THE EFFECTS OF ROOM ACOUSTICS ON THE SPEECH PRIVACY OF MEETING ROOMS

John S. Bradley, Marina Apfel and Bradford N. Gover

Institute for Research in Construction, National Research Council, Montreal Rd., Ottawa, K1A 0R6

Introduction

Initial listening tests [1] established a uniform weighted signal-to-noise ratio (SNR_{UNI32}) as a good predictor of both the intelligibility and audibility of speech transmitted from an adjacent room. The same work established criteria for the speech privacy of meeting rooms in terms of the thresholds of audibility and intelligibility of speech from the room. However, subsequent validation tests in actual rooms [2] suggested that the criterion values were influenced by spatial and temporal room acoustics effects. Further listening tests reported here can quantitatively explain the differences.

The Previous Listening Tests

The initial listening tests [1] were carried out in approximately free-field conditions. As shown in Figure 1, speech sounds, modified to represent transmission through various walls, were reproduced by loudspeakers in front of the listener. Simulated ventilation noise was radiated from loudspeakers above the subject. The realistic separation of the speech and noise sources was intended to represent a worst-case condition for speech privacy in which the subject could understand more of the speech sounds.

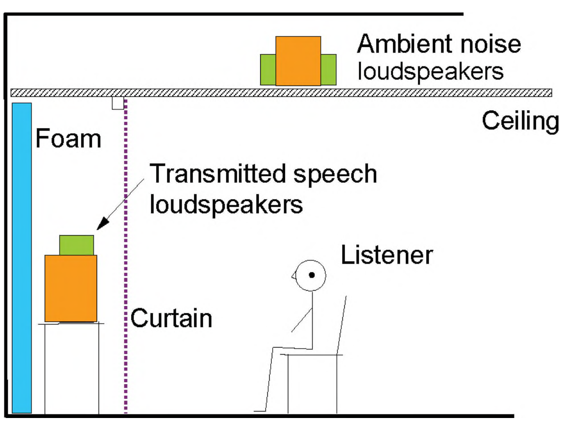

Figure 1. Initial listening test [1] set up in approximately free-field conditions.

The subsequent validation tests [2] involved radiating speech into one room from where it was transmitted through actual walls into a second room as shown in Figure 2. Both rooms had moderate reverberation times (0.8 and 0.64s) and simulated ventilation noise in the receiving room arrived diffusely at the listener who was located 0.25 m from the test wall. Although exactly the same speech tests were carried out, some results were quite different than in the first free-field experiment. Ratings of the audibility of speech sounds were very similar in both experiments. However, the intelligibility of the transmitted speech and the threshold of the intelligibility of the speech were different and the differences were equivalent to over a 5 dB change in signal-to-noise ratio. Ignoring these effects could lead to a costly over-design of the meeting room sound insulation.

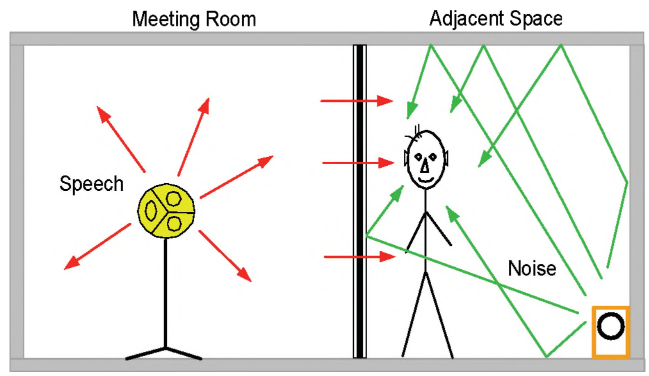

Figure 2. Two-room validation test setup in which subjects heard speech from an adjacent room in the presence of diffuse simulated ventilation noise.

