AN OBJECTIVE ASSESSMENT METHODOLOGY FOR A SOUND FIELD AMPLIFICATION SYSTEM IN SIMULATED CLASSROOM

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1 INTRODUCTION

The assessment of the acoustical quality of schools both objectively and subjectively has been extensively investigated [1,2,3]. It has been found that speech intelligibility in rooms with poor acoustics was detrimental to learning [4,5,6], as have classrooms with high levels of background noise [7,8,9]. There was particular acoustic related learning difficulties with bilingual children or children with additional needs in poorly performing spaces [10]. However, sound field amplification has been found to provide improve children's behaviour in cross cultural environments [11,12,13].

With a significant investment in new schools and a programme of refurbishment currently being undertaken in the UK, it is necessary to determine how to most effectively improve speech intelligibility in classrooms [14], either by reducing the room reverberation through the application of acoustic treatment, the introduction of a sound reinforcement system into room, or a combination of the two approaches. This type of comparison has not been undertaken before, as the algorithms used in sound reinforcement systems are not disclosed. To this end this paper attempts to objectively quantify under what conditions such a system improves speech intelligibility considering two variables: ambient noise and reverberation both with and without the sound reinforcement system giving a total of 50 scenarios. The paper details the equipment setup, the experimental method used, and provides results in the form of a new term: effective noise reduction for the various scenarios. From these results an empirical model was proposed which could be used as a tool to help make informed decisions as to what approach to take in refurnishing classrooms or similar spaces.

2 EXPERIMENTAL PROCEDURE

The reverberation chamber at London South Bank University was used for the tests to simulate a typical Victorian classroom, volume of 202 m^3 and surface area of 213 m^2, under a number of acoustic conditions. Porous sound absorbing material (0.17 m thick hung in strips on the wall) was introduced into the space to achieve different reverberation times (T_{60}) at 1 kHz (0.4, 0.6, 0.8, 1.0 and 1.2 s), see Figure 1.

Figure 1 The reverberation chamber showing the measurement setup including absorption,T_{60}=0.4 s

A mouth simulator (Berhinger B205D loudspeaker) was positioned at the front of the room at a height of 1.5 m. A STIPA signal, set at 65 $dBL_{Aeq,\ 15s}$ at 1 m in the free field, was used to determine the speech transmission index using the STIPA method [15], at the measurement microphone 2.5 m from the loudspeaker 61.2 $dBL_{Aeq,15s}$ in the simulated classroom. In addition, two loudspeakers (Yahama HS50M), positioned 2.5 m from the measurement microphone, see Figure 2, generated competing random noise (with the same spectral envelope as the STIPA signal) at five levels to give a controlled signal to noise ratio.

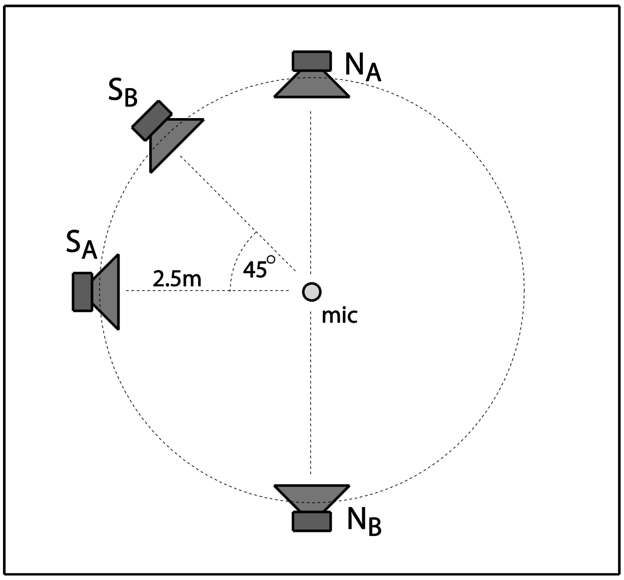

Figure 2 Shows the position of the mouth simulator (SA), the sound field amplification system (SB), and two noise generating sound sources (NA and NB)

For each T_{60} value, a baseline STIPA measurement was made for each competing noise level (40,50, 55, 60, 70 dBA) chosen, see Table 1. Once the baseline was determined, the Phonak Digimaster 5000 sound-field amplification system (SFA), with the SFA boom microphone placed on axis at a distance of 0.05 m, was activated and allowed to acclimatize to the noise for 20s before the measurement was taken. Based on this measurement, an iterative process was used to adjust the noise level until the original STIPA value was again achieved (within 0.02 over an average of three 15 s measurements).

