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IMPACT THAT ACOUSTIC DESIGN HAS ON HIGHER EDUCATION FOR NON-ENGLISH SPEAKING STUDENTS

Rodrigo Sanchez-Pizani and Stephen Dance

email: rgosp@yahoo.co.uk

London South Bank University, School of the Built Environment, London, UK,

Speech is one of the main forms of communication, and in teaching environments it is fundamental to transmit the message effectively. Significant amounts of research have been undertaken concentrating on measuring and studying the impact of intelligibility on native populations, particularly children. There is also evidence that the acoustic design of a room has impact on the overall student experience. This investigation therefore focuses in the analysis of the possible effects that acoustic design and characteristics of heritage buildings has in higher education environments, with a particular interest in those students for whom English is not their first language. Rooms and people with similar characteristics from King's College London were used as sample for the environmental and subjective evaluation respectively. The study compares the measured Speech Transmission Index, with the marks obtained by the students during an English exam, data from a survey to evaluate the students' experience, and a phonetically balanced word test. Results will be presented together with analysis on whether intelligibility correlates to student experience.

1. Introduction

One of the central aims of the work is to provide an internal acoustic assessment for teaching facilities in a higher education institution, and to compare these measurements with current standards and guidance.

The study of the relationship between acoustic parameters and student satisfaction then becomes the main focus, concentrating efforts in those individuals whose English is not their first language. It is based on these people and their exam results that the acoustic parameters for reverberation, noise and intelligibility are compared and analysed both objectively and subjectively. Techniques and theory is mainly dictated by the BS EN 60268-16:2011, BS 7445-1:2003, BS EN ISO 3382-2:2008, and BS EN ISO 18233:2006.

1.1 Background

Anecdotal observations seem to indicate that there is dissatisfaction from university students and the public with the overall acoustics of the rooms, particularly in heritage buildings such as those at King's College London on the Strand campus; therefore, these rooms are a good place to start to investigate the extent and impact that the acoustic design has on student satisfaction.

Previous research has shown advantages and disadvantages to acoustic treatments in university classrooms (1). In particular, the fact that excessive absorption can have an impact on the sound-to-noise ratio, and hence negatively influence unaided speech. In addition, studies have shown that students found it easier to concentrate in spaces with acoustic treatment (2); another study concludes that 'during listening tasks a substandard classroom built environment can have a measurable negative effect on adult student learning and performance' (3). It is therefore easy to theorise that acoustic design of teaching rooms will have an impact on students' results and experience, and that these results are valid for higher education environments.

For this investigation, there is actual interest in students whose first language is not English and are at tertiary level.

In addition to the above; results tested for the Spanish language, by Escobar and Morillas, indicated a relationship between the STI (speech transmission index) and the actual intelligibility in university classrooms (4) ; therefore, it seems that the initial hypothesis for the project is reasonable.

1.2 Overview

Four rooms, all with flat floors, and of a shoebox shape, were measured. The main construction comprises of concrete walls, tiled carpet, high ceilings and medium upholstery seating.

Table 1: Room Characteristics

Floor	**Room**	**Capacity**	**Volume** *(m^3)*	**Objective Test**	**Subjective**
Ground Floor	STD/K0.16	49	526.8	STIPA/RT	Survey
Ground Floor	STD/K0.18	43	537.0	STIPA/RT/PB	Survey/Exam
Ground Floor	STD/K0.20	48	575.7	STIPA/RT/PB	Survey/Exam
4th	STD/K4U.12	150	774.2	STIPA/RT/PB	Survey/Exam

From experience and first-hand conversations with several lecturers, three main forms of teaching have been identified:

- **Classic lecture**: the teacher speaks without any electroacoustic amplification or support (e.g. microphones, amplifiers, speakers, etc.) from the front of the room.
- **Classic assisted lecture**: the teacher speaks using electroacoustic aids, normally from a fixed position, usually a lectern.
- **Playback**: this is a method in which the student listens to some pre-recorded material through the installed PA system.

As the present study focuses on listed buildings and given that noise control will, in most cases, require modification to the fabric of the building (changing windows, or adding mass to walls or replacing doors, etc.) this type of work is less likely to be approved by Historic England and therefore it will be excluded from the scope of this study.