New Listening Tests

New listening tests were carried out to understand the differences between the two previous tests, and how spatial and temporal room acoustics effects influence speech privacy. The new tests were carried out in simulated conditions in an anechoic room. Speech and noise test sounds could arrive from one or more of the 8 loudspeakers shown in Figure 3. Speech sounds from each loudspeaker could include: (a) direct sound only, (b) direct sound plus early reflections, or (c) direct sound, early reflections and reverberant sound. Simulated ventilation noise arrived from one loudspeaker or incoherently from all loudspeakers. The subjects repeated back test sentences so that the intelligibility of the speech could be determined.

Summary of Listening Test Results

It is well known that separating speech and noise sources in free-field conditions leads to a Spatial Release from Masking (SRM). SRM means that spatially separating speech and noise sources reduces the masking effect of the noise on the speech and hence leads to increased intelligibility scores. The magnitude of the release from masking can be described by the equivalent signal-to-noise ratio change relative to the case of coincident speech and noise sources.

In these new results these effects were sometimes further complicated by the addition of diffuse noise rather than uni-directional noise as well as varied amounts of early reflections and reverberant speech energy.

Figure 3. Eight-channel room acoustics simulation system in anechoic room.

The following key results were obtained:

Horizontally separating speech and noise sources by 32 degrees in free-field conditions reduced the masking effects on the speech by over 5 dB (in terms of equivalent signal-to-noise ratios) relative to the case of coincident speech and noise sources.

When diffuse noise was used instead of uni-directional noise, the results were similar to the case of coincident speech and noise sources for which there is no spatial release from masking.

A 90-degree vertical separation of speech and noise sources reduced the masking effects on speech by approximately 2 dB relative to the case of coincident speech and noise sources.

As expected [3], added early reflections of speech sounds that arrived within 50 ms after the direct sound had no effect on the intelligibility of the speech when the total speech level was kept constant.

When reverberant speech was added, while maintaining a constant overall speech level, the increase in the masking effect of the noise (in terms of equivalent signal-to-noise ratio) was proportional to the logarithm of the reverberation time (T_{60}) above T_{60} values of 0.5 s.

Diffuse noise and reverberant speech had additive independent effects that both increased the masking of the speech relative to spatially separated speech and noise sources.

The masking effects of the speech were the same for both natural speech and speech modified to represent the change in spectrum shape after transmission through a wall when using SNR_{UNI32} values to describe the conditions. For other signal-to-noise measures transmission through a wall changed the magnitude of the effects.

When simulated ventilation noise was radiated predominantly from groups of 3 loudspeakers, results were intermediate to those for completely diffuse noise and uni-directional noise.

Differences Between the Two Previous Experiments

The differences between the initial free-field and two - room experiments described in Figures 1 and 2 can be explained as due to two factors:

(1) The difference between the vertically separated speech and noise in the free-field experiment and the diffuse ambient noise in the two-room experiment changes the masking of the speech equivalent to about a 3.2 dB shift in signal-to-noise ratio.

(2) The room reverberation in the two-room experiment led to a further 3 dB increase in the masking of the speech, equivalent to a 3 dB increase in noise level.

The combined 6.2 dB effect is a reasonable estimate of the observed effects on intelligibility scores and intelligibility thresholds. In other rooms the differences could be a little larger or smaller depending on the actual reverberation times and spatial characteristics of the sounds.

Conclusions

The new results give a good estimate of the differences between the free-field and two-room experiments. They also give a quantitative indication of the importance of spatial and temporal room acoustics factors on the speech privacy of enclosed rooms. This improved understanding will make it possible to estimate the likely effects for other situations as they arise and to avoid costly over-design of the sound insulation of rooms.

Acknowledgements

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References

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[2] Bradley, J.S. and Gover, B.N., "Validation of Architectural Speech Security Results", IRC Research Report, RR-221, March 2006.

[3] Bradley, J.S., Sato, H. and Picard, M., "On the Importance of Early Reflections for Speech in Rooms", J. Acoust. Soc. Am. 113 (6) 3233-3244 (2003).