# Subjective Evaluation of Restaurant Acoustics in a Virtual Sound Environment

Nicolaj Oestergaard Nielsen[1]; Marton Marschall[1]; Sébastien Santurette[1]; Cheol-Ho Jeong[1]

[1]Department of Electrical Engineering, Technical University of Denmark

## ABSTRACT

Many restaurants have smooth rigid surfaces made of wood, steel, glass, and concrete. This often results in a lack of sound absorption. Such restaurants are notorious for high sound noise levels during service that most owners actually desire for representing vibrant eating environments, although surveys report that noise complaints are on par with poor service. This study investigated the relation between objective acoustic parameters and subjective evaluation of acoustic comfort at five restaurants in terms of three parameters: noise annoyance, speech intelligibility, and privacy. At each location, customers filled out questionnaire surveys, acoustic parameters were measured, and recordings of restaurant acoustic scenes were obtained with a 64-channel spherical array. The acoustic scenes were reproduced in a virtual sound environment (VSE) with 64 loudspeakers placed in an anechoic room, where listeners performed subjective evaluation of noise annoyance and privacy and a speech intelligibility test for each restaurant noise background. It was found that subjective evaluations of acoustic comfort correlate with occupancy rates and measured noise levels, that survey and listening test results agreed well and that, in the VSE, speech reception thresholds were similar for the five reproduced restaurant backgrounds.

Keywords: Restaurant noise, Virtual sound reproduction, Noise annoyance I-INCE Classification of Subjects Number(s): 63.2, 63.3, 51.4

## 1. INTRODUCTION

More and more restaurateurs are following the trend of having smooth rigid surfaces made of wood, steel, glass, and concrete in their restaurants. This minimalistic aesthetic design is modern and simple, while surfaces are easy to clean. A negative effect of rigid surfaces is lack of absorption, which consequently keeps sound longer in the room. Restaurants are notorious for having very high sound pressure levels during service. This can partly be explained by the fact that many owners desire as much noise as possible. Noise is associated with an exciting dynamic environment and therefore many restaurant owners overlook the problems that too high noise levels can result in. High noise levels can cause guests to feel uncomfortable and mentally exhausted. Moreover, staff undergoes a risk of hearing damage when working long hours. In many countries the noise level is required to be below 85 dB during an 8-hour work shift by law. However, this limit is often reached if not exceeded. Sound levels can easily reach more than 80 dB during peak hours (1, 2, 3) due to guests being packed into small confined spaces. A recent study by Svennson (4) also showed that increasing the number of people in an eating establishment reduced the acoustic comfort. The evolution of the restaurant business has resulted in increased noise complaint rates, and some places noise is a bigger concern to guests than poor service, which was traditionally the biggest source of complaints until recent times (5). Besides the health of the staff and guests, there is also an economic incentive to keep a close eye on the acoustics in restaurants. James reported that 72% of restaurant goers actively avoid establishments that are too loud (5). It is inarguable that restaurant noise is an important problem that must be addressed, which was the main motivation for the present study.

This study attempted to describe various factors that influence acoustic comfort, with the aim to give restaurateurs a better foundation for achieving good restaurant acoustics that provide the best possible experience for both staff and customers. In order to do so, three major attributes of acoustic comfort in restaurants were addressed: noise annoyance, speech intelligibility, and sense of privacy. Based on this scope, the research objective was to determine the main objective parameters that affect

[1] noen.nielsen@gmail.com

perceived noise annoyance, speech intelligibility and privacy, and to bring clarification to the term "sense of privacy" in a restaurant context.

These objectives were achieved by comparing objective acoustic parameters with subjective evaluations of acoustic comfort. The term "*acoustic capacity*" was introduced as a predictor for acoustic comfort (6), and is defined as "the maximum number of persons allowed in the room for *sufficient* quality of verbal communication", where *sufficient* quality is achieved for a signal-to-noise ratio (SNR) between speech and ambient noise level above -3dB Lazarus (7). A model for estimating acoustic capacity was proposed in (6) as:

$$N_{\max} = V / 20T \, , \tag{1}$$

where $N_{max}$ is the acoustic capacity, $V$ the volume, and $T$ the reverberation time in furnished and unoccupied state at frequencies 500 Hz-1 kHz.

