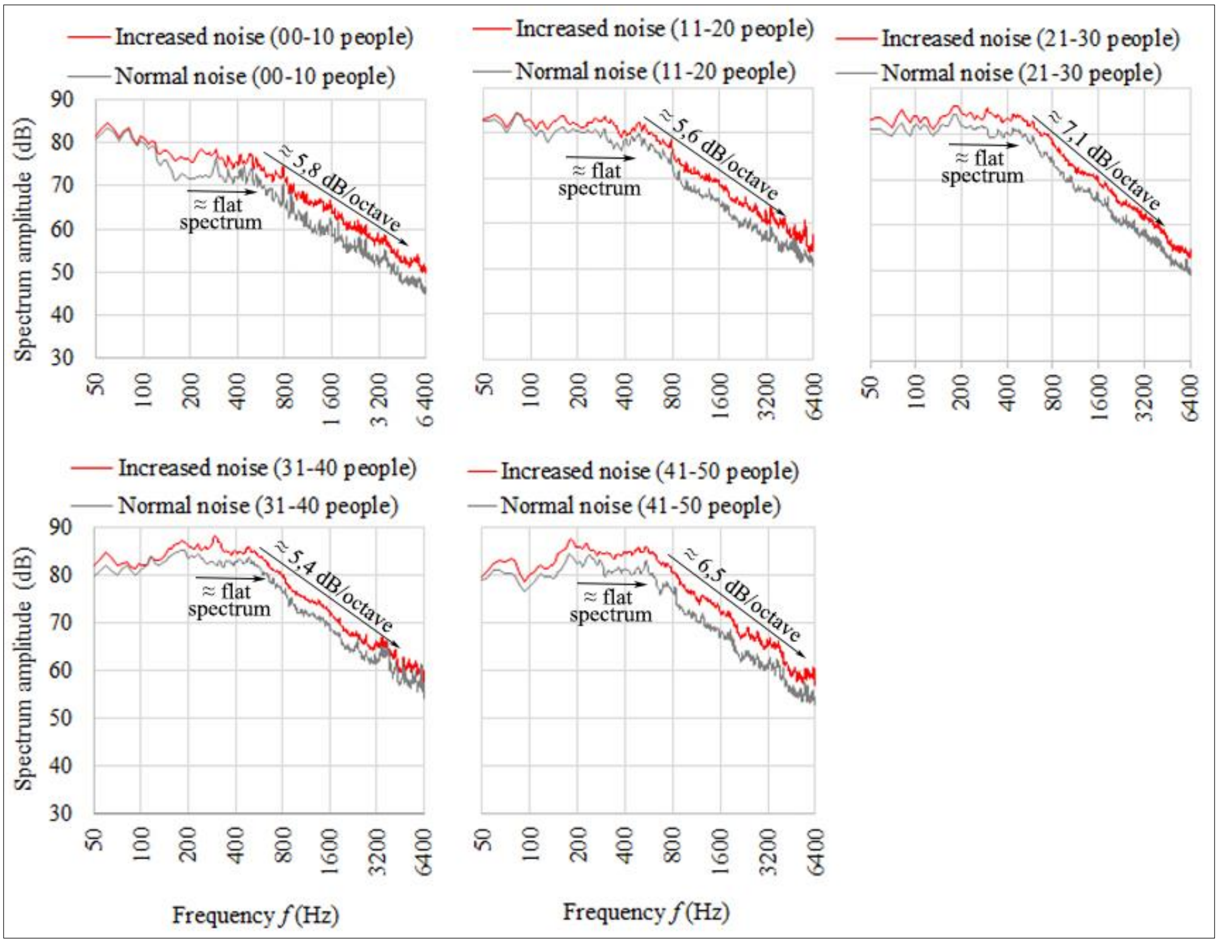

Figure 5 – Spectral analysis of steady state and noise burst fragments for different amounts of people present.

Figure 5 shows that the spectrum of crowds of talkers is rather flat between 200 Hz to 400 - 500 Hz, and then decreases with approximately of 6 dB per octave for higher frequencies, following the spectral features in vowel sounds.

Not being produced by speech, the very low frequencies are found to be not affected by the number of people or by the occurrence of noise bursts. The level differences of 3,5 dB between noide bursts and steady state sound can be a consequence of an increase or the fraction of talkers (3 dB corresponds to an increase of talkers of about 40 %), further enhanced the Lombard effect. Except for the overall level, the noise spectrum does not seem to be influenced by the number of people or by the speech activity. There is a weak indication of an increase of detailed spectral features with decreasing level.

Conclusion

Recordings in a restaurant with a maximum seating capacity of 80 persons and a maximum acoustic capacity of 25 – 40 speakers confirm a substantial influence of the Lombard effect with increasing number of people present. Typically, between one third and one half of the people were simultaneously talking. From the sound pressure level, the typical vocal output level of a person and the number of people, it turns out that the Lombard effect adds up to 12 dB of increase in sound pressure level.

The magnitude of level fluctuations in sound pressure level were found to decrease from larger than 10 dB with less than 30 people present to 5- 10 dB in more crowded situations, probably due to a limitation of people's individual vocal power. In the investigated restaurant, sound levels saturated and noise bursts were quenched at about 70 - 75dB(A). Fluctuations in sound pressure level of about 3,5 dB, between silent and noisy periods, seem to go along with situations of subjectively just good acceptable enough/just too bad speech situations in terms of *SNR*. There are no clear indications of influences of the number of speakers or the total sound pressure level on the spectral content of the sound.

Acknowledgements

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