Table 1. Measurement conditions showing the combinations of achieved reverberation times (T_{60} at 1 kHz) and competing noise levels used for the individual measurement trials.

T_{60} (s)	Background noise level	Competing noise levels ($dBL_{Aeq,15s}$)				
0.4	24.8	40.4	50.2	N/A	60.2	70.3
0.6	24.8	40.1	50.3	N/A	60.1	70.1
0.8	30.4	40.0	50.1	54.9	60.0	70.0
1.0	N/A	N/A	50.1	55.0	60.0	70.0
1.2	N/A	N/A	N/A	55.1	60.0	70.0

Next, the SFA system was turned off and the ambient noise level was measured. The difference between the noise levels with and without SFA that produced the same criterion STIPA was taken as a new metric, termed the equivalent noise reduction (ENR) achieved by the system.

Finally, the room impulse responses were measured under ambient noise conditions and at each of the five noise levels using winMLS 2004 based on exponential sine sweeps in accordance to ISO 3382-1:2009. This was used to measure and verify the simulated classroom's reverberation times, Figure 3. Due to the dynamic nature of the Digimaster 5000 SFA, it was not possible to measure impulse responses (which requires linear time invariance) when the SFA was active.

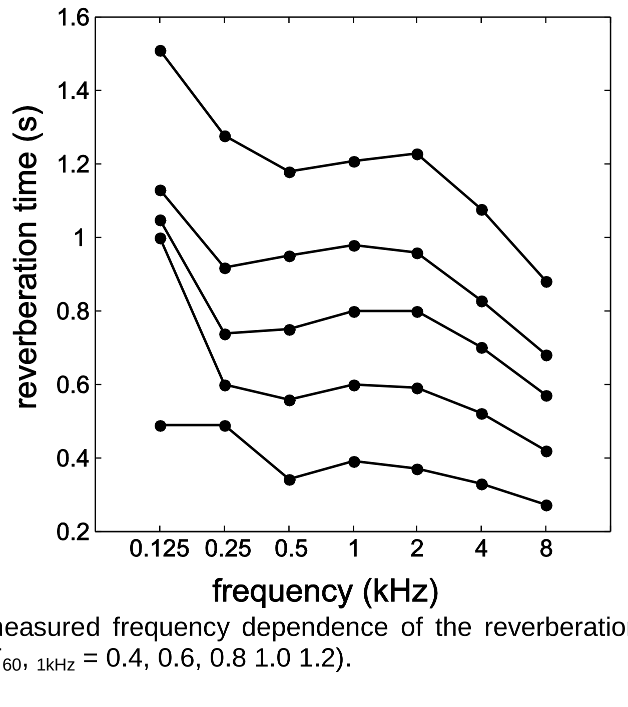

Figure 3. Shows the measured frequency dependence of the reverberation times (T_{60}) for the 5 different room setups ($T_{60,\ 1kHz}$ = 0.4, 0.6, 0.8 1.0 1.2).

3 ANALYSIS

The STIPA measurement results were plotted against competing noise levels and this data was fitted experimentally to determine the following equation:

$$STI = Ae^{-\alpha(x+0.0005)} \tag{1}$$

where x representing competing noise in terms of pressure, Pa_{rms}, (not dB SPL). The two free parameters, A and α (governing the y-axis intercept and curvature) were calculated using a Nelder-Mead search method to minimize the local sum of the squared error between the model and the data.

R^2 was calculated and used to evaluate the goodness of fit between the model and measured data. Of course, this equation is only a model for the Phonak sound field amplification system under investigation.

4 RESULTS

Activating the SFA system increased the STIPA by an amount equivalent to the increase one could achieve by reducing the competing noise, Figure 4. The amount of this 'equivalent noise reduction' or ENR was found to depend on the level of noise, the room's reverberation time and presumably the placement of the system relative to the listener.

