Impact of late sound reflections on acoustic conditions in a restaurant integrated in a large shopping mall

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Summary
The background noise in large shopping malls or atria covered by glass is typically and dominantly generated by the people present. The combination of a large hall volume with the presence of many hard surfaces is responsible for audible late sound reflections. Although the total sound level in shopping malls is not extremely high, background noise can have a substantial impact on acoustic comfort in restaurants integrated in such spaces, and thus on the behavior of their visitors. Our study is based on a number of laboratory perception tests, in which two test persons were exposed to a controlled time varying auralized background restaurant sound in which they were supposed to lead a dialogue. The sound levels of two talking people were monitored and analyzed in terms of their vocal output under different noise conditions and privacy settings.

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1. Description of the experiments

Experiments were designed for two kinds of "distance setting", three kinds of "privacy settings" and one background noise profile. In each experiment a vocal output of two talking people sitting opposite each other was monitored. People were seated in the listening room of the acoustic laboratory at TGM Wien, at the table arranged to evoke the restaurant environment. The width of the table between the two people was 80 cm. Two different distance settings (DS) were used in experiments. In the first one (DS1), a fixed distance of 80 cm was presumed between the two talking people not allowing them to move in order to get closer to each other (for sake of improvement of the signal to noise ratio). In the "flexible distance" setting (DS2), test persons were allowed to change their mutual distance by moving head forwards, in order to increase the speech intelligibility and speech privacy at the same time. Their mutual distance was monitored by a camera and measured by a scale placed behind them. In each of the two distance settings, three kinds of "privacy settings" (PS) were applied. In the first one "privacy setting 1" (PS1), no special request was asked to test persons and they could freely talk and adopt their voice to background sound so that they could easily communicate with each other. In the second setting, "privacy setting 2" (PS2), a balance between speech privacy and speech intelligibility was questioned. Test persons were asked to optimize their vocal output so, that a partner at the table could follow the conversation but a virtual person sitting at 1,6 m distance wouldn't. In the third setting "privacy setting 3" (PS3), a virtual