Currently there is no regulation or British Standard for the acoustic design of teaching rooms in higher education institutions in England; however, BB93 can be used as an initial recommendation (5); consequently, this is to be used as the benchmark to measure the acoustic of the heritage rooms in the report – i.e. to ensure repeatability, accepted and approved British Standards are used for measurement of values for Reverberation Time (RT) and STI.

Table 2: Standard used for Measurement

Method/Measurement	**Standard used**	**Benchmark**	**Descriptor**
STIPA	BS EN 60268-16:2011	0.6	STI
RT (Using Sweep)	BS EN 18233:2006	0.8-1 s	T_{mf}

Additionally, it is expected for poor acoustics to be one of the main contributors to student dissatisfaction, as described by Yang, Becerik-Gerber and Mino (6). Their study, however, only examines the general influence of the acoustic environment and not the individual elements. It is the intention of this research to investigate the possible impact of some of the individual factors, i.e. reverberation time, STI.

To this purpose, the results from a survey, a phonetically balanced test, and a language test are compared with the acoustic measurements of individual rooms given in Table 1.

At least 12 source-microphone combinations with a minimum of 6 different receiver locations and 2 sources positions were used to measure reverberation time. STI was measured using a mouth simulator, to comply with recommendations from current standards.

2. Measurements

Three different scenarios were studied in each room, to see if the STI changed when different system configurations were used.

- **Natural acoustics:** A Yamaha MS101 II Studio Monitor Speaker was used to reproduce a STIPA signal from a CD player without any other audio aid. Norsonic Nor140 used.
- **Program Audio or PA acoustics:** The STIPA signal was fed to the sound system directly and used the main front program audio speaker system. Norsonic Nor140 used.
- **100V system:** Three of the rooms also included a distributed sound system, and in this case STIPA was measured using the Yamaha speaker whilst the lectern microphone was on (K0.20 included an additional measurement with a tie mic)
- **Reverberation Time:** WinMLS using sweep technique through a hemi-dodec was the chosen method.

For comparison, K0.20 was also tested before and after acoustic treatment was introduced in the form of 18 panels distributed, see Figure 1.

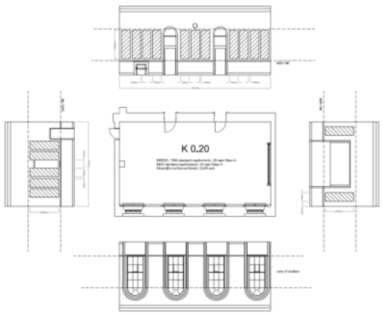


Figure 1: Installation of Acoustic Panels in Room K0.20, used with permission from King's College London

For K4U.12 STIPA measurements were taken before and after the introduction of electronic active equalisation. The results of the different measurements for all the rooms are shown in Table 3.

2.1 Results and Comparison

Figure 2, shows with a correlation of 0.82, that after equalisation in K4U.12 the STIPA measurements improve.

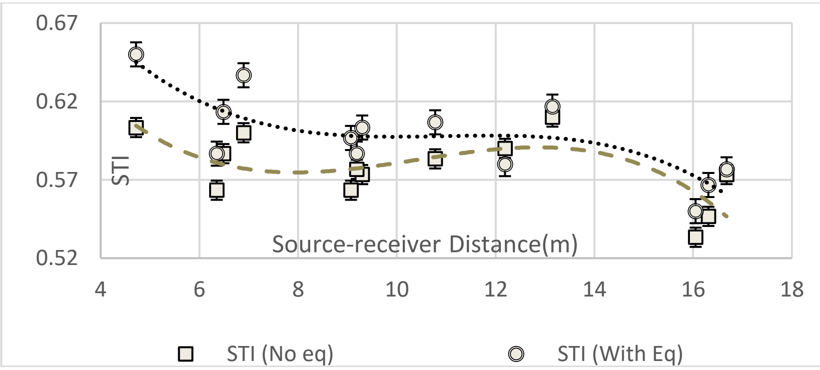


Figure 2: STIPA in K4U.12, Equalised and not Equalised,as a Function of Distance

Figure 3 seems to be consistent with the findings by Hodgson about classroom design, that these tend to favour control of reverberation having a detrimental impact on speech levels (1). Hodgson's conclusion seems to be perfectly consistent with this research, as it shows the decay in level of approximately 3dB per position when comparing level of natural acoustic in a treated and untreated room for all positions.