Relationships between acoustic properties and subjective ratings are typically difficult to establish due to very high variability in the answers of questionnaires combined with low response rates. In order to obtain more controlled subjective evaluations in the present study, laboratory experiments were also performed in which the acoustic scenes of real restaurants, in which customers answered questionnaires, were convincingly reproduced.

Three experiments were conducted. The first experiment explores the relationships between subjective evaluations and objective parameters measured in five different restaurants. The second experiment explores the relationships between objective parameters measured and subjective evaluations of acoustic comfort in the same five restaurants through reproduction of the acoustic scenes in a virtual sound environment (VSE). The third experiment explores speech intelligibility in the five restaurants by using a VSE.

## 2. EXPERIMENT I: RELATIONSHIP BETWEEN OBJECTIVE ACOUSTIC PARAMETERS AND SUBJECTIVE EVALUTION RESTAURANT ACOUSTICS

### 2.1 Measurement of objective parameters

Objective acoustic parameters were measured in five restaurants in compliance with (8) using a setup with a laptop, a loudspeaker, and a microphone. The recordings were made in the restaurants off-hours, when only a few staff members were present. A laptop with the B&K room acoustic software DIRAC was used for producing output signals and processing input signals. The sound source was a dodecahedron speaker connected to an amplifier. The receiver of the impulse response was an AKG C34 microphone connected to an AKG S42 control box and to an RME Quad Mic 4-Channel microphone preamplifier. The directional pattern of the microphone was adjusted using the control box to measure lateral fraction. The speaker amplifier, the microphone amplifier and the built-in amplifiers in DIRAC were adjusted such that the peak level of the impulse sound resulted in an SNR of at least 35 dB. For improved SNR an exponential sweep (e-sweep), of duration 1.5 seconds, was chosen and repeated 5 times for every measurement. According to (8) air attenuation in large rooms is negligible if the reverberation time is below 1.5 s at 2 kHz and below 0.8 s at 4 kHz. This was the case for all restaurants. At least 3 decays for 6 different source-receiver positions were measured, which is the requirement for the engineering method.

### 2.2 Measurement of subjective attributes

In order to gather empirical data regarding subjective parameters, a questionnaire in English and Danish language was distributed to dining guests at the same five restaurants. The construction of the survey was based on the method from Fields (9). The response options and questions were:

- Responses: Extremely, Very, Moderately, Slightly or Not at all.
- Noise annoyance question: "Thinking about your dinner, how much did noise from the restaurant bother, disturb, or annoy you?"
- Speech intelligibility question: "How difficult was it to hear and understand the other guests at your table?"
- Privacy question: "How difficult was it to maintain a private conversation with the other guests at your table?"

Regarding the noise annoyance question, it was assumed that restaurant guests perceived noise as either a neutral or a negative influence, hence the choice of a unipolar scale ranging from “extremely” to “not at all”. The response modifiers “extremely”, “very”, “moderately”, “slightly”, and “not at all” were assumed to cover a continuous scale equidistantly between 0 and 100, Fields (9). The translation of the questions to Danish was done as directly as possible with regards to maintaining a natural phrasing.

It was decided that the questions should be similar regarding context, scale, and response modifiers. Since the scale was unipolar going from negative to neutral, a contextual anchor was chosen to be the degree of difficulty of performing some act. The question about speech intelligibility thus evaluated the degree of difficulty of hearing and understanding other people around the table and the question about privacy referred to the difficulty of having a private conversation. These questions allowed the scale itself, the direction of the scale, and the response modifiers to stay the same throughout the questionnaire, securing continuity in the survey questions and making the answering task easier for the respondents.

Questionnaires were printed on A5-size paper and distributed to the restaurants. The staff in restaurants 1, 2, and 3 was instructed to only hand out the questionnaires if their respective restaurant was considered full (more than 75% of capacity seated by guests). In restaurant 4 the average utilization of seats was reportedly around 25%. Therefore the staff was instructed to hand out questionnaires at all times. In restaurant 5 the utilization of seats was reportedly around 50% on average, and the staff was instructed to hand out questionnaires when the restaurant was approximately half full. All staff was instructed not to read out load or repeat the questions to the respondents.

