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Abstract. Excessive noise and reverberation times degrade listening abilities in everyday life environments. This is particularly true for school settings. Most classrooms in Italy are settled in historical buildings that generate competitive acoustic environments. So far, few studies investigated the effect of real acoustics on speech intelligibility and on the spatial release from masking, focusing more on laboratory conditions. Also, the effect of noise on speech intelligibility was widely investigated considering its energetic rather than its informational content. Therefore, a study involving normal hearing adults was performed presenting listening tests via headphone and considering the competitive real acoustics of two primary-school classrooms with reverberation time of 0.4 s and 3.1 s, respectively. The main objective was the investigation of the effect of reverberation and noise on the spatial release from masking to help the design of learning environments. Binaural room impulse responses were acquired, with noise sources at different azimuths from the listener's head. The spatial release from masking was significantly affected by noise type and reverberation. Longer reverberation times brought to worst speech intelligibility, with speech recognition thresholds higher by 6 dB on average. Noise with an informational content was detrimental by 7 dB with respect to an energetic noise.

1. Introduction
Poor acoustic conditions in classroom are detrimental for talkers and listeners. The former may incur into excessive vocal effort to be heard [1,2], the latter are challenged in discriminating useful sounds like target voices from background sounds like people chatting [3,4].

Long reverberation times and excessive noise in classrooms are the main acoustic properties to be controlled to provide teachers and students with optimal conditions [5]. Most classrooms in Italy are settled in historical buildings with big volumes and vaulted ceilings that create unfavourable acoustic environments that do not comply with national or international standards [6,7]. Focusing on the listening task, classrooms typically include students with different mother tongues, backgrounds, and cognitive abilities, which requires development of strategies for the enhancement of speech intelligibility that account for different premises at the same time [8,9]. First, it is crucial to assess impact of classroom acoustic on speech intelligibility using accurate and multilanguage speech tests [10] in order to make the recommendations and standards comparable across languages. Then, there is a need to go beyond the available knowledge as research has primarily focused to study the effect of reverberation and stationary noise on speech intelligibility [11]. Spatial listening including binaural aspects were investigated mainly under laboratory conditions [12,13], whereas only few studies considered these aspects in ecologically valid environments. Last, the effect of noise on speech intelligibility was widely studied considering its energetic and not its informational content [14].

This work investigates the combined influence of reverberation and noise on binaural aspects of speech intelligibility in two real primary school classrooms. Listening tests were based on the "Simplified Matrix Sentence Test" (SiIMAx) [15], that was optimized and evaluated for accurate and internationally comparable measurements of speech recognition. Here it is adapted for the research investigation under real classroom acoustics.

2. Method

2.1. Case study and experimental set-up

Five experiments were designed to study the effects of reverberation and masking noise (both energetic, EM, and informational, IM) on speech intelligibility in two representative Italian classrooms, one with acoustical treatment (room A with reverberation time, T30, of 0.4 s) and one without (room B with T30 of 3.1 s), where binaural room impulse responses were measured at a head and torso simulator ears (model 4128 by Brüel&Kjær). The speech-source consisted in a TalkBox (by NTi Audio) that has the same polar directivity diagram of the human voice, and the noise-source consisted in an omnidirectional dodecahedron (by Brüel&Kjær).

In each experiment, different talker-to-receiver distances and noise source position were considered, in order to reproduce typical classroom scenarios. In particular, the receiver was placed at two distances from the speech-source in room A, i.e., at 1.5 m and at 4 m, and at three distances room B, i.e., at 1.5 m, 4 m and 6.3 m. The noise-source was moved around the receiver's head at several angles, i.e., at 0°, 120° and 180°, and distances, i.e., at 1 m and 2.5 m, in order to investigate on the spatial release from masking due to the spatial separation of the noise source from the speech-source.

2.2. Listening tests preparation and administration

The recorded binaural impulse responses were convolved with the speech and noise signals to consider different location and distances under real acoustic conditions. Using the open-set format of the SiIMax test, speech intelligibility was evaluated in terms of Speech Recognition Thresholds (SRTs) with an adaptive procedure adjusting the signal-to-noise ratio (SNR) to yield 80% correct recognition scores (SRT80, dB SNR). The noise level was fixed at 60 dB corresponding to the average level of background noise in real classrooms [16,17].

Listening headphones (Sennheiser HDA200) tests were performed in the anechoic room of Politecnico di Torino, Department of Energy, with 43 normal-hearing adult listeners (mean age 28.0 ±6 years). Based on the acquired absolute values of SRT80s, the Spatial Release from Masking (SRM) was calculated as the difference between the SRT80 measured with the noise source in the co-located (at 0° or 180°) and spatially separated (at 120°) positions [18]. SRM values were compared across different acoustic conditions, i.e., EM *vs* IM noise, and low *vs* high reverberation.

