ACOUSTICS IN OPEN PLAN CLASSROOMS - TOWARDS REVISED SPEECH INTELLIGIBILITY CRITERIA

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1 INTRODUCTION

Open plan classrooms are becoming increasingly popular in new school design in the UK. As part of a PhD research project[1], Speech Transmission Index (STI) measurements were carried out in open plan primary school classbases to assess compliance against acoustic performance standards defined in Building Bulletin 93 (BB93)[2].

The BB93[2] criterion for speech intelligibility within open plan classbases (STI > 0.6) is intended to achieve 'good' speech intelligibility, as described by the ISO-9921[3] standardised rating scale. This paper explores the scope of the rating scale and hence the suitability of the BB93[2] criterion for specific listener types in various contextual educational settings. Consideration is given to message complexity, urgency, importance, and frequency in each listening context, in addition to both age and proficiency of the listener, and typical vocal effort of the talker.

The relationship between measured STI, A-weighted speech-to-noise ratio and mid-frequency reverberation time was investigated using multiple regression analysis. This paper extends previously reported optimum STI criteria for critical listening in primary school settings[4] by considering minimum practicable STI criteria, plus normative minimum criteria for older students, and non-critical listening scenarios. Consideration is also given to the re-graded rating scale for STI to be included in the new revision of BS EN 60268-16[5].

2 BACKGROUND

2.1 Scope of research project

In order to investigate whether open plan classroom designs are acoustically fit for purpose with respect to current and future learning trends in the UK primary school sector, acoustic conditions were surveyed in 42 open plan primary classrooms over a two year period using both objective techniques (acoustic measurements) and subjective techniques (questionnaire surveys of children and teachers). Measurement methodologies were developed in accordance with relevant standards, to assess compliance against the acoustic performance standards of BB93[2]. The objectives of the work included the following:

- Review research on noise, acoustics, speech intelligibility, speech privacy and international design criteria in open plan classrooms, and identify potential vulnerable listener groups
- Develop and validate a method of measuring STI and other acoustic parameters in open plan classrooms.
- Carry out an objective acoustic survey in existing open plan classrooms, including ambient and intrusive noise levels (fluctuation and distribution), speech-to-noise ratios (S/Nw and S/N(A)) speech intelligibility within classbases (STI, SIL, SII), speech privacy between classbases (SII), reverberation times (T_{mf}, EDT) and other acoustic parameters (C_{50}, D_{50}).
- Questionnaire survey of children including perceived noise sources and annoyance, ability to hear the teacher and peers in specific listening situations.

- Questionnaire survey of teaching staff including perceived advantages/disadvantages of open plan design, perceived acoustic conditions, teaching methods, classroom management techniques, and coping strategies.
- Review current standards and guidance in light of the results.

2.2 Standards and guidance

Design criteria for speech intelligibility in enclosed spaces are widely expressed as combinations of maximum background noise levels, and maximum mid-frequency reverberation times, assuming that the students are quiet and listening to the teacher during lessons. Previous research generally recommends at least 15 dB speech-to-noise ratio throughout the classroom (with occupied reverberation time controlled to 0.4-0.5 s) to ensure that all participating listeners are able to receive the signal without degradation[6-12]. However there is also an observed trade off between background noise level and reverberation time to achieve equivalent speech intelligibility scores. Criteria need to represent the intended listening population, and alternative speech-to-noise ratios may be appropriate depending on the age and listening proficiency of the audience.

Since 2003, acoustic performance standards for schools have been mandatory under Approved Document E of The Building Regulations[13] in England and Wales. The normal means of achieving compliance with the Regulations is to achieve the performance criteria set out in BB93[2], which include combinations of maximum reverberation time and maximum ambient noise level criteria for enclosed classrooms. However for open plan classrooms, with simultaneous independent learning activities occurring in each classbase, the intelligibility of natural speech depends on the combination of the active fluctuating speech-to-noise ratio (which in turn depends on the classroom activity and listening situation) and room acoustic characteristics. Therefore it is more appropriate to use a parameter which combines both effects. BB93 uses a minimum Speech Transmission Index (STI) criterion for open plan classrooms. STI theory and the suitability of STI as a design criterion compared to other intelligibility parameters is discussed elsewhere[1,4, 14].