## 2.3 Results

Mean values for the objective parameters and subjective attributes obtained in the various measurements are presented in Table 1.

Table 1 – Objective and subjective parameters obtained by measurements and surveys. Subscripts regarding acoustic parameters and subjective ratings denote the standard deviation and standard error of the mean, respectively. Absorption area per patron was calculated using Sabine’s formula, where each patron present furthermore was assigned 0.2 m$^2$ of equivalent absorption, according to Rindel (2). Utilization of acoustic capacity denotes how many times the acoustic capacity is used.

| Restaurant | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Reverberation time, $T20_{0.125\text{-}8\ \mathrm{kHz}}$ [s] | $0.63_{0.17}$ | $0.64_{0.10}$ | $0.50_{0.12}$ | $0.53_{0.11}$ | $0.43_{0.07}$ |
| Early Decay Time, $EDT_{0.125\text{-}8\ \mathrm{kHz}}$ [s] | $0.55_{0.17}$ | $0.54_{0.13}$ | $0.46_{0.12}$ | $0.47_{0.13}$ | $0.35_{0.09}$ |
| Definition, $D50_{0.125\text{-}8\ \mathrm{kHz}}$ | $0.70_{0.15}$ | $0.74_{0.09}$ | $0.76_{0.12}$ | $0.71_{0.13}$ | $0.83_{0.09}$ |
| Clarity, $C50_{0.125\text{-}8\ \mathrm{kHz}}$ [dB] | $4.1_{3.2}$ | $4.9_{2.3}$ | $5.6_{2.9}$ | $4.2_{2.8}$ | $7.6_{3.0}$ |
| Bass Ratio, *BR* | $1.05_{0.27}$ | $0.94_{0.12}$ | $0.99_{0.18}$ | $1.21_{0.13}$ | $1.13_{0.16}$ |
| Rapid Speech Transmission Index, *RA* | $0.71_{0.05}$ | $0.73_{0.04}$ | $0.73_{0.06}$ | $0.74_{0.02}$ | $0.80_{0.03}$ |
| $N_{max}$ utilization, $NU_{max}$ | 2.46 | 2.02 | 2.55 | 0.38 | 0.91 |
| Patron density. Patrons per m$^2$, *Rho* | 0.51 | 0.5 | 0.62 | 0.09 | 0.3 |
| Absorption area per patron, *AP* [m$^2$] | 1.56 | 1.84 | 1.53 | 8.37 | 3.52 |
| Survey sample size | 40 | 63 | 39 | 29 | 45 |
| Mean noise annoyance rating, *NA* | $26.6_{4.1}$ | $30.6_{3.9}$ | $35.3_{4.8}$ | $10.3_{2.6}$ | $18.9_{3.4}$ |
| Mean speech difficulty rating, *SD* | $25.6_{4.3}$ | $25.0_{3.8}$ | $30.1_{4.3}$ | $7.8_{2.5}$ | $13.3_{2.8}$ |
| Mean privacy difficulty rating, *PD* | $18.8_{3.7}$ | $25.4_{3.8}$ | $28.2_{5.1}$ | $12.2_{2.9}$ | $15.0_{2.9}$ |

For visual clarification the subjective evaluations obtained in the surveys are presented in Figure 1.

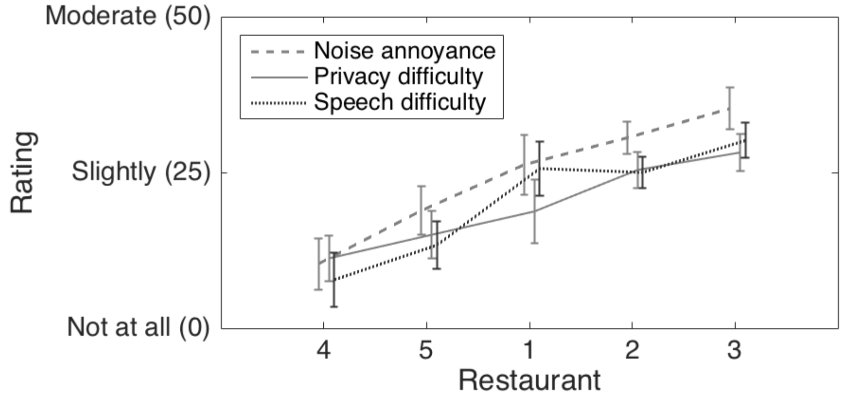


Figure 1 – Subjective ratings obtained in surveys for the 5 different restaurants.