From Figure 4, no increase in the STI metric was observed for background noise below 40 dBA, collaborating the field measurement results of Dockrell and Shield [16]. The STI metric monotonically increased with increasing competing noise but eventually saturated at 7.7 dBA ENR at the measurement microphone position.

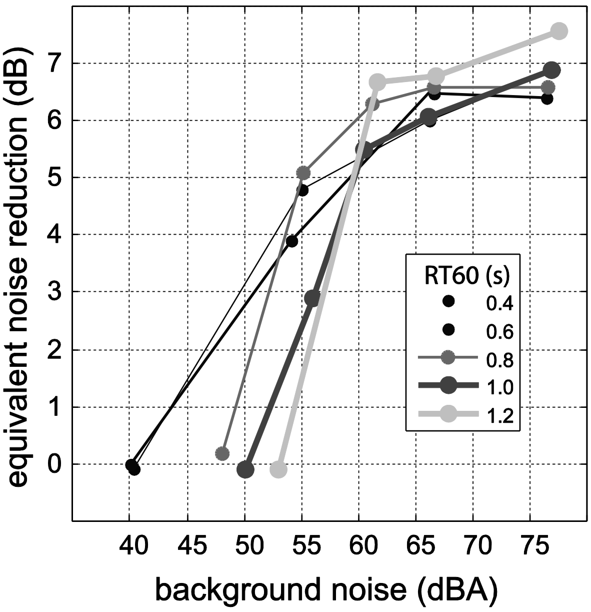

Figure 4 Shows the effect of adding the sound-field reinforcement system on STIPA terms of an equivalent noise reduction for 5 different room configurations (curves).

The same data was re-plotted as the measured STI metric vs. the measured competing noise (dBA), see Figure 5. The same two parameter model was used to fit both SFA and no-SFA datasets with excellent correlation found, all R^2 values > 0.97, see Figures 5A and 5B, respectively.

