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Towards accessible acoustic criteria for inclusion in mainstream classrooms

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ABSTRACT

New and refurbished school buildings in England and Wales need to comply with criteria for acoustics set out in Building Bulletin 93 (BB93). However, the acoustic design strategy to comply with Equality law and to ensure that *'people with disabilities, including those with hearing impairment, must not be placed at a disadvantage'*, is unclear and is complicated by other design factors and current funding constraints. This paper sets out to establish acoustic criteria for inclusion of children with special, hearing and communication needs (SHCN) in mainstream classrooms, using a 'reasonable adjustments' approach (which underpins Equality law). Listening disadvantage is quantified by each type of need according to a review of the speech perception studies evidence base. Holistic design and management of the classroom is considered, by quantifying the prevalence of children with SHCN; examining classroom management strategies and provision of assistive listening systems; accounting for teacher's voice protection; and considering other design aspirations (such as sustainability) alongside acoustic design objectives.

Keywords: Classrooms, Inclusion, Special Educational Needs, Access, Speech Perception

1. INTRODUCTION

New and refurbished school buildings in England and Wales should comply with criteria for acoustics set out in Building Bulletin 93 (BB93) (1). In accordance with UK law (2), schools are required to make 'reasonable adjustments' to put children with disabilities on a more level footing. The Government's specification for new and refurbished school buildings (3), requires that *'People with disabilities, including those with a hearing impairment, must not be placed at a disadvantage by the design of the Building'*.

School Premises Regulations (SPR) guidance (4) states that *'pupils with special needs may need to be taught in spaces with lower noise levels and shorter reverberation times than in mainstream classrooms'*, and *'where pupils with special needs are taught in mainstream schools, the acoustics of the spaces where they are taught may need to be enhanced to the same standards as those special units*', and '*provision will usually be required to teach these pupils in smaller groups so that noise from other pupils is lower and the distance between teacher and pupil is minimised'*. Acoustics of Schools: A Design Guide (5) also acknowledges that pupils with SHCN should be taught in rooms which meet enhanced acoustic criteria and that '*occasionally specialised provision may be directly attached to a mainstream class in the form of a 'quiet room' leading from the classroom'*. The Government specification (3) requires the school design to *'ensure and demonstrate that all layouts allow for disabled pupils to be able to access all activities on offer in at least one space of each type or within each suite'*. This suggests that it would be acceptable to provide a quiet room or SEN room achieving the enhanced acoustic criteria within each teaching suite, and to send children with SHCN to these rooms to access the majority of their teaching and learning. However, whether this practice is inclusive is questionable (6). The acoustic strategy for inclusion in mainstream classrooms is

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complicated by the following:

a) The current funding crisis in UK schools (7) has diminished resources to teach in small groups.
b) It is difficult to achieve the enhanced reverberation time criteria in mainstream classrooms, particularly low frequency reverberation time, given competition for wall space, and trends for exposed soffits for sustainability reasons.
c) The UK Government's budget does not currently allow for the enhanced BB93 acoustic criteria for pupils with SHCN to be provided in mainstream classrooms.
b) Natural ventilation remains a priority, with indoor ambient noise levels up to 40-45 dBA.
d) Assistive listening systems are not provided *per se* in general mainstream classrooms (8).
e) Given the current prevalence, all mainstream classrooms should anticipate the presence of children with SHCN.

2. Criteria

2.1 Acoustic Criteria

In order to comply with the Building Regulations (9) and the Government Specification (3), new school buildings in the UK must achieve the standards in BB93 (1) as summarised in Table 1 (for naturally ventilated classrooms). The criteria for refurbished school buildings must be achieved to comply with the Government Specification (3). 'Rooms intended specifically for children with SHCN' in mainstream schools include Special Education Needs (SEN) rooms and Designated Units or Specialist Resource Provision. The enhanced acoustic criteria for these rooms are practicable for smaller SEN rooms with low occupancy and high staff-to-student ratios, and a short communication distance. Ambient noise level criteria are based on an assumed teacher voice level and communication distance to obtain sufficient signal-to-noise ratio (SNR). SNR is also stipulated in the BATOD (10) and 2005 ASHA (11) guidelines.

Table 1 – BB93 acoustic criteria for naturally ventilated classrooms

Space	Maximum indoor ambient noise level $L_{Aeq,30min}$ (dB)	Maximum mid-frequency RT, T_{mf} (s)	
		Primary	Secondary
Classrooms:			
Mainstream new build	40	0.6[a)]	0.8
Refurbished/APS[a)]	45	0.8	1.0
Rooms intended specifically for SHCN:			
New build	35[b), c)]	0.4 (125-4kHz)[b), c)]; 0.6 maximum at any frequency	
Refurbished/APS [a)]	40	0.4[c)]	

Notes: a) APS = Alternative Performance Standard. b) BATOD (10) compliant. BATOD also recommends 20 dB SNR at 125-750 Hz, and 15 dB SNR at 750-4000 Hz; c) ASHA (11) compliant. ASHA also recommends 15 dB SNR.

3. Prevalence of children with SHCN in mainstream schools

SHCN covers several different types of special need as outlined in Figure 1. BB93 (1) states "*In order to fulfil their duties under the Equality Act 2010, school client bodies should anticipate the needs of deaf and other disabled children as current and potential future users of the school".* The Equality Act also covers age discrimination (for example young children) and children with English as an additional language (EAL) (2). Both of these groups may be disadvantaged by poor acoustic conditions in the classroom and may also be considered as having SHCN. In order to address the

knowledge gap in this area, an assessment of the prevalence of children with SHCN in mainstream classrooms was undertaken following detailed analysis of Government statistics (12, 13), see Figure 1.

Overall prevalence of children with SHCN in mainstream schools (all needs combined) is 6% (see Figure 2). The breakdown is 6.8 for primary schools and 5.6% for secondary schools. That is an average of just over 1 child per average sized secondary school classroom, and up to 2 per average sized primary school classroom. The most common forms of SHCN in mainstream schools are Speech Language and Communication Needs (3% of entire mainstream population), Specific Learning Need, which includes AD/HD and Dyslexia (2%) and Autistic Spectrum Disorder (1%). Hearing impairment specifically has a very low level of prevalence of 0.3%, or 0.1 children per classroom, which is less than 1 child per average sized primary school and less than