Error bars denote the standard error of the mean.

The relationships between objective parameters and subjective rating of acoustic comfort were investigated with a correlation matrix presented in Table 2. It is clear that patron density is a predictor that correlates very well with subjective attributes. With nine predictors and Bonferroni correction, correlations are significant at the 0.55 % confidence level when the Pearson's correlation factor is greater than or equal to 0.97. This indicates that correlations between *Rho*, *NA* and *SD* are significant.

Table 2 – Pearson's correlation factor between objective and subjective measures, where values equal to or greater than 0.89 are marked bold and are significant at the 5 % confidence level. Values equal to or greater than 0.97 are significant at a confidence level of 0.55%. The responses *NA*, *SD*, and *PD* are subjective evaluations of noise annoyance, speech difficulty, and privacy difficulty respectively. Additional parameters are objective predictors of acoustic comfort. For clarification on abbreviations see Table 1.

| | *NA* | *SD* | *PD* | *EDT* | *T20* | *D50* | *RA* | *C50* | *BR* | *AP* | *Rho* | $NU_{max}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *NA* | **1** | | | | | | | | | | | |
| *SD* | **0.97** | **1** | | | | | | | | | | |
| *PD* | **0.97** | **0.92** | **1** | | | | | | | | | |
| *EDT* | 0.36 | 0.49 | 0.36 | **1** | | | | | | | | |
| *T20* | 0.29 | 0.41 | 0.28 | **0.97** | **1** | | | | | | | |
| *D50* | 0.08 | -0.10 | 0.07 | -0.84 | -0.76 | **1** | | | | | | |
| *RA* | -0.43 | -0.58 | -0.43 | **-0.92** | -0.80 | 0.86 | **1** | | | | | |
| *C50* | 0.02 | -0.14 | -0.01 | -0.87 | -0.79 | **0.99** | **0.89** | **1** | | | | |
| *BR* | **-0.93** | **-0.89** | **-0.93** | -0.48 | -0.48 | -0.03 | 0.42 | 0.04 | **1** | | | |
| *AP* | **-0.91** | **-0.90** | -0.80 | -0.26 | -0.27 | -0.20 | 0.26 | -0.18 | 0.86 | **1** | | |
| *Rho* | **0.98** | **0.99** | **0.92** | 0.37 | 0.31 | 0.03 | -0.46 | -0.01 | **-0.89** | **-0.94** | **1** | |
| $NU_{max}$ | **0.93** | **0.99** | 0.85 | 0.54 | 0.47 | -0.18 | -0.63 | -0.21 | -0.84 | **-0.90** | **0.97** | **1** |

## 3. EXPERIMENT II: SUBJECTIVE EVALUATION OF ACOUSTIC COMFORT IN A VIRTUAL SOUND ENVIRONMENT

### 3.1 Recording restaurant acoustic scenes

Recordings were made at each restaurant during opening hours with a 64-element spherical array of radius 9.75 cm, similar to that of a human head (B&K WA 1565) connected to a B&K LAN-Xi data acquisition (B&K 3099A). It was attempted to keep situational features the same at all restaurants. These features included the microphone array being positioned at a realistic spot, for instance at a table, the distance to nearest patron being the same, patrons not being aware of the microphone setup, and the language of the speaker near the microphone being Danish.