The BB93[2] criterion for speech intelligibility in an open plan classroom is STI ≥ 0.6, which corresponds to at least 95% sentence intelligibility, and >90% intelligibility of individual meaningful words for typical hearing adult native listeners, according to BS EN 60268-16[5]. However it is not known whether this criterion truly represents the full scope of listener types in an educational setting, nor the listening context or activity taking place. The results of the objective acoustic survey are analysed in this paper to investigate this issue.

2.3 Speech intelligibility criteria and ratings

STI has been shown to correlate well with subject based measures of speech intelligibility for adult listeners with typical hearing[5]. A five point rating scale has been standardised in ISO 9921[3] and BS EN 60268-16[5] to determine the quality of the communication situation (see Table 1). The relationship between this rating scale and various subject based intelligibility scores (Sentences, non-optimized speech reception threshold (SRT) for sentences, Consonant-Vowel-Consonant (CVC) nonsense words, and meaningful Phonetically Balanced (PB) words) for normal hearing adult listeners are also tabulated.

Table 1: ISO 9921[3] and BS EN 60268-16[5] intelligibility rating scale

		Subject based speech intelligibility scores			
Rating	STI	Sentences	Sentences (non optimized SRT)[5]	CVC nonsense words	Meaningful PB words
Excellent	>0.75	100	100	>81	>98
Good	0.60-0.75	100	95-100	70-81	93-98
Fair	0.45-0.60	100	70-95	53-70	80-93
Poor	0.30-0.45	70-100	63-70	31-53	60-80
Bad	<0.30	<70	<63	<31	<60

Table 1 shows that normal hearing adults can maintain near optimum sentence intelligibility test scores at STI values of 0.60 and above. However, intelligibility scores are slightly lower for tests based on single Meaningful PB words, and significantly lower for CVC nonsense words, due to fewer clues being available in the speech test material. For younger children, single word intelligibility tests are more relevant, since children's speech and word familiarity is still developing at this age.

BS EN 60268-16[5] is currently under revision and a new version is expected to be published in 2010. The new version is likely to include a re-graduated rating scale for STI, which takes account of measurement accuracies and perceptual difference limen[15]. The draft standard is still subject to comment but it is understood that a scale categorized from A-J (with U as unclassified) is likely to be incorporated into the standard as shown in Figure 1.

The selected category for a given communication situation will depend on listener proficiency (age, linguistic experience, hearing ability etc), and the listening context (learning modality, message complexity/importance/urgency/frequency etc).

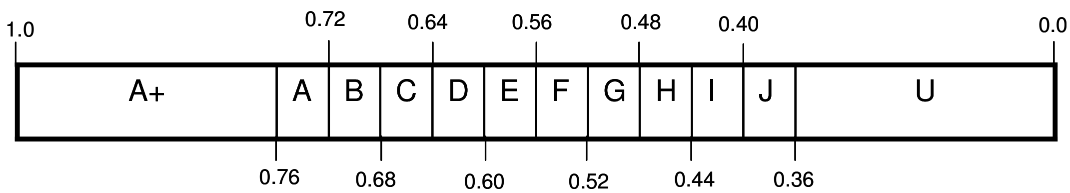


Figure 1: Revised STI scale for BS EN 60268-16[15]

2.4 Listener proficiency

Typically the speech recognition ability of listeners in the classroom depends on their hearing ability, age and linguistic experience. In classroom design it is necessary to consider a minimum criterion for objective speech intelligibility to accommodate the expected range of listener proficiencies.

It has been shown that younger children are more susceptible to poor acoustic conditions than adults[7,9,11,12,16-18]. Spoken word recognition in noise and reverberation appears to improve systematically with increasing age as language develops, and does not reach an adult level until around 13-15 years in either noisy or reverberant conditions[18].

Typical-hearing young adults have been shown to understand familiar spoken material presented in speech-to-noise ratios of around 0-1 dB[,12,16-18] which, as an effective signal-to-noise ratio, corresponds to an STI value of around 0.50[3]. However in practice, adults report high listener difficulty (65%) at this SNR condition[12]. A higher SNR would reduce the extra effort required by the listener, which would be necessary if listening for longer periods of time, or to complex messages. ISO 9921-1 states that an SNR of 0-6 dB would represent 'satisfactory' conditions, whilst an SNR of 6-12 dB would represent 'good' conditions. According to Bradley and Sato[12], an SNR of >6 dB corresponds to a mean listener difficulty rating of <15%.