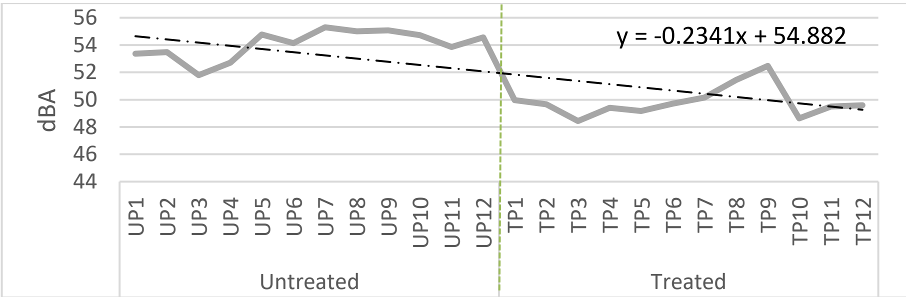


Figure 3: Comparison of Natural Acoustics Levels between an Untreated and Treated Room

Background noise and reverberation time were higher than the levels recommended by BB93, while STI showed values lower than 0.6 for all rooms, except for the treated K0.20.

Table 3 shows a clear improvement between the values obtained before (U) and after (T) the installation of the panels in K0.20.

Table 3: Summary of Results of Measured Rooms (U) And (T) Indicate Untreated and Treated Conditions and Results for Program Audio in K4U.12 Are Shown with (eq) and Without Equalisation

Parameter/Room	***K0.20 (U)***	***K0.16***	***K0.20 (T)***	***K0.18***	***K4U.12***	***K4U.12 (eq)***
STI Program Audio	*0.51 ± 0.01*	*0.49 ± 0.01*	*0.60 ± 0.01*	*0.47 ± 0.01*	*0.56 ± 0.01*	*0.57 ±0.01*
STI 100 V System	*0.41 ± 0.01*	*0.46 ± 0.01*	*0.48 ± 0.01*	*0.45 ± 0.01*	*n/a*	*n/a*
STI Natural Acoustics	*0.47 ± 0.01*	*0.47 ± 0.01*	*0.53 ± 0.02*	*0.50 ± 0.01*	*0.52 ± 0.01*	*n/a*
RT_{mf} (seconds)	*1.69 ± 0.01*	*1.65 ±0.01*	*0.96 ± 0.01*	*1.73 ± 0.01*	*1.19 ± 0.01*	*n/a*
Noise Levels LAeq (dBA)	*39*	*45*	*37*	*39*	*43*	*43*
STI value without signal	*< 0.2*	*< 0.2*	*< 0.2*	*< 0.2*	*< 0.2*	*< 0.2*
Average Temperature (C)	*24*	*27*	*24*	*26*	*27*	*27*
Relative Humidity (%)	*39*	*43*	*42*	*56*	*52*	*52*

As the STIPA results are directly related to different styles of teaching, it seems important to understand if there is any evident correlation amongst them. In Table 4, the correlation appears to improve when equalisation is added, and it becomes close to perfect for natural acoustics and distributed sound after treatment is applied; i.e. non-treated rooms have a weaker correlation between the natural acoustics of the room and scenarios where audio visual aids are used.

Table 4: Room by Room Correlation of STIPA Measurements

	Totals			**K0.18**			**K0.16**		
	(Natural)	*(PA)*	*(100v)*	*(Natural)*	*(PA)*	*(100v)*	*(Natural)*	*(PA)*	*(100v)*
STI (Natural)	1.00			1.00			1.00		
STI (PA)	0.35	1.00		-0.11	1.00		0.64	1.00	
STI (100v)	0.84	0.39	1.00	0.59	-0.23	1.00	0.71	0.35	1.00
	K0.20 (T)			**K0.20 (U)**			**K4U.12**		
	(Natural)	*(PA)*	*(100v)*	*(Natural)*	*(PA)*	*(100v)*	*(Natural)*	*PA (No Eq)*	*PA (Eq)*
STI (Natural)	1.00			1			1.00		
STI (PA)	-0.06	1.00		0.27	1.00		0.27	1.00	
STI (100v)	1.00	-0.06	1.00	0.18	0.23	1	0.43	0.82	1.00

3. Parameters Comparison

As with Escobar's research, it is noticeable that the background noise has an impact on the STI but it does not seem to be the main contributor (4). For example, in room K0.20, the circled area in Figure 4, it is evident that after the treatment of the room there is a substantial improvement in the STI despite the background noise level remaining relatively unchanged.

