Good Acoustical Quality in Restaurants: a Compromise Between Speech Intelligibility and Privacy

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Abstract

Speech communication in a restaurant can be a difficult matter. Conversations at the tables becomes difficult due to high noise levels; on the other hand, speech privacy is not ensured for low noise.

The major cause of noise in a dining room is due to the talking of customers rather than external sources, and the problem consists of the intelligibility of speech in a background of competing speech, which is commonly called the "cocktail party problem" [1].

In this work the quality of speech communication was evaluated in four pizzeria-restaurants located in the centre of Turin (Italy) by means of questionnaire and measurements.

1. Introduction

Noise control for good speech communication in a restaurant is not an easy matter. The noise essentially consists of speech babble. It is not constant because the customers do not always talk at the same time and their number fluctuates during the day. Plus, there is the *Lombard* effect where people talk louder as other people talk louder in order to be heard [1]. The noise from adjacent rooms, HVAC and kitchen activities, is often negligible when customers are present.

The most effective methods for reducing background noise levels are the addition of sound absorbing material in the dining area and the limitation of the seating density, as the greater the number of people seated in a dining area the higher the noise level will be. Establishing a maximum seating density in a restaurant for a quiet area is difficult. As a general rule, if the RT is short then the seating density can be increased, but the type of customers can also effect the background noise level: older adults are quieter than younger adults and families.

According to the research program "Quiet areas in restaurants" [2], for good speech communication, especially for hearing–impaired individuals, the maximum average reverberation time for the frequency range from 500 to 2000 Hz measured at 1/3 or 1/1 octave band frequencies, with no customers present ($RT_{500\text{-}2000\ Hz,\ empty}$), should not exceed 0.5-0.6 s and the maximum equivalent background noise level, Leq, with customers present, should not exceed about 60 dB(A), that is the *normal* speech level at 1 m in front of a male speaker, so as to have at least a signal to noise ratio (SNR) of 0 dB(A).

The aim of the work was to investigate both speech communication and privacy at the table which depend on sound reverberation, seating density and the type of customers (only adults or families).

Speech privacy at tables in a dining room is determined by the degree to which intruding speech sounds from adjacent tables exceed the ambient sound pressure levels at the listener's ear, while speech intelligibility is the rating of the proportion of speech understood by the people at their own table. Both can be quantified as the percentage of a message that is understood correctly.

Normal speech privacy is indicated at Articulation Index values of between 0.05 and 0.20 [4]. In this range, concentrated effort is required to understand intruding speech. Some describe unacceptable privacy as values above 0.30. At AI values above 0.40, there is essentially no privacy.

In this work we assumed SII as an index of quality both for speech privacy and speech intelligibility. Recently SII replaced the AI, as described in ANSI S3.5-1997 [5]. They are both a single number rating but SII values can be expected to be a little different from AI values.

Though there is some uncertainty as to how the speech privacy criteria, in terms of AI, can be translated to SII values, we arbitrarily assumed that SII values should be greater than 0.45 at the customers own table, for fair speech intelligibility [3], but lower than 0.20 in correspondence to the neighbouring tables, for good privacy.

Four pizzeria-restaurants in the centre of Turin were selected for the study. They are here referred to as *LS, LE*, *PA, ST*. The analyses were carried out in one dining room in each restaurant. The main characteristics of these dining rooms are shown in Table 1.

As far as the room construction, most of the rooms have plaster ceilings and walls (NRC 0.10), wood tables with tablecloths and wood or metal chairs and one window. The exceptions are the dining room in the *LE* restaurant, which has an acoustical ceiling (NRC 0.65) and sound-absorbing material on part of the walls and *ST*, which has unpainted bricks on the ceiling and two more windows.

Table 1. *Main characteristics of the restaurant dining rooms.*

	LS	*LE*	*PA*	*ST*
				
Floor surface [m^2]	(≈ 6.1 x 4.8 m) 29.0	(9.6 x 4.4 m) 42.3	(6.9 x 4.1 m) 28.3	(11 x 5.8 m) 63.8
Height [m]	3.6	3.7	3.5	3.0
Volume [m^3]	104.0	156.5	99.0	191.4
ΣS [m^2]	141.0	188.2	133.6	228.4
$V/\Sigma S$ [m]	0.7	0.8	0.7	0.8
$a_{m\ (500\text{-}2000\ Hz,\ empty)}$ [-]	0.16	0.36	0.16	0.24
$RT_{(500\text{-}2000\ Hz,\ empty)}$ [s]	0.73	0.37	0.75	0.57
S. capacity [n. of people]	29	41	30	88
Seating density [people/m^2]	1.0	1.0	1.1	1.4
S. density during test [p/m^2]	0.95	0.95	0.5	0.4
$a_{m\ (500\text{-}2000\ Hz,\ test)}$ [-]	0.27	0.48	0.22	0.30

2. Field monitoring

Three sets of acoustical measurements were carried out in each dining room.