To investigate children's speech intelligibility, Bradley and Sato[19] carried out speech intelligibility tests in real classrooms with relatively low reverberation times (average unoccupied RT = 0.45 seconds). Average speech-to-noise ratios required to obtain 95% intelligibility are shown in Table 2. The results of the study indicate that between 8 dB to 15 dB SNR is required for young children to obtain intelligibility scores equivalent to that of young adults, with younger listeners requiring significantly higher speech-to-noise ratios to achieve equivalent intelligibility scores.

Table 2: Bradley and Sato's[19] average S/N(A) for 95% intelligibility

Listener group	Nominal age (years)	Average S/N(A) (dB)
Adults (listener difficulty 65%)	> 13-15	+1
Adults (listener difficulty 20%)	> 13-15	+5
Adults (listener difficulty 15%)	> 13-15	+6
Adults (listener difficulty 5%)	> 13-15	+8
Grade 6	11	+8
Grade 3	8	+12
Grade 1	6	+15

Other types of learners who are particularly vulnerable to the effects of noise and require significantly better acoustic conditions than their typically developing peers or adult listeners include children who are hearing impaired, children with English as an additional language (EAL), children with Autistic Spectrum Disorders (ASD), children with language, learning and reading disorders, and also children with mild temporary hearing problems[7,22]. Since these groups comprise a significant proportion of a typical classroom at any time, good acoustic conditions need to be provided to ensure an inclusive learning environment.

Several studies have shown that adult native listeners outperform adult non-native listeners in speech intelligibility tests in noise[20,21], with an average improvement in SNR of +7 dB necessary for adults unfamiliar with the instructional language to gain equivalent scores to adult native listeners. Non-native children are identified in a study as being at 'double jeopardy' to the effect of classroom noise[22]. This study implies that at SNRs of less than 10 dB, speech identification becomes significantly more difficult for typically developing EAL learners than for their native peers[22]. Research has shown that, for experienced non-native speakers (>5 years experience, daily users of second language), a minimum criterion of STI 0.68 is recommended in order to achieve 'good' equivalent speech intelligibility[21] (that is, equivalent to STI > 0.60 for a native, normal hearing adult listener). For non-experienced EAL listeners, a criterion of 0.86 is recomended[21].

ISO 9921[3] states that adults with a mild hearing loss require a higher signal-to-noise ratio of approximately +3 dB to achieve equivalent speech intelligibility to normal hearing adult listeners. However for children with mild hearing loss, +12 dB SNR has been recommended in the literature[22].

3 RATING THE LISTENING CONTEXT

Open planning is becoming increasingly popular in many new build schools in both primary and secondary sectors to achieve flexibility for personalised learning, a key part of the UK Government's current initiatives for education. The concept behind personalized learning is that learning is multi-faceted, and a variety of different spaces are required to support different learning tyes[23]. Eighteen different *learning modalities* have been identified by Nair and Fielding[23] as indicated in Table 3.

The listening context and speech communication needs for each learning modality may be assessed by considering the following factors[24]:

- Message complexity: The difficulty of the speech material presented eg simple warning instructions/familiar relaxed conversational speech/teaching of new knowledge and languages.
- Message urgency: The need to understand the spoken message at first attempt. For example, for whole class instruction, the communication situation should ensure that the speech material is intelligible at first attempt by all listeners. However, for personal communication involving small groups, pairs or individuals, it may be more acceptable to repeat the spoken message on occasion, without causing significant disruption to the teaching process.

- Message frequency: How often speech communication occurs during a particular learning mode. For example, for individual study and research, speech communication will occur less often than for collaborative group work or instruction/discussion.

To apply this previous research[23,24] to the current project, a nominal rating for each factor has been assigned to each learning modality identified by Nair and Fielding[23], in order to rate the listening context, see Table 3. Each modality was then grouped into a quadrant illustrating how critical speech intelligibility is, and the tolerance to noise, as shown in Figure 2.

The quadrant helps to identify the main listening contexts under consideration: Whole class instruction/discussion; personal speech communication, individual study (formal); individual study (informal); project/practical work and social conversation.

It is also important to consider communication distances involved in each learning mode. For whole class instruction, the class may be situated at desks (source-receiver distance 5-8 m), or, as is typically observed in open plan primary classrooms, the class gather closely around the teacher (eg sitting together on the carpet area, within 2-3 m of the teacher), improving speech intelligibility.