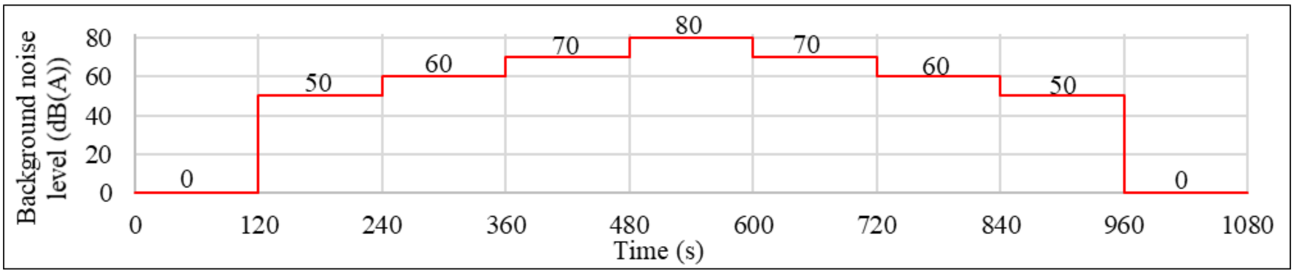

Figure 1 Profile of a background noise level, used during perception tests

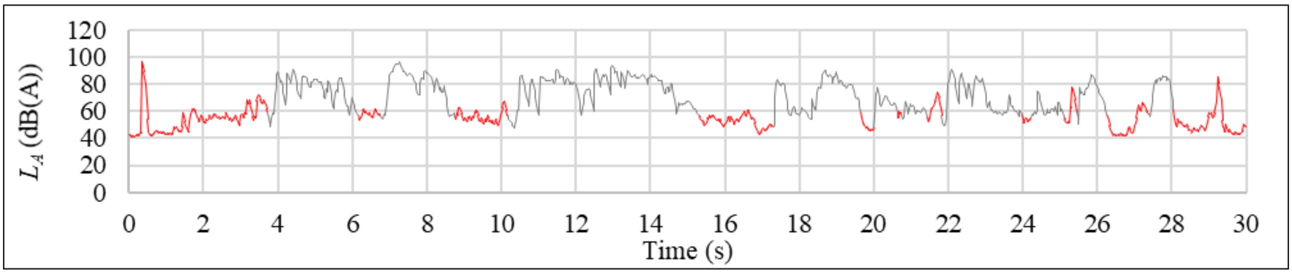

Figure 2 Example of a sound sample with indication of analyzed signal (gray) and silent and/or unwanted sounds in a speech recording (red).

person was sitting at the distance of 3,2 m. 12 people (6 male, 6 female) have participated on laboratory experiments. In total 36 dialogues were analyzed. Each test person was wearing an open headphone and microphone placed at 5 cm from his/her mouth. Controlled, time varying background noise, typical restaurant sound, was played through headphones to both test participants simultaneously. The background sound pressure level profile is shown in the Fig.1.

2. Results and Analysis

Data analysis was performed on a calibrated recording of speech. For calculation of the sound pressure level, an integration interval of 25 ms was used. This value was optimized based on strong fluctuation in speech in time. In order to perform an analysis that expresses the vocal effort of a talking person, silent parts as well as coughing or "hmm" sounds were removed from recording before the analysis.
Example of an A-weighed sound pressure level in a time domain with indication of kept (gray) and removed (red) parts is shown in the Figure 2.

2.1. Test A1 (distance setting 1): Fixed distance between subjects (80 cm)

First set of tests (Test A1) was performed under the fixed distance between the two test persons (DS1). Statistical analysis was applied on each time

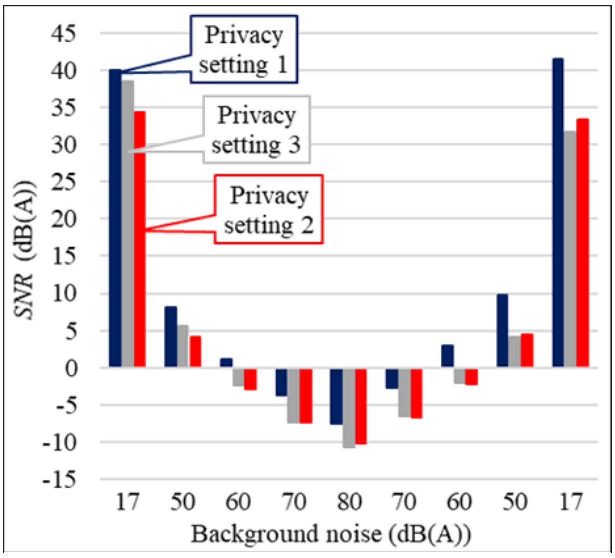

Figure 3 The signal-to-noise ratio at the position of listener at the distance 80 cm.

step/interval based on perceived background noise level, as shown in Figure 1.
The Figure 3 shows the signal to noise ratios kept under different background noise levels. Signal was calculated from a voice recording of talking person at 5 cm from a persons' mouth and recalculated at the position of the ears of a partner in conversation (i.e. the other test subject). The background noise in the tests was the controlled noise played via opened headphones in listeners ears. We can see a trend between the 3 privacy settings. As expected, the largest values of S/N ratios are in case of privacy stetting 1, (Figure 3, blue bars) where privacy of