The first set was made to determine the reverberation time (RT) in the unoccupied rooms (see Fig. 1). It was performed for octave bands, by means of the interrupted noise method using a 4296 type Brüel & Kjær omni-directional sound power source, with a pink noise test signal.

The octave band RTs were averaged from 500 to 2000 Hz, thus obtaining $RT_{(500\text{-}2000\ Hz,\ empty)}$. With the exception of *LE* restaurant, which had a sound absorbent treatment, the average reverberation times were longer than the optimal values of 0.5 s [2].

The octave band average sound absorption coefficients (a_m) were calculated from the octave band RTs and averaged from 500 to 2000 Hz ($a_{m(500\text{-}2000\ Hz,\ empty)}$). The octave band a_m values, corrected for room occupancy during the test, give the $a_{m(500\text{-}2000\ Hz,\ test)}$ values (Tab. 1).

The second set of measurements involved the recording of the background noise levels with customers present, during peak restaurant activities. They were recorded over a time period of 10 minutes in which the number of customers remained constant. The background level essentially included noise from the customers; kitchen activities, HVAC system and traffic were not significant with respect to the noise from customers.

The locations of the microphone were at a normal seating position at a table, near the middle of the dining room. Measurements were taken at the same time the subjective survey was performed.

In order to characterize the noise level in the dining rooms we used the A-weighted equivalent sound level, Leq. Since the seating density during the measurement interval was different for each restaurant, the noise levels were normalised (operating on the sound power with reference to a diffuse-field) to the maximum seating density encountered during the evaluations (0.95 p/m^2) so as to compare data from different dining rooms.

As can be seen from Fig. 2 the Leq values ranged from 67.4 dB(A) for *PA* to 75.9 dB(A) for *LS*, while the normalised level, Leq(N), ranged from 69.2 for *PA* to 76.8 dB(A) for *ST*.

As far as Leq is concerned, *LS* and *LE,* with the same seating density and, according to the *Lombard* effect [3] people who speak with a *raised* vocal effort, show different noise levels because of the different amount of sound absorption, higher in *LE* than in *LS*.

The higher noise levels in *ST* compared with the others are due to the type of customers in the restaurant. These customers were families with children who tend to generate higher noise than adults without children. On the other hand the lower noise levels of *PA* are due to the fact that customers with a lower seating density speak with a lower vocal effort.

As far as Leq(N) is concerned, the normalised levels do not take into account the change of vocal effort due to the increment of people in the dining room. As a consequence in the *PA* and *ST* restaurants higher sound levels can be expected.

The third set of measurements concerns the spatial distribution of the voice levels in the dining rooms [4].

A 4128 type Brüel & Kjær head and torso simulator was used as a speech source. The source, emitting a white noise test signal, was pre-calibrated in an anechoic chamber, where output octave band levels were measured at 1 m in front of the mouth.

The source was located at a table in the dining rooms to simulate a customer speaking to another customer in front of him. Receiver positions were placed 1 m from the source's mouth and in some typical listener positions uniformly distributed on a grid over the seating area, at ear height.

In order to maximise the signal-to-noise ratio, it was checked that the source levels at the measurement locations exceeded the noise level by at least 10 dB, over the entire frequency range. The diffuse-field theory was applied to correct the unoccupied source levels for room occupancy, starting from the measured sound power levels of the speech source.

The source level reductions were obtained for each receiver position, with respect to the anechoic level measured 1 m in front of the source's mouth, in octave bands. The same reductions, in octave bands, were applied to the 1 m anechoic levels of a male speaker with a *normal* and *raised* voice effort in order to obtain the speaker's overall A-weighted speech level distribution throughout the room and to calculate the speech spectrum levels needed for SII computations [5].