During activities involving smaller groups (so-called ‘Personal’ speech communication), speech intelligibility will still be critical, however communication distances will be considerably shorter, and therefore more noise may be tolerable. During individual/group work, the teacher will typically use a non verbal cue to capture the children’s attention before speaking to address the (quiet) whole class.

There is obviously still a need to control intrusive noise levels in order to avoid distraction and annoyance (and other effects on cognitive processing). This was explored as part of the research work[1] but is not reported here.

Table 3: Learning modality and rated listening context

Learning modality[23]	Requirements of spoken message		
	Complexity	Urgency	Frequency
1. Independent study	N/A	N/A	Low
2. Peer tutoring	High	Mid	Mid-High
3. Team collaborative small group work	High	Mid	Mid-High
4. One-on-one learning with the teacher	High	Mid	High
5. Lecture format	High	High	High
6. Project based learning	Mid	Mid	Mid
7. Technology based learning with computers	N/A	N/A	Low
8. Distance learning	Generally occurs outside the classroom		
9. Research via the internet	N/A	N/A	Low
10. Student presentations	High	High	High
11. Performance and music based learning	Generally occurs outside classroom		
12. Seminar style instruction	High	High	High
13. Community service learning	Generally occurs outside the classroom		
14. Naturalist learning	Generally occurs outside the classroom		
15. Social/emotional learning	Low-Mid	Low-Mid	Mid
16. Art-based learning	N/A	N/A	Low
17. Storytelling	High	High	High
18. Learning by building – hands on	Mid	Low-Mid	Low-Mid

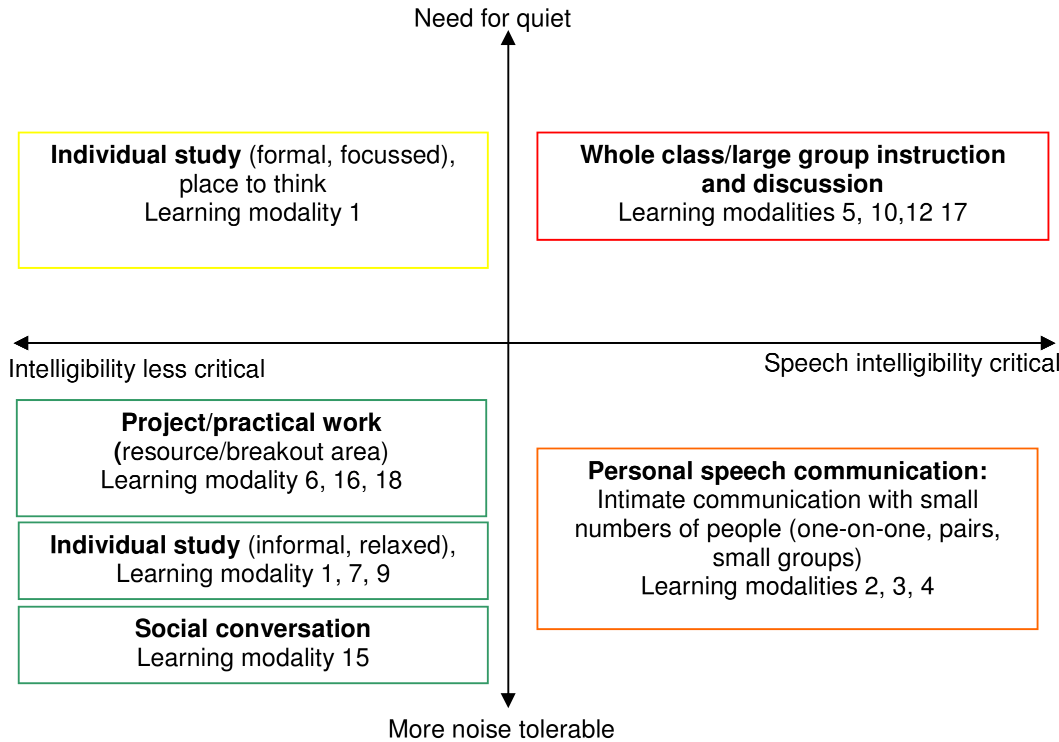


Figure 2: Listening context quadrant

4 SURVEY AND METHODOLOGY

For the objective survey, STI measurements focused on teacher-to-student communication as the most critical aspect of speech communication within the classroom, namely whole class instruction with the class quiet and listening to the teacher (either at desks or gathered around the teacher on the 'carpet' area).