3. Results

3.1. Influence of masker type and reverberation on speech recognition

Regardless of the talker-to-listener distance, average SRT80s were lower (better) when reverberation time was shorter (classroom A) and when EM was present. High reverberation time (classroom B) resulted in an average detrimental effect of 5.7 dB compared to the conditions with low reverberation time (classroom A) (with mean SRT80s of -6.8 dB SNR and -0.8 dB SNR in classroom A and B, respectively, under IM, and of -13.0 dB SNR and -7.6 dB SNR in classroom A and B, respectively, under EM). The negative effect of having an IM noise could be evaluated in a higher (worse) average

SRT80 by 6.1 dB SNR and 6.8 dB SNR in classroom A and B, respectively. Although these results could be expected, there is a lack of evidence in the magnitude of the effect of real classroom acoustics on speech intelligibility as the combined influence of real reverberation and noise is still under intensive research now.

3.2. *Spatial release from masking (SRM) as a function of reverberation and noise*

Figure 1 reports the configurations based on which the calculations of SRM values were obtained in classroom A and B, and table 1 gives the results of these SRM calculations. Based on the application of a one-way ANOVA, a statistically significant difference (p-value < 0.05) was found under both reverberation conditions when SRM was measured under IM and EM for close talker-to-listener (1.5 m) and noise (1 m) distance. So far, unforeseen significant SRM were found under very low reverberation with EM and under very high reverberation with IM, anyway, always consisting in about 3 dB of spatial benefit. Particularly, in classroom A only under EM for target-to-listener distances of 1.5 m and 4 m and for noise-to-receiver distance of 1 m. In classroom B, instead, a significant SRM only occurs in the case of target-to-listener distance of 1.5 m and noise-to-receiver distance of 1 m.

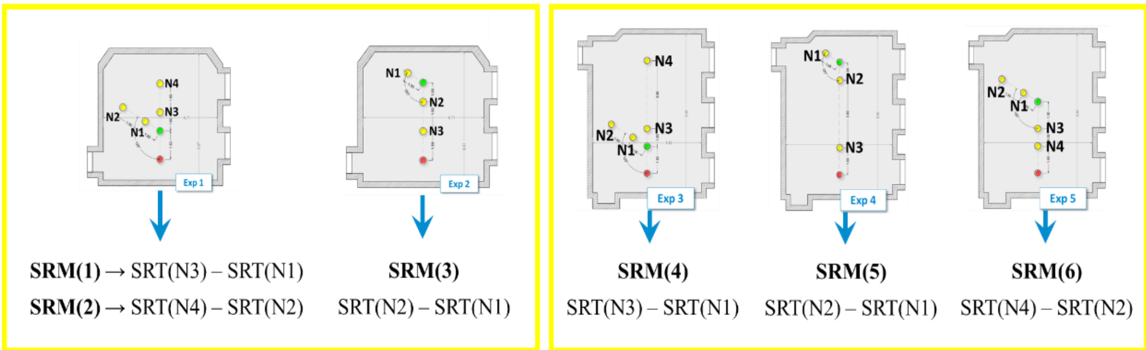

Figure 1. Scheme of the Spatial Release from Masking (SRM) configurations based on the speech recognition thresholds (SRT) from experiment 1 (Exp1) to experiment 5 (Exp5), in classroom A with low reverberation (left) and in classroom B with high reverberation (right). The noise source position is identified with letter "N" and a progressive digit.

Table 1. Spatial Release from Masking (SRM) for the different spatial configurations and under energetic (EM) and informational (IM) masking noise.

Classroom A				Classroom B			
Configuration		Under EM	Under IM	Configuration		Under EM	Under IM
SRM(1)	$T_{1.5}M_1$	***2.8***	*0.4*	SRM(4)	$T_{1.5}M_1$	*-0.2*	***3.4***
SRM(2)	$T_{1.5}M_{2.5}$	-0.7	0.4	SRM(5)	$T_4M_{2.5}$	-0.3	1.4
SRM(3)	T_4M_1	**3.4**	0.7	SRM(6)	$T_{6.3}M_1$	1.4	1.9

In summary, these results may help in the acoustic design of classrooms as long reverberation times and excessive noise levels in learning environments degrade speech intelligibility. Having measured SRM values for several spatial configurations also highlighted which conditions can be worse for a listener and thus may contribute in understanding the effects of, e.g., open plan *vs* traditional approaches in teaching and learning settings.

4. Conclusions

The main outcomes of the presented work can be summarized as follows:

- The extent to which reverberation and noise type, i.e., informational and energetic masking, affect speech intelligibility is still largely unexplored under ecological settings. This study highlighted that longer reverberation time and noise with informative content significantly degrade speech recognition, thus a poor acoustic design of classrooms may play a critical role on learning with consequences on the cognitive development of children;

– Spatial benefits in terms of SRM were found in the maximum range of 3 dB for EM under short reverberation and for IM under long reverberation. Further investigations on this are needed to implement everyday practice, especially deepening the perceptual segregation of speech from noise in real complex auditory scenes.

Acknowledgment
This research was partially supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Projektnummer 352015383 – SFB 1330 A5.

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