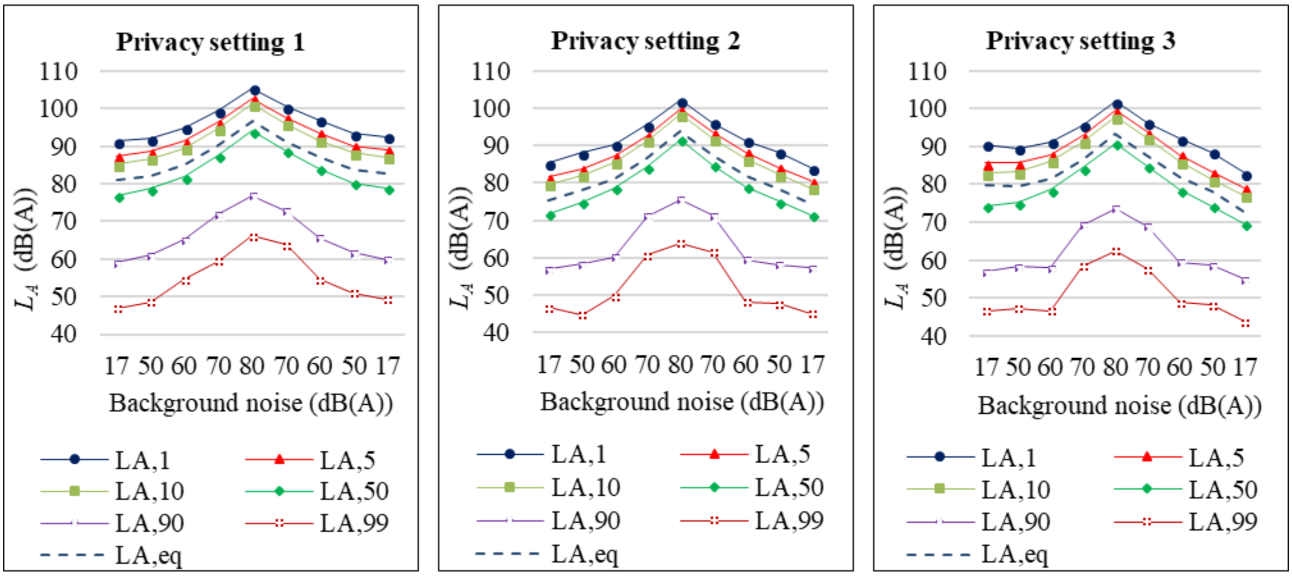

Figure 1 Statistical analysis of voice level at different background noise levels.

speech was not considered. The largest differences between privacy setting 1 and privacy setting 2 were observed at low levels of background noise, which is a logical result. At very low levels of background noise, such as 70 – 80 dB, where S/N is from - 5 to - 10 dB, it is not expected that someone at a near table (at 1,6 m distance) will be able to follow the conversation easily.
In case of the tests "without limitation", i.e. privacy setting 1 where subjects were not requested to keep eye also on their speech privacy, a quasi linear increase and decrease of vocal output is observed (Figure 4 – left).
The absolute sound levels are higher than in cases where speech privacy was also involved. Similar trend is observed for privacy setting 2, but the sound levels are slightly lower, mainly for lower values of background noise. In case of privacy setting 3, there were no significant differences in comparison with a case where people were not restricted to keep a privacy of speech.

2.2. Test A2 (distance setting 2): Variable distance between subjects

In the second set of tests (Test A2), the starting distance between the talking test persons was 80 cm, but head movements were allowed during the experiment.
The nearest physically possible distance between the two talking people was ca 40 cm, however people were reaching distances only up to 55 cm between them. If we look at the results showing the head movements of test persons (Figure 5) we will see that the nearest approaching distance is at maximal background noise level (of 80 dB).

Interestingly both privacy settings PS2 and PS3 resulted in the same values at the highest noise conditions, whereas the PS1 has allowed people to keep larger distance of 65 cm.