### 3.2 Reproduction of acoustic scenes

All recordings were presented in an anechoic room 6 m in height, 7 m in width and 8 m in depth. The spherical loudspeaker array included 64 loudspeakers. The radius at zero elevation was 2.4 m and the radius at $-\pi/2$ or $\pi/2$ elevation from the horizontal plane was 2 m. Differences in distances between speakers to the sides and above were compensated for with time delay. The lower frequency limit of playback was approximately 70 Hz. The sound field reproduction technique used was Ambisonics. The recordings from the spherical array were used to estimate the spherical harmonic components that describe the sound field in a spherical region of space. The reconstruction of the sound fields was done by decomposing the spherical harmonic representation into plane waves, emitted from the 64 loudspeakers said to be in the far field. "Basic" decoding and a regular layout of loudspeakers were used in the decoding process.

### 3.3 Stimuli

Sound material presented in the test consisted of background noise recorded in the restaurants and anechoic recordings of monologues. The content of the monologues was dynamic in level and was similar to natural speech expected in a restaurant. In total 30 different background noise scenarios were presented through the 64 loudspeakers, and each scenario included speech coming from the front speaker. The level of the background noise at the position of the test subject's head was equal to the level recorded in the restaurants, and the speech level was normalized to an SNR of 0dB.

### 3.4 Procedure

Both the noise annoyance and privacy difficulty measurement method was a MUSHRA test consisting of 6 pages where each page lets the test subject rate each of the 5 restaurants. In order to make the test more realistic a talker was introduced. The test subject rated each scenario by moving a continuous slider on a tablet going from 0 to 100, with the response modifiers presented as well.

Table 5 – Objective and subjective parameters obtained by measurements and surveys. Subscripts regarding subjective ratings denote the standard error of the mean. Acoustic parameters are not included in the table see Table 1.

| Restaurant | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Patron density. Patrons per m$^2$, *Rho* | 0.61 | 0.58 | 0.84 | 0.08 | 0.25 |
| $N_{max}$ utilization, $NU_{max}$ | 3.18 | 2.13 | 3.52 | 0.32 | 0.78 |
| Absorption area per patron, *AP* [m$^2$] | 1.38 | 1.76 | 1.04 | 9.99 | 4.06 |
| Measured sound pressure level, $L_{Aeq}$ [dBA] | 69 | 69.4 | 76.7 | 59.8 | 67 |
| Loudness level, *LS* [Sone] | 11.1 | 11.3 | 16.7 | 5.9 | 8.2 |
| Laboratory sample size | 20 | 20 | 20 | 20 | 20 |
| Mean noise annoyance rating, *NA* | $39.4_{1.7}$ | $38.7_{1.7}$ | $72.0_{2.0}$ | $14.3_{1.4}$ | $27.7_{1.6}$ |
| Mean privacy difficulty rating, *PD* | $36.7_{2.0}$ | $36.2_{1.9}$ | $61.9_{2.5}$ | $19.6_{1.7}$ | $29.5_{1.7}$ |

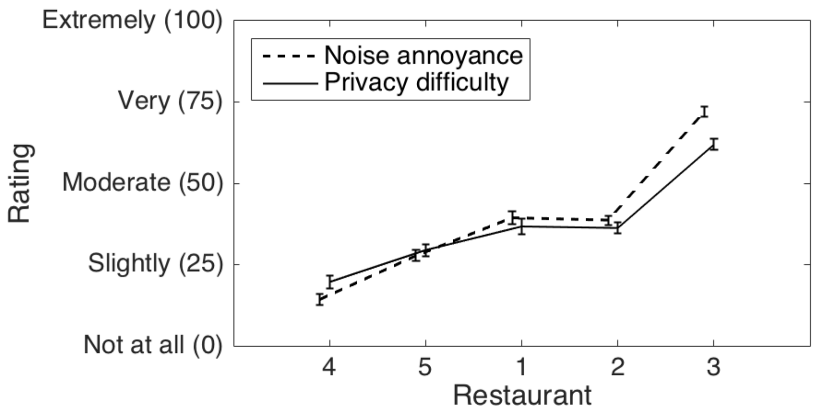


Figure 2 – Graph showing subjective ratings obtained in the laboratory for the 5 different restaurants. Subscripts denote standard error. Note: Data points are shifted slightly on the x-axis for clarification.