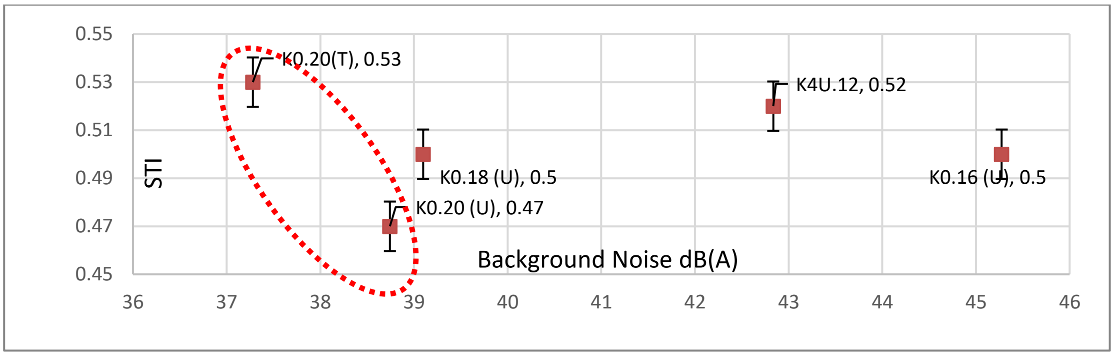


Figure 4: Comparison of Total Average STI Values per Room as a Function of Background Noise in dB(A)

The relationship between reverberation and STIPA was investigated in all four rooms and the results showed a significant relationship in all cases. However, in two of the rooms the early decay time (EDT) proved to have a better relationship than T_{20} for the mid frequency (averaged 500 Hz-2kHz).

Table 5: STI Compared as Function of $T_{20,mf}$ and EDT_{mf}

Room	F	R^2	p	Sig.	Parameter
K0.20 (U)	13.97	0.66	p<0.001	**	T_{20}
	26.08	0.78	p<0.001	**	EDT
K0.20 (T)	6.45	0.53	p<0.001	**	T_{20}
	4.31	0.43	p<0.02	*	EDT
K4U.12	15.74	0.68	p<0.001	**	T_{20}
	8.27	0.53	p<0.001	**	EDT
K0.16	0.08	0.01	p<0.97	no	T_{20}
	3.21	0.29	p<0.05	*	EDT
K0.18	1.96	0.23	p<0.2	no	T_{20}
	4.80	0.42	p<0.011	*	EDT

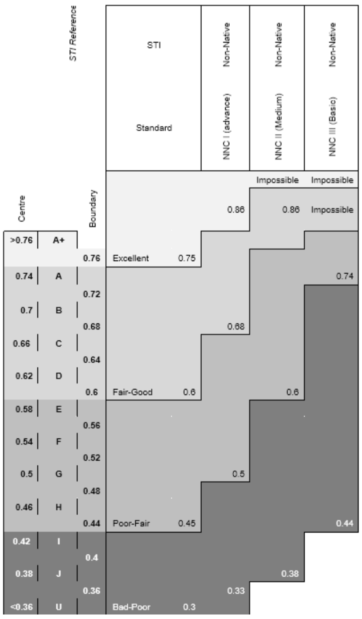
4. Intelligibility Results

To measure the impact of the intelligibility on students results, an exam administered by the English Language Centre (ELC) to a diverse population of students (28 different nationalities) whose English is not their first language was compared with the measured STI at each seat position.

It is important to highlight that students who undertook the ELC exam did so in accordance with the regular procedures, as set out by the exam board and timetable. As such, at no point were the students, knowingly nor intentionally, put in a disadvantageous position due to the research, and all conditions were made as fair as possible for the students – a real-life scenario.