The objective survey is summarised here and described in detail elsewhere[1,25]. All room acoustic parameters were measured using the WinMLS 2004 PC based software analyser, which uses a maximum length sequence signal (MLS) for excitation, where the average spectrum and level distribution of speech is represented within the test signal. The noiseless room impulse response is determined using the autocorrelation properties of the MLS signal. From this, the STI value can be calculated by correcting for the actual speech-to-noise ratio achieved in various conditions during post processing, based on measured intrusive noise levels during active periods. There is no need to simulate occupancy noise directly in the measurement, which can be time consuming and often inaccurate.

A head sized loudspeaker was used as the test source, located at a height of 1.65 m above ground level at the teacher's usual speaking position. Laboratory measurements of directivity were carried out and compared with those of a mouth simulator to validate the use of the loudspeaker as a test source[1]. The test signal was set to a 'Raised' vocal effort spectrum equivalent to 67 dB(A) at 1 m in accordance with BB93[2] and ANSI 3.5[10] for teacher-to-student communication, for both male and female talkers. As reported previously[1,25], a standardised 'raised' vocal effort of 67 dB(A) at 1 m is a suitable compromise between delivering sufficient speech signal level to listeners, whilst controlling the speech signal to maintain speech privacy between classbases, and minimising unwanted vocal strain and risk to teacher's health.

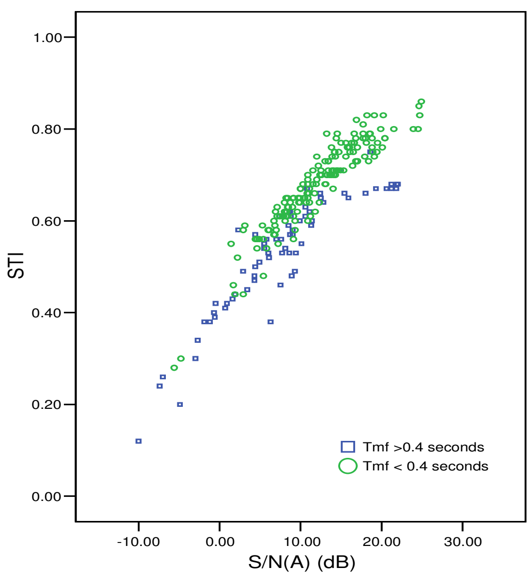
The octave band intrusive noise level (L_{eq}) was measured using a hand held sound level meter in three main positions in each classbase: at the back of the classbase near the opening (worst case); in the middle of the room; and at the front within 2-3 m of the teacher's usual speaking position (best case). The dominant activity occurring in adjacent classrooms during the measurement period was also recorded.

Whereas many surveys have used a long term averaged (L_{eq}) noise spectrum to account for the effect of occupancy noise on STI[2], it is also important to consider the fluctuation in STI with time (this varies with the type of teaching activity and with general fluctuation of noise). Therefore a short two-minute measurement period was used, and the STI was calculated for each noise sample obtained. Previous studies have shown that this method gives a good indication of the fluctuations of noise within a classroom without interfering with the teaching process, and is usually short enough to capture a single activity type before the dominant activity in adjacent classbases changes[1].

5 RESULTS

A strong positive correlation ($r = 0.94$, $p < 0.001$) was found between STI and A-weighted speech-to-noise ratio, S/N(A) (ie the difference between the measured A-weighted speech signal level and intrusive noise level at each receiver position), as indicated in Figure 3. The figure shows that a strong linear approximation exists between STI and S/N(A) up to around S/N(A) = 15 dB, after which a plateau is reached, in line with STI theory.

Considering the 95% confidence interval achieved for all data in the linear part of the range (not shown in Figure 3 for clarity), the results suggest that, in order to achieve the BB93 criterion of STI > 0.6, a speech to noise ratio of 8-13 dB S/N(A) would be required. Although a speech-to-noise ratio of 8 dB could be considered acceptable for normal hearing, native older children (11 years +), a higher S/N(A) is recommended for younger children and other vulnerable listeners.