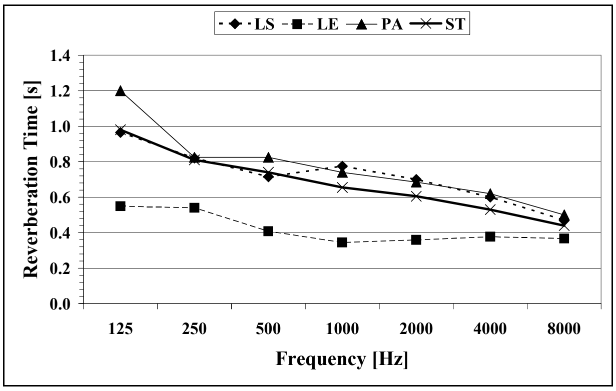


Figure 1: *Reverberation time vs. frequency measured in the dining rooms.*

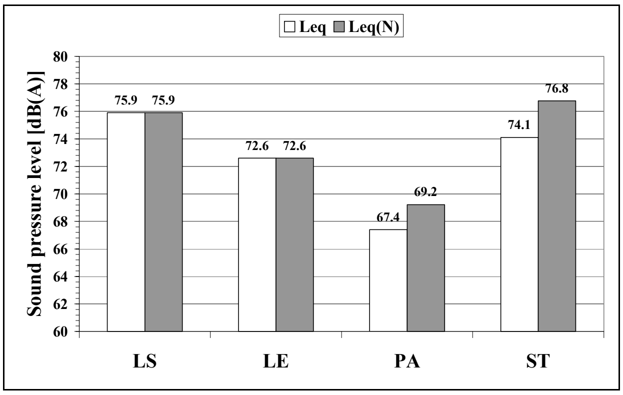


Figure 2: *A-weighted sound pressure levels measured in the dining rooms.*

3. Subjective analysis

A questionnaire was specifically drawn up for environmental quality assessment in the dining rooms. It consists of general information and acoustic comfort sections.

The general information concerns age, sex and a judgement of the pleasantness of the room on a five point discrete scale with semantic descriptors and consecutive integer numbers from "very unpleasant" (1) to "very pleasant" (5). The questions on acoustic comfort concern the quantitative evaluation of noise annoyance from different sources (people moving and speaking in the room, the HVAC system, cooking activities, traffic, etc.), speech comprehension at the table and speech comprehension of the conversation at the neighbouring tables (speech privacy). One further scale was added to judge "overall acoustic comfort". The answers are expressed by means of five point discrete scales with steps labelled by semantic descriptors and integer consecutive numbers from "not at all" (1) to "very much" (5), while acoustic comfort scale ranges from "unacceptable" (1) to "excellent" (5).

The full sample consists of 125 questionnaires. Most of the customers were aged 30-39 (45.6 %) and were almost equally divided into male (53.6 %) and female (46.4 %).

The highest score for noise annoyance refers to noise coming from the customers in the room. The average values of noise annoyance, acoustic comfort, room pleasantness, speech intelligibility and speech privacy are shown, for each dining room, in Fig. 3.

LE compared to *LA* shows lower values of noise annoyance from talking customers, higher values of acoustic comfort, room pleasantness, speech intelligibility at the table and speech privacy. The speech intelligibility scores are however approximately the same in all the dining rooms because people adjust their vocal effort in order to be heard so to maintain the required SNR, that according to Plomp is about 0 dB [6]. As far as speech privacy is concerned there are higher scores for *LE*, while noise annoyance, room pleasantness and acoustic comfort scores show the same trend as the speech intelligibility scores.

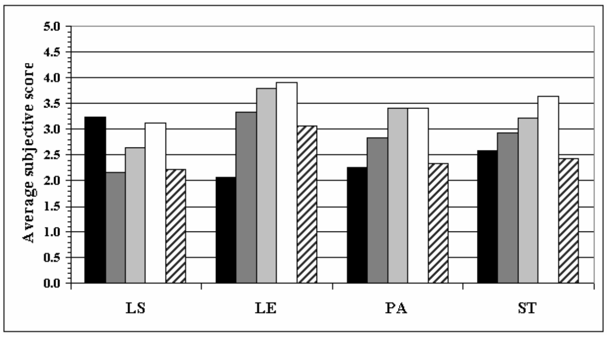


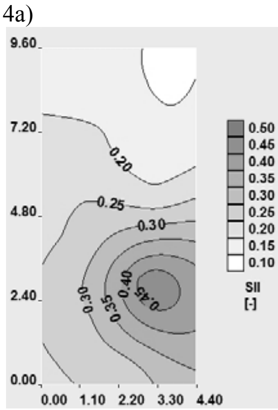
Figure 3: *Average scores of noise annoyance from customers (solid bl.), room pleasantness (dark grey bl.), acoustic comfort (pale grey bl.), speech intelligibility at the table (white bl.) and speech privacy (slashed bl.) for each dining room.*