Table 6 – Matrix showing the correlations between objective and subjective measures, where values marked bold are equal to or greater than 0.88 and are significant at a confidence level of 5 %. The responses *NA* and *PD* are subjective evaluations of noise annoyance and privacy difficulty respectively.

| | *NA* | *PD* | *EDT* | *T20* | *D50* | *RA* | *C50* | *BR* | *AP* | *Rho* | $NU_{max}$ | $L_{Aeq}$ | $L_{sone}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *NA* | **1** | | | | | | | | | | | | |
| *PD* | **1.00** | **1** | | | | | | | | | | | |
| *EDT* | 0.15 | 0.11 | **1** | | | | | | | | | | |
| *T20* | 0.01 | -0.03 | **0.97** | **1** | | | | | | | | | |
| *D50* | 0.12 | 0.14 | -0.84 | -0.76 | **1** | | | | | | | | |
| *RA* | -0.37 | -0.34 | **-0.92** | -0.80 | 0.86 | **1** | | | | | | | |
| *C50* | 0.08 | 0.10 | -0.87 | -0.79 | **0.99** | **0.89** | **1** | | | | | | |
| *BR* | -0.71 | -0.69 | -0.48 | -0.48 | -0.03 | 0.42 | 0.04 | **1** | | | | | |
| *AP* | -0.77 | -0.75 | -0.28 | -0.28 | -0.18 | 0.29 | -0.15 | 0.86 | **1** | | | | |
| *Rho* | **0.94** | **0.92** | 0.42 | 0.32 | -0.06 | -0.56 | -0.11 | -0.85 | **-0.89** | **1** | | | |
| $NU_{max}$ | 0.87 | 0.85 | 0.50 | 0.40 | -0.23 | -0.67 | -0.25 | -0.75 | -0.85 | **0.97** | **1** | | |
| $L_{Aeq}$ | **0.97** | **0.97** | 0.10 | 0.01 | 0.25 | -0.26 | 0.21 | -0.79 | **-0.88** | **0.94** | 0.86 | **1** | |
| $L_{sone}$ | **1.00** | **0.99** | 0.23 | 0.10 | 0.07 | -0.43 | 0.02 | -0.77 | -0.81 | **0.97** | **0.90** | **0.97** | **1** |

### 3.5 Participants

In total 20 Danish native speakers with self-reported normal hearing participated in the experiment. They were paid for their participation and all participants gave written informed consent. The Science-Ethics Committee for the Capital Region of Denmark approved all experiments.

### 3.6 Results

Mean values for objective parameters and subjective attributes obtained in the various measurements are presented in Table 5. Loudness values in Sones were calculated using Steven's method of loudness summation (10). The measured sound pressure levels weare associated with observed patron density and utilization of acoustic capacity during recordings.

For visual clarification the subjective evaluations obtained in the surveys are presented in Figure 2.

The relationships between objective parameters and subjective rating of acoustic comfort were investigated with a correlation matrix presented in Table 6. It was found that subjective attributes *NA* and *DP* were highly correlated with patron density and noise level $L_{Aeq}$.

## 4. EXPERIMENT III: SPEECH RECEPTION THRESHOLD IN DIFFERENT RESTAURANT NOISE RECORDINGS

### 4.1 Stimuli

The audio material used in the experiment was 64-channel background noise recorded in the restaurants and 750 speech sentences recorded in anechoic conditions. For each restaurant there were between 11 and 15 samples of restaurant noise of 5-s duration. The noise levels were equal to that in the restaurants during recordings. The sentences were taken from the Dantale2 test and consisted of 5 words each including a *name*, a *verb*, a *number*, an *adjective* and a *noun,* (11). All sentence levels were normalized.