$T_{mf} < 0.4$ s: $r = 0.93$; $n = 162$; $p < 0.001$
$T_{mf} > 0.4$s; $r = 0.91$; $n = 69$; $p < 0.001$

Figure 3: STI vs. A-weighted speech to noise ratio and T_{mf}

However, some trade off between S/N(A) and reverberation time is apparent. An optimum reverberation time of T_{mf} 0.4 seconds was established by investigating the relationship between unoccupied (ambient) STI and reverberation time.

Since each open plan unit was unoccupied during ambient STI measurements, the speech-to-noise ratio was in excess of 15 dB and therefore the STI was only affected by room acoustic effects best described by Early Decay Time (EDT). A significant negative correlation was found between STI and EDT_{mf} ($r = -0.75$, $n = 114$, $p < 0.001$). A slightly lower but still significant correlation was also found between STI and T_{mf} ($r = -0.72$, $n = 114$, $p < 0.001$).

Figure 4 shows the relationship between $EDT_{mf(furnished)}$ and ambient STI. The results fall into two distinct regions – those classbases with non-sound absorbent ceilings (highlighted in red) with EDT_{mf} in excess of 0.35 seconds, and those with sound absorbent ceilings (highlighted in green) with $EDT_{mf} < 0.35$ seconds For the latter case, the corresponding ambient STI achieved is at least 0.71 for all measurements. For classbases with acoustically reflective ceilings, STI falls below 0.7 for higher early decay times (> 0.6 s).

For the occupied case, speech-to-noise ratio and hence STI is degraded by the presence of intrusive noise. The ambient STI therefore needs to be as high as possible to ensure that the BB93 criterion is still achievable when the classbases are occupied (whilst being in line with the limitations of the design cost). The cut off point between the two design types (sound absorbent ceiling vs. sound reflective ceiling) is around $EDT_{mf(furnished)}$ 0.35 seconds which would be an optimum design criterion to ensure sufficient ambient STI. For practical design purposes, this corresponds to a $T_{mf(furnished)}$ of around 0.40 seconds[1].

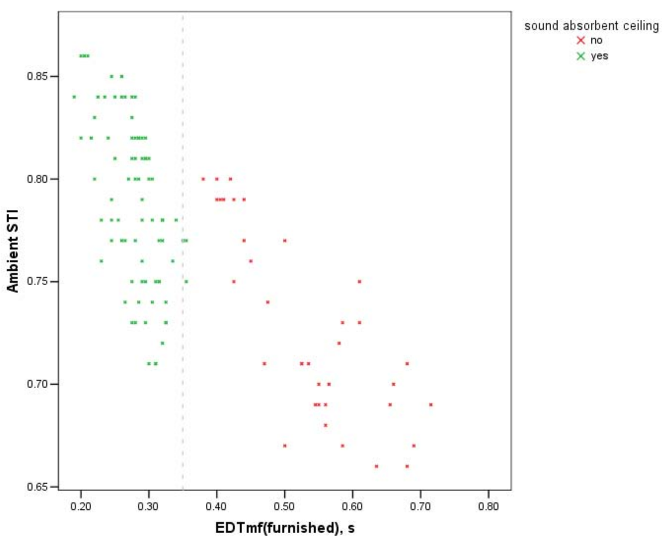


Figure 4: Relationship between EDT_{mf} and Ambient STI

Figure 3 shows results split into data for shorter, 'optimum' mid-frequency reverberation times ($T_{mf,\ furnished} \leq 0.40$ seconds highlighted in green) and longer mid-frequency reverberation times ($T_{mf,\ furnished} > 0.40$ seconds highlighted in blue). For longer reverberation times, the STI begins to plateau at lower speech-to-noise ratios, since the STI becomes limited by the reverberation time at this point. However for shorter reverberation times, the linear relationship continues to hold at higher speech-to-noise ratios, resulting in a 'double tail' relationship.

Multiple regression analysis was carried out (over the linear portion of the data; S/N(A) ≤ +15 dB) to investigate the relationship between STI, speech-to-noise ratio, and reverberation time. S/N(A) accounted for 88% of the variance in STI, ($F_{1,167} = 1240.14$, $p < 0.001$), and T_{mf} accounted for a further 2% of the variance ($F_{1,167} = 35.65$, $p < 0.001$). The regression equation for these predictors is given in Equation 1.

$$STI = 0.021(S/N(A)) - 0.131(T_{mf}) + 0.481 \qquad \text{Equation 1}$$

where S/N(A) = A-weighted speech-to-noise ratio
T_{mf} = Unoccupied, furnished mid-frequency reverberation time
(arithmetic average of 500 Hz, 1k Hz and 2 kHz bands)

The lower bounds of the 95% confidence interval for the regression coefficient values are 0.02 and -0.175 for S/N(A) and T_{mf} predictors respectively.