Identical exam files and similar AV equipment were used in the rooms where the test was administered. The signal was adjusted to an average of 63±1 dB(A), measured at the same designated seating position in each room before and after the examination.

Table 6: Proposed Unified STI Matrix for Native and Non-Native Speakers, Based on BS EN 60268-16:2011



The group of students had a similar level of English as they all shared the same training and were at category NNCII as described in Table 6. As such, a random selection of the ELC exam score can be analysed, see Figure 5.

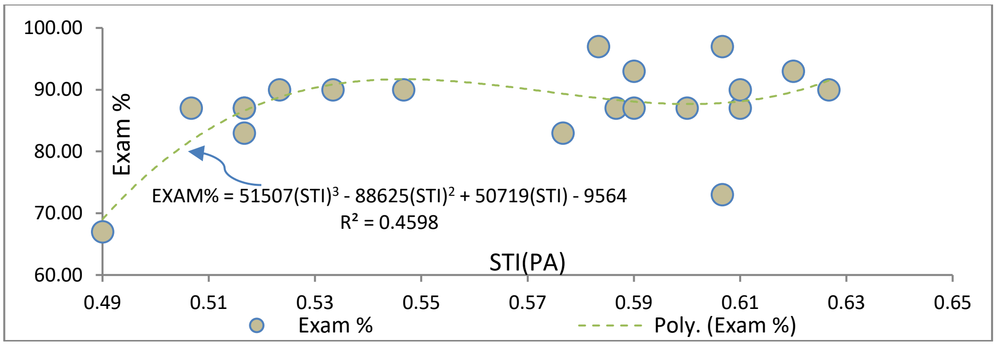


Figure 5: Exam Marks as Function of STI

Figure 5 shows that if the exam results are compared as a 1-1 relationship with the STI measurement and centring the study in the middle values, then a relationship between the exam results and the measured STIPA seem to exist. Based on a third polynomial fit, this accounts for approximately 46% of the total variance of the results; i.e. the overall regression model was significant, $F(3,16) = 4.54$. $p<0.02$, $R^2=0.46$.

Morales's research (7 p. 58) found a third-degree polynomial relationship between PB and STI for native English speaking population, as result it was decided to study the relationship between STI and PB for non-native volunteers.

The results in Figure 6 indicate that if the model is taken as a polynomial function, the STIPA accounts for approximately 70% of the total variance of the results. The overall regression model was significant, $F(3,32) = 24.41$. $p<<0.001$, $R^2=0.70$.

Taken as a linear function, the STIPA accounts for approximately 68% of the total variance of the results. The overall regression model is significant, $F(1,34) = 73.12$. $p<<0.001$, $R^2=0.68$.

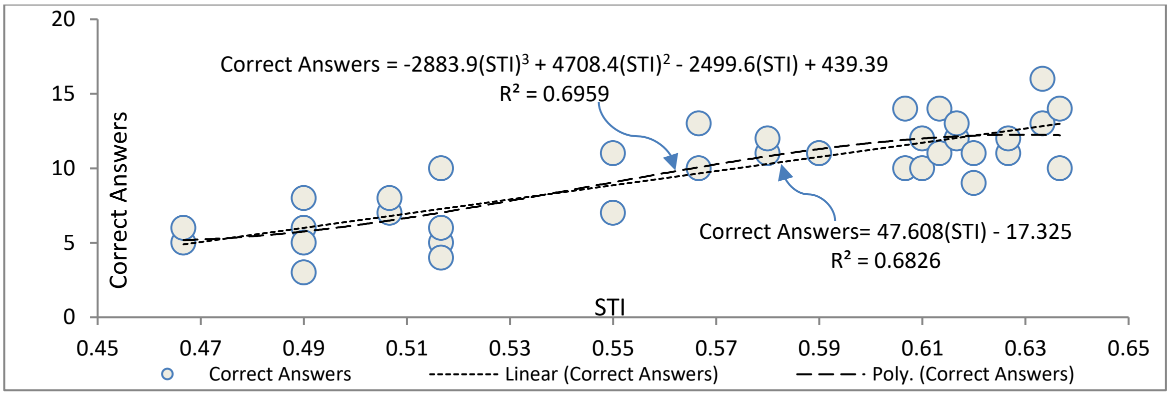


Figure 6: Analysis of the Correct Answers as Function of the STI (Program Audio) for Non-Native Speakers

5. Subjective results

The final part of the research focuses on studying the subjective evaluation of some acoustic parameters. For this, 71 students from the English Language Centre and Summer Schools were surveyed in the previously analysed rooms, and were asked if the quality of the sound and intelligibility was important for their learning. The survey was given to the tutor of the students, who encouraged them to fill in this at the end of the class. Results of this survey are as follows.