### 4.2 Procedure

Each experiment measured the Speech Reception Threshold (SRT) at which 50 % of the sentences were understood correctly with background noise from 1 restaurant at a time. The 5 s long noise samples were played through the 64 loudspeakers and the approximately 2.5 s long sentences were played from the loudspeaker in the front. The initial level of the sentences was set well above the level of the background noise. Depending on the number of correct words identified, the sentence level was adjusted correspondingly. After a minimum of 8 reversals or 40 trials, the threshold was calculated by taking the mean of the speech levels at the reversal points excluding the first 3 reversal points. A simple up-down adaptive procedure was used for measuring the SNR at 50% correct. This procedure was chosen because it is faster to perform than e.g. the method of constant stimuli. Furthermore, it was observed by Preis (12) that no significant difference was found between the adaptive method and the method of constant stimuli when doing a similar experiment. By choosing the adaptive method, the program adaptively adjusted the level of the speech sentence based on the number of correct answers given in the preceding trial. The background noise was kept constant at the real level recorded in the restaurants, with minor fluctuations.

### 4.3 Participants

In total 20 Danish native speaking test subjects, with self-reported normal hearing, participated in the experiment, they were paid for their participation and all participants gave written informed consent. All experiments were approved by the Science-Ethics Committee for the Capital Region of Denmark.

### 4.4 Results

In Table 9 the measured SRTs are presented as well as the mean levels of the maskers and speech materials used. In Figure 3 the SRT values are also graphically presented.

An analysis of variance was performed on the data with SRT as outcome observation and test subjects and restaurants as effects, where test subjects are attributed as random effects. The model equation for the two-way ANOVA is given in Equation 2.

$$SRT_{ij} = T_i + R_j + \varepsilon , \tag{2}$$

where *SRT* is the *ij*th observation of SRT, *T* is the *i*th test subject, *R* is the *j*th restaurant and *ε* is the corresponding residual. The ANOVA model showed that there was a significant main effect of $R_j$ [$F(4,76)=6.74$; $p<0.001$]. The Shapiro-Wilk W test showed that the residuals were normally distributed with goodness-of-fit [$W=0.98$; $p=0.27$]. Despite statistical significance in the ANOVA, post hoc tests revealed that only restaurant 3 differed from the others in SRT.

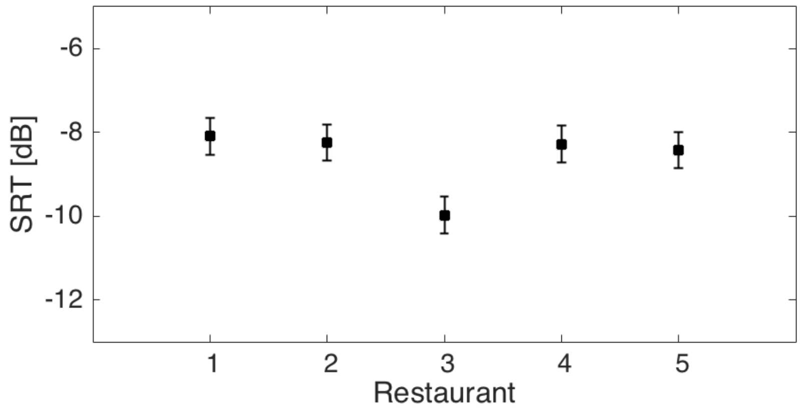


Figure 3 – Mean speech reception threshold as a function of restaurant where error bars denote the standard error of the mean.

Table 9 – Mean sound pressure levels of masker and speech stimuli at threshold i.e. 50 % of speech was understood correctly and corresponding speech reception threshold. Subscripts denote the standard error of the mean.

| Restaurant | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Test subjects [#] | 20 | 20 | 20 | 20 | 20 |
| Mean masker level [dBA] | 69.0 | 69.4 | 76.6 | 59.8 | 67.0 |
| Mean level of speech [dBA] | 60.9 | 61.2 | 66.6 | 51.5 | 58.6 |
| Speech Reception Threshold, *SRT* [dBA] | $-8.1_{0.44}$ | $-8.2_{0.44}$ | $-10.0_{0.44}$ | $-8.3_{0.44}$ | $-8.4_{0.44}$ |