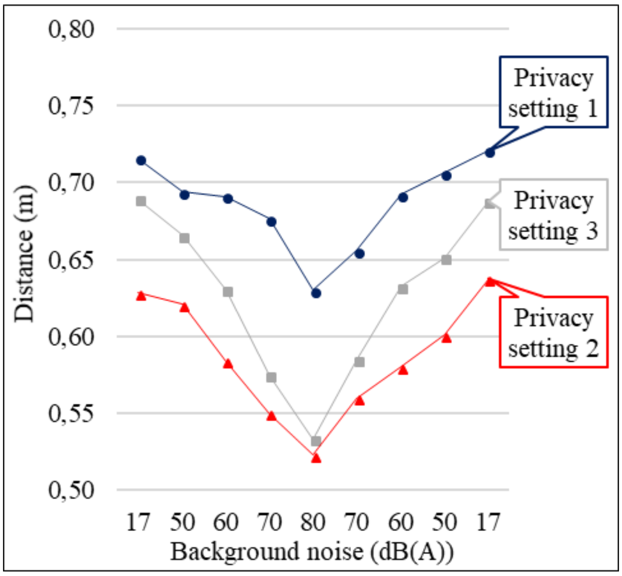

Figure 5 Distance between the tested subjects under different background noise conditions.

If we look at the statistical analysis of speech signal by means of $L_{A,10}$ and $L_{A,90}$, we can see that the variation in speech levels are less pronounced at higher levels of background noise (ca 14 – 15 dB). In cases, in which people were exposed to relatively low levels of noise, the sound pressure level variation in their speech was reaching significantly

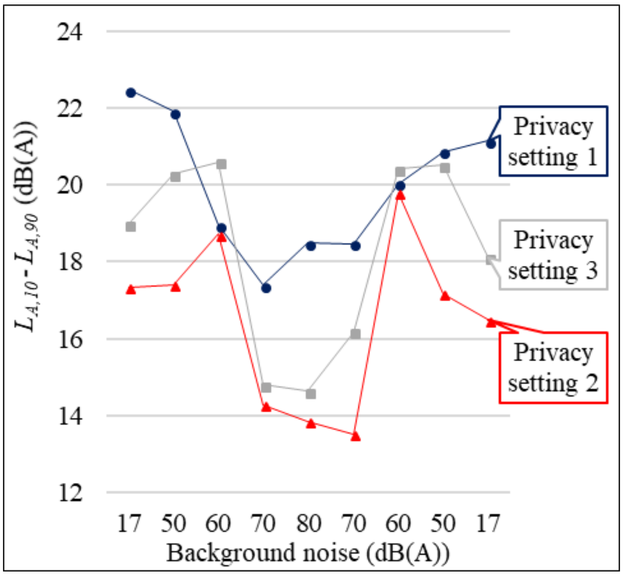

Figure 6 Difference between the $L_{A,10}$ and $L_{A,90}$ showing spread of values.

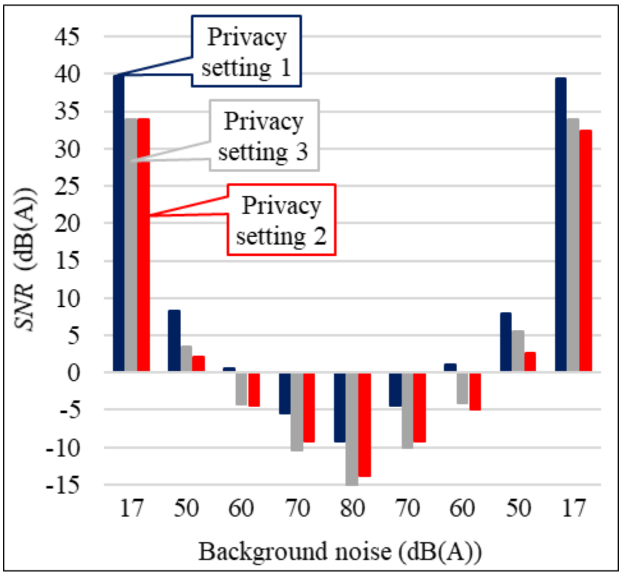

Figure 8 The signal-to-noise ratio at the position of listener at the variable distance.

higher values between 16 – 22 dB difference between $L_{A,10}$ and $L_{A,90}$ (Figure 6). Whereas the distance between people was under increasing background noise changing almost lineary in all privacy settings, the variations in sound levels were very similar for noise of 70 and 80 dB and (very similar for PS2 and PS3). Also amplitude variations in speech were very similar for noise levels 17 – 60 dB. It can be therefore concluded, that level variations are changing more abruptly when background noise level is increasing from 60 to 70 dB. Results from the 3 different privacy settings are shown in the Figure 7. There is an obvious difference between the three settings. The flexible distance has helped to reduce the voice levels by ca 10 dB in PS2 in comparison with PS1. Interestingly also results of PS3 were strongly affected by the flexibility in mutual distance between people.