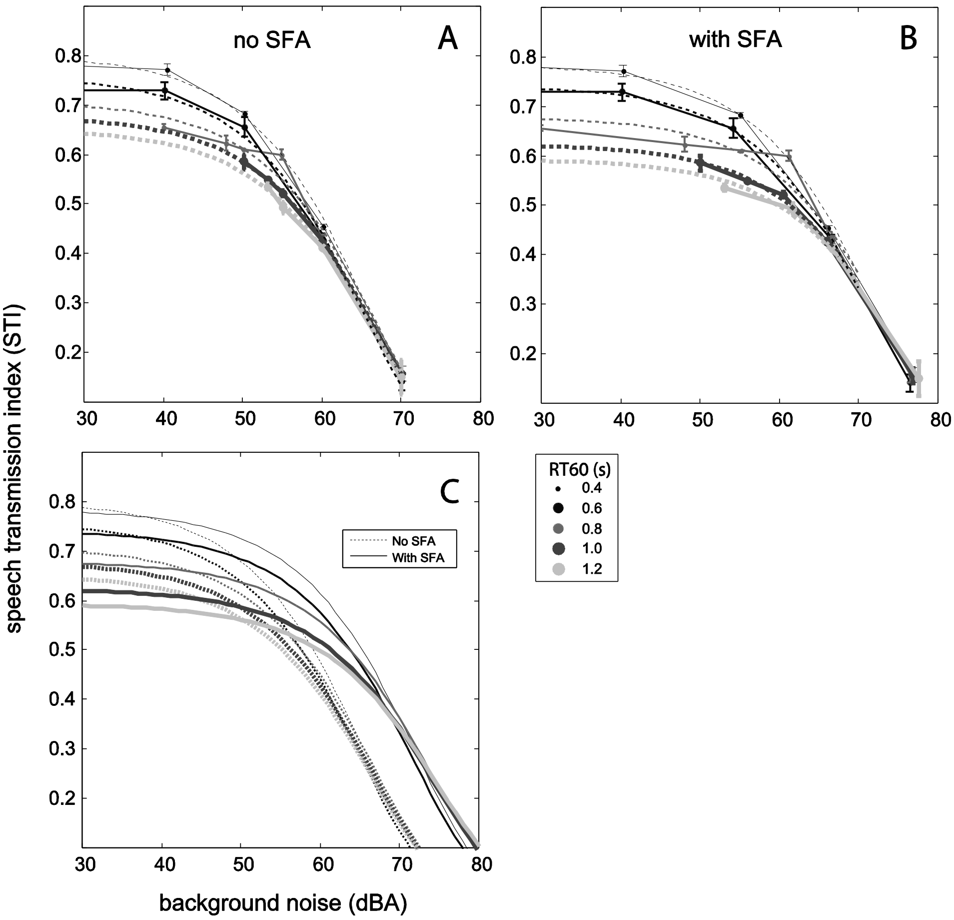

Figure 5. Panel A shows how STIPA changed with competing noise for various room reverberation times (curves) without sound-field amplification. Data points (solid) are overlaid with a two parameter mathematical model (dashed lines). Panel B shows the same type of plot with sound-field amplification. Panel C is a comparison of the model fits extracted from B.

For room reverberation times ≥ 1.0 s, adding sound-field amplification increased STIPA values for competing noise levels above 50 dBA, see Figure 5C. For reverberation times ≤ 0.6 s this threshold was 38 dBA and for T_{60}= 0.8 s it was 44 dBA. Below these thresholds the modeled data indicate that adding SFA would actually reduce STIPA and that this deterioration would be larger for more reverberant rooms, for example modeled STIPA was reduced by 0.05 for T_{60}=1.2 s.

Table 2 shows the coefficients A and alpha from equation (1) and the correlation to the measured STIPA values based on competing noise levels. From Figure 6 it can be seen that both A and alpha coefficients were affected by activating the SFA, but only parameter A was sensitive to room reverberation time. Taken together these parameters suggest that just by taking account of room reverberation a simple model can capture the effects of SFA in noisy environments in terms of speech intelligibility.

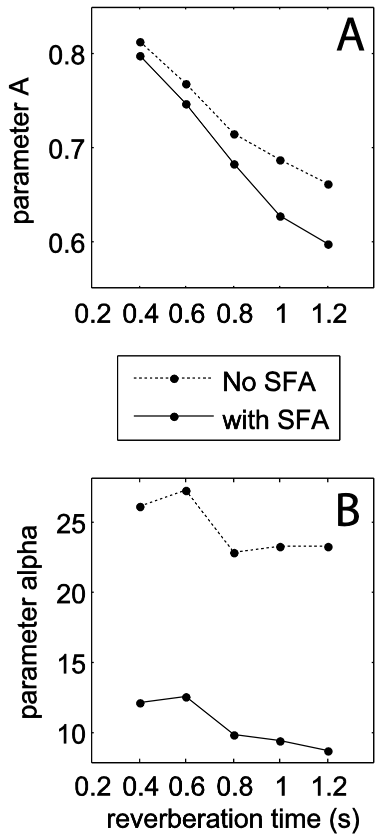

Figure 6 Shows how model parameters controlling the model's curvature (parameter alpha) and y-intercept (parameter A) are affected by reverberation time and activating the SFA.

Table 2. Model parameter values and goodness of fit, R^2 values, of the empirical model with SFA.

	Model Parameters					
	No sound field amplification			With sound field amplification		
T_{60} (s)	A	α	R^2	A	α	R^2
0.4	0.8124	26.13	0.9973	0.7989	12.2	0.9960
0.6	0.7686	27.28	0.9950	0.7466	12.68	0.9993
0.8	0.7155	22.78	0.9815	0.6823	9.93	0.9731
1.0	0.6875	23.34	1.0000	0.6277	9.47	0.9979
1.2	0.6621	23.28	0.9986	0.5974	8.72	0.9949

5 CONCLUSIONS

After a series of laboratory based measurements using different reverberant and competing noise levels the effective noise reduction (ENR) parameter was developed to indicate the potential benefit of sound-field amplification systems. Based on these measurements an empirical model was developed to predict the expected speech intelligibility performance improvement when using a sound amplification system in noisy environments under a range of reverberant conditions. The ENR parameter provided a method by which the value (performance/cost) of adding a sound-field system to a room could be compared with acoustic treatment solutions.

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