## 5. DISCUSSION

The two methods of measuring subjective ratings for noise annoyance, privacy difficulty, and speech difficulty showed the same trends but laboratory ratings were generally higher in all circumstances. The fact that subjective attributes obtained in the laboratory, using realistically reproduced acoustic scenes from restaurants, were similar to what was obtained by surveys proves that the reproduction method is useful and can be recommended for future investigations. The data analysis showed that ratings were particularly dependent on the noise levels, patron densities, and utilization of acoustic capacity. An increase in density of people will ultimately increase the noise levels due to the Lombard effect (7). Both survey and laboratory results proved this relation to be true, but laboratory ratings were approximately twice as high as the survey ratings. This can be explained by the fact that people in the restaurants get used to noise over time whereas in the laboratory test subjects go from almost absolute silence to very high noise levels in a matter of seconds. Furthermore, it is reasonable that restaurant guests expect some degree of noise, because a vibrant somewhat noisy environment is associated with a busy and popular restaurant. This sort of positive association with noise is difficult to bring into a virtual environment, and could therefore be a reason why the ratings in the lab were higher.

Subjective evaluations were based on individual judgments and consequently resulted in a high degree of variance within respondents. With that in mind it was observed that the variances of the survey ratings were much larger than the variances of the laboratory ratings. A possible reason for these differences can be that guests in the restaurants do not have a reference at hand in contrast to the laboratory tests where the subjects listened to 5 different scenarios with varying noise levels. It is difficult to recall acoustic scenes by memory, but another possible reason why the variance of the survey ratings were so high could be that some guests had visited other restaurants recently and therefore used different references for answering the questionnaires.

Results obtained in this study indicate that sense of privacy is correlated with noise levels and patron density. Logically a higher patron density will result in people sitting more closely together, reducing the distance between them and hence reducing privacy. What is not logical is that an increase in noise should reduce the sense of privacy. It is apparent that more research has to be done before the term privacy is fully understood. The results in this project suggest that noise affects privacy negatively when asked: "How difficult was it to maintain a private conversation with the other guests at your table; Extremely, Very, Moderately, Slightly or Not at all?". It is not clear how respondents interpreted the question, whether they focused on how easy it was for other people to hear their voice, to what degree they could hear others' voices, or if speech from other tables just disturbed their own conversation by babble masking.

The reason for conducting SRT tests was to identify whether noise level, interior, and acoustic properties had an effect on speech intelligibility. The most dominant noise source in a modern restaurant like the ones in this study is speech noise from guests. Other noise sources are cutlery, chairs, bar, kitchen noise, and music. The acoustic scenes used in this project varied in all these aspects, where some had music, some had an open kitchen very close to the seating area. Even though the acoustic scenes and the acoustic properties varied, it was only possible to identify a difference in restaurant 3 in terms of SRT. It is thus clear that restaurants of this size should emphasize absorption to decrease the ambient noise level and hereby give the guests some relief in terms of vocal effort. It is possible that the similar SRT values are only reproducible in small to medium size restaurants, and that larger eating establishments with longer reverberation time would show different speech intelligibility scores as a function of objective parameters. Another possibility is that the test method was not sensitive enough to identify significant differences between the other 4 restaurants. Other speech intelligibility tests may show different results.

## 6. CONCLUSIONS

In this study it was found that noise annoyance was highly associated with restaurateurs seating guests too closely together. Noise annoyance correlated well with patron density and the associated noise levels produced. Furthermore surveys did prove that relatively high noise levels i.e. 76.7 dBA led to a mean response of slightly/moderately annoyed. This indicates a relatively high noise tolerance in restaurants. Speech difficulty was found to be dependent on the amount of people, the volume, and the RT, as suggested by Rindel (6). One should note that the patron density, i.e. patrons per $m^2$, was an equally strong predictor for speech difficulty as utilization of acoustic capacity, and further investigations are needed in order to determine which predictor is the most reliable. SRT values for the 5 different restaurants proved to be similar with restaurant 3 as one exception. The term "Sense of privacy" is still very difficult to define, but there is evidence that it is dependent on noise levels. This was supported by the fact that both restaurant surveys and laboratory experiments produced the same results when respondents were asked "How difficult was it to maintain a private conversation with the other guests at your table?". The reproduction of acoustic restaurant scenes in a VSE proved to be useful and supported the surveys with similar trends of subjective evaluations of acoustic comfort produced both in the laboratory and on site with questionnaires.

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