The Figure 8 illustrates the signal to noise ratios in experiments in which people were allowed to move their heads towards each other. If we compare these results with those from the test A1 with fixed distance betwen people, only little differences in S/N in average are observed. The most significant is the improvement in S/N ratio in privacy setting 2. The fact that people were allowed to change the distance betwen them has help them to improve the S/N ratios up to 5 dB, (while keeping the speech privacy).

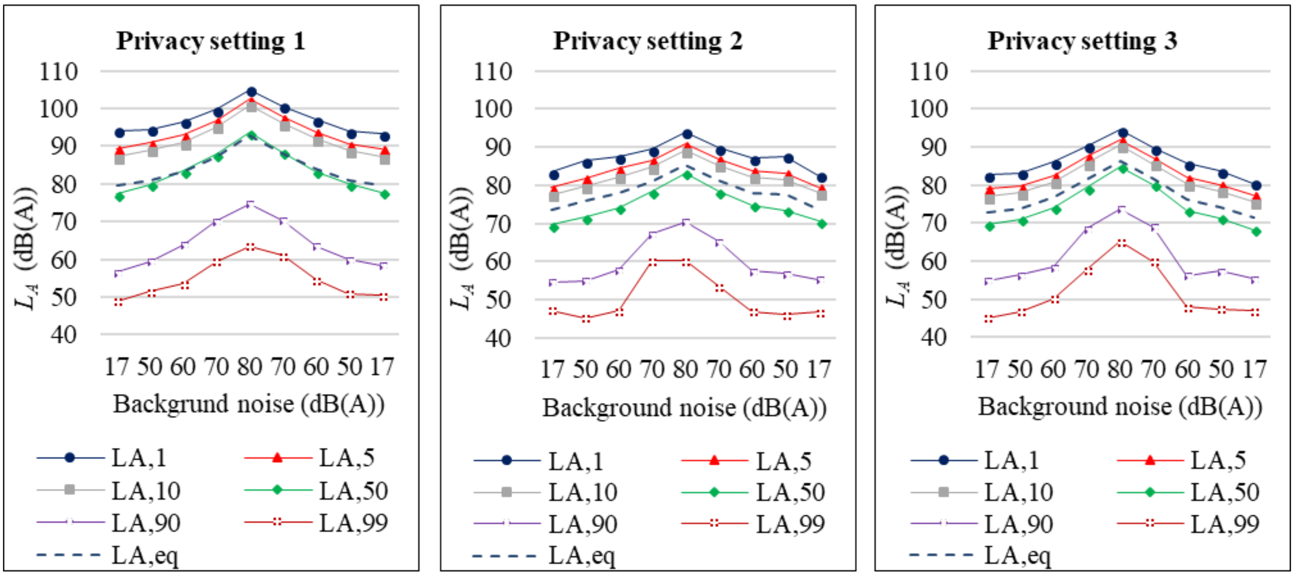

Figure 7 Statistical analysis of vocal effort and calculation of equivalent level of vocal effort depending on the background noise level.

3. Conclusions

In this article a vocal output of people under different background noise conditions was monitored. 2 different distance settings and 3 different privacy settings were compared. There was a significant difference found between the two distance settings and also between the privacy settings. In case of flexible distance and allowed head movements, improved signal to noise can be reach around 5 dB while keeping the same privacy conditions and has also helped to reduce the voice levels by ca 10 dB in PS2 in comparison with PS1.

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