4. Speech intelligibility and privacy

Using HyperComfort (HC) [7], SII was calculated for twelve receiver points uniformly distributed on a rectangular grid in the dining rooms. It was also possible to interpolate the index values and to spatially represent isometric curves.

The SII values were obtained, applying the octave band procedure, from the speech spectrum levels at the listener positions and from the noise spectrum level, that was considered constant inside the room. Iso-SII curves for different seating densities and vocal efforts of a male speaker seated at one table in the *LE* dining room are shown in Figures 4-5.

4a)



4b)

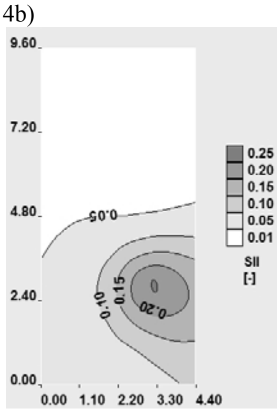
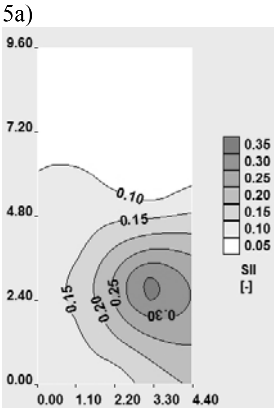


Figure 4: *Spatial representations of SII in the LE dining room: a) 0.95 p/m^2 and raised vocal effort of the speaker (meas. condition); b) 0.95 p/m^2 and normal vocal effort.*

5a)



5b)

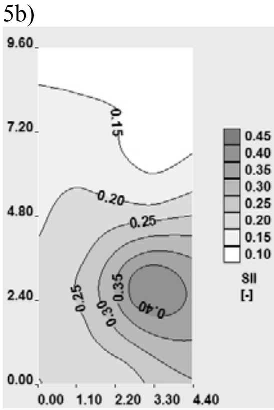


Figure 5: *Spatial representations of SII in the LE dining room: a) 0.4 p/m^2 and normal v. e.; b) 0.2 p/m^2 and normal v. e.*

SII-curves for the measurement condition are given in Fig. 4a: with a seating density of 0.95 p/m^2 the noise level was 72.6 dB(A) and, due to the *Lombard* effect, a *raised* vocal effort was given to the speaker [3]. According to the subjective results, fair intelligibility at the table resulted but not enough privacy, considering a distance between tables of about 1.5 m.

The noise level in Fig. 4b is the same and the speaker has a *normal* vocal effort. In this case the speech intelligibility at the table is poor. Figures 5a and 5b show SII-curves for a seating density of 0.4 and 0.2 p/m^2 respectively, and a *normal* vocal effort of the speaker. The corresponding calculated noise levels are 69.4 and 66.7 dB(A).

Speech intelligibility and privacy targets are achieved only with a seating density of 0.2 p/m^2 (Fig. 5b). This density corresponds to 9 people in the room who can be grouped in two tables placed far from each other.

According to the Gardner's study [8], doubling the number of individuals, the noise level increases by 6 dB instead of the 3 dB that would occur if the vocal effort was constant. Allowing for this, a noise level with 0.4 p/m^2 should correspond to a noise level with a seating density of 0.2 p/m^2 and the SII map would become the map in Fig. 5b, so that, with more people (18), speech privacy at the table would not be ensured.

5. Conclusions

In this work an attempt was made to assess speech communication in some dining rooms, acting on acoustic absorption and seating density and taking into account the *Lombard* effect and the type of customers.

Further measurements are needed to better investigate the influence of these aspects on sound pressure levels measured in an occupied dining room and further subjective investigations should be carried out to correlate these levels to acoustic comfort.

Good conditions of both speech intelligibility and privacy are difficult to achieve. More precise reference SII values should be used for accurate predictions.

6. Acknowledgements

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7. References

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