Table 7: Relative Importance of Intelligibility on Student Experience

Importance	Total	%
Not Important (5,8)	7	9.86%
Somewhat Important (9, 11)	12	16.90%
Very Important (12, 14)	32	45.07%
Extremely Important (15)	20	28.17%
Total interviews	71	100.00%

Students were also asked about their view on reverberation and noise in the room on the same survey. In general, what seems to have a larger influence on the subjective evaluation of the student experience is the noise levels, followed by the reverberation.

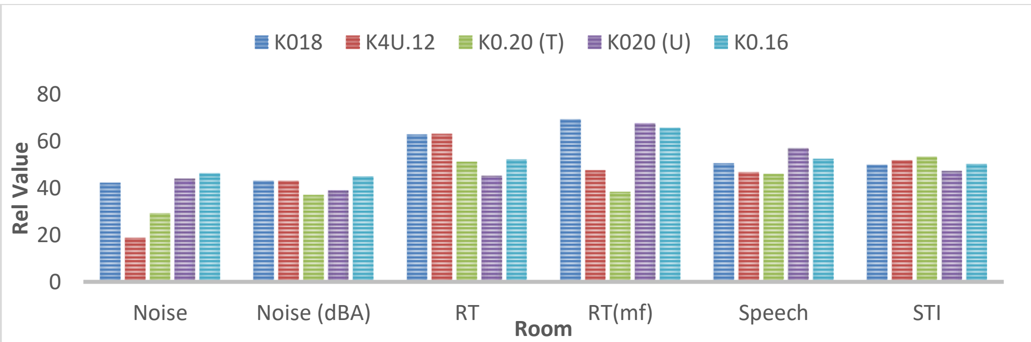


Figure 7 Subjective and Measured Values Relationship per Room for Noise, Reverberance and Speech

For both the reverberation and noise, the higher the subjective value the more difficult it was to understand the speech; therefore, lower the student experience and this trend seemed to be independent of the mother tongue.

The subjective results can be compared per room with their measured counterparts, see Figure 7.

From Figure 7, it is possible to see some relationship between the actual or measured values (Noise(dBA), RT(mf) and STI) and their relative subjective values (Noise, Reverberance, Speech).

Table 8: Correlation of Measured Values and Subjective Results. Subjective Headers in Bold

	Noise	***RT***	***Speech***	*STI*	*RT(mf)*	*Noise dB(A)*
Noise	**1.0**					
RT	**-0.5**	**1.0**				
Speech	**0.8**	**-0.6**	**1.0**			
STI	***-0.7***	***0.4***	***-1.0***	*1.0*		
RT(mf)	***0.8***	***-0.1***	***0.8***	*-0.9*	*1.0*	
Noise dB(A)	***0.2***	***0.5***	***0.1***	*-0.2*	*0.5*	*1.0*

Table 8 shows the correlation between subjective values (**bold**) and measured values (*italic*), with the shadowed area indicating the subjective-measured correlation of the acoustics factors.

Interestingly, although the correlation between the measured noise and reverberation time with their subjective counterparts is not entirely obvious, in the case of intelligibility, it is essentially perfect. In the survey, the higher the value, the more difficult it was to understand or lower the intelligibility, so a correlation value of -1 shows exactly that.

6. Conclusions and recommendations

In terms of intelligibility, non-native students, as expected, had a lower score than predicted by current standards and studies with native population.

There is also evidence of a direct correlation between the STI and the student experience; therefore, this shows the relevance of good acoustics design in rooms to be used by students whose English is not their first language.

To summarise, there is an evident difference between native and non-native listeners; therefore, non-native students should be encouraged to sit at the front of the room or closer to the source, and intelligibility should be actively considered during building design and refitting of heritage spaces used for teaching.

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