Considering the minimum average S/N(A) required for different listener groups to achieve 95% word intelligibility scores as proposed in the literature[12,17-22], optimum STI criteria (based on Equation 1 for optimum conditions of $T_{mf} < 0.4$ seconds) are presented in Table 4. The upper and lower bounds of the 95% confidence Interval are also presented in column 4. The rating band according to BS EN 60268-16: 2010 is also given below, taking into account minimum criteria and the 95% Confidence Interval range.

Table 4: STI criteria for different groups to achieve 95% word intelligibility

	Minimum S/N(A) (dB)	STI	95% CI range	BS 60268-16: 2010 rating
Adults (13-15+), greater listening difficulty (60%)	1	0.45	0.43-0.47	H
Adults 13-15+, listener difficulty 20%	5	0.53	0.51-0.56	F
Adults (13-15+), listening difficulty 15%	6	0.55	0.53-0.58	F/E
Adults with EAL (experienced users)	7	0.58	0.55-0.60	E
Adults (13-15+), listening difficulty 5%	8	0.60	0.57-0.62	E/D
11 year olds	8	0.60	0.57-0.62	E/D
8 year olds and children with mild hearing loss	12	0.68	0.65-0.71	C/B
6 year olds	15	0.74	0.71-0.78	A

6 DISCUSSION

6.1 Secondary school criteria

Since additional research concerning listener difficulty ratings has been carried out for normal hearing native adult listeners (ie fully developed listeners aged 13-15+), it is possible to explore suitable criteria for non-critical listening as well as critical listening activities for secondary school students.

Whilst a criterion of STI > 0.6 (band D according to the proposed revision to BS EN 60268-16) may still be desirable for the most critical listening activities and lower listener difficulty where the physical classroom design allows (ie in enclosed classroom areas) the results indicate that band E would still achieve 95% intelligibility for typical hearing adults (including experienced EAL adult listeners), and only 15% listener difficulty. Therefore band E may be tolerable for critical listening activities in open plan classrooms. For activities involving personal speech communication with lower message urgency, it may also be possible to consider the lower bound value as a minimum criterion (ie band F). According to ISO 9921[3], this corresponds to 90% intelligibility for PB word scores.

Secondary schools include students of age 11-12, and the lower bound for this age group indicates that band E may still be acceptable as a minimum for the youngest secondary school aged normal hearing listeners.

For non-critical listening activities, such as informal individual study; project/practical work and social conversation, which may take place in resource areas, breakout spaces, dining and café areas etc, a higher listening difficulty rating (eg 20%) may be more tolerable, due to the lower message frequency, complexity and urgency. In this case, band F may be a tolerable minimum criterion as indicated in Table 4. However it should be noted that this band would not be suitable for vulnerable listeners.

Further work would be required to establish criteria for hearing impaired secondary school aged listeners, however it is likely that a much higher STI criteria would be suitable, (bands B to A+). Suggested STI criteria for secondary school aged listeners are summarised in Figure 5 below.

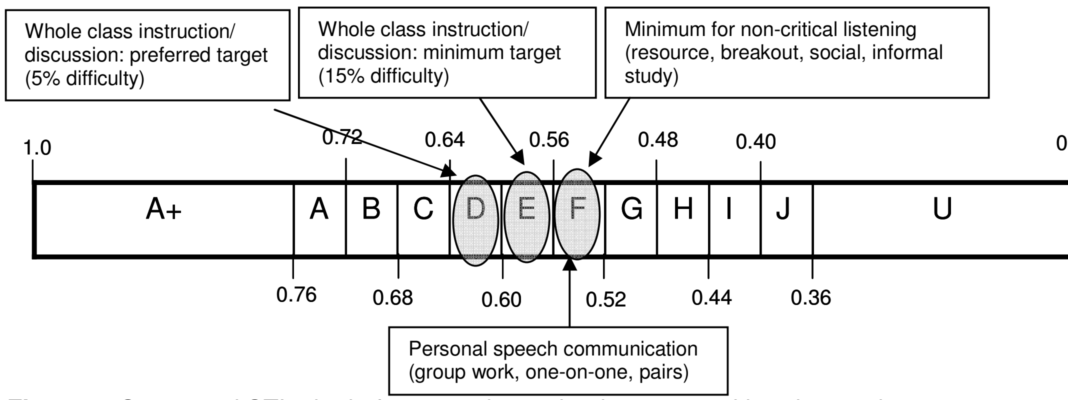


Figure 5: Suggested STI criteria for secondary school age normal hearing students

6.2 Primary school criteria

The results suggest that, although the BB93 criterion of STI > 0.6 (band D) would appear to provide suitable speech intelligibility conditions for critical listening activities for older primary school aged children (native with typical hearing), younger years are likely to benefit from a higher criterion of STI 0.68-0.75 (bands C to A). Children suffering from mild hearing loss (which could account for a significant proportion of the class at any one time) are likely to benefit from a higher criterion of STI 0.68 (band B), which is also suitable for experienced EAL listeners[22]. For activities involving personal speech communication with lower message urgency, it may also be possible to consider the lower bound value as a minimum criterion for each listener group (as shown in Figure 6).

Suggested STI criteria for primary school aged listeners are summarised in Figure 5 below. Further information on children's listening difficulty ratings would be necessary to determine minimum criteria for non-critical listening activities. Further work would also be required to establish criteria for listeners with permanent hearing impairments, however it is likely that a much higher STI criterion would be suitable (bands B to A+).

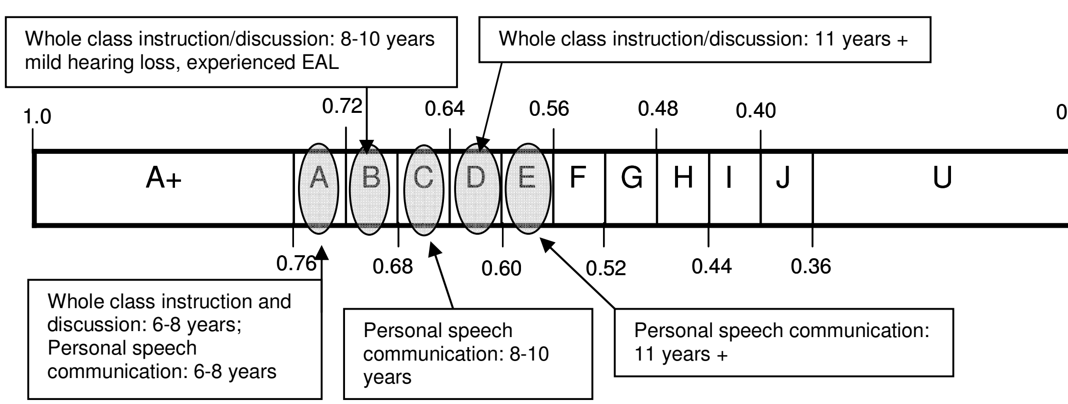


Figure 6: Suggested STI criteria for primary school age students

7 CONCLUSIONS

The BB93[2] criterion for speech intelligibility in open plan classrooms of STI > 0.6 (band D) has been scrutinised by considering specific listener groups (age, hearing ability, language acquisition) and listening context (whole class instruction/discussion; personal speech communication (groups, pairs, one-on-one); individual study; project/practical work).

The results suggest that, for typical hearing listeners involved in whole class instruction/discussion, a lower STI criterion may be appropriate for secondary school aged listeners (band E), however a higher criterion may be appropriate for younger primary school aged listeners (band C to A). For personalised speech communication (one-on-one instruction, working in pairs or groups), a lower criterion may be tolerable given the lower message urgency (band F for secondary schools, band E to C for primary schools). For non-critical listening activities (individual informal work, practical work), band F is likely to be tolerable for secondary school students, however further research involving listener difficulty ratings is required for younger listeners to establish if this is also the case for primary school audiences.

However it is also necessary to provide an acoustically inclusive environment for vulnerable listeners, who require significantly higher STI criteria (bands B to A+). In practice this is likely to require provision of both enclosed as well as open plan spaces, in order to provide a truly personalised learning environment and satisfy a wide variety of different listener needs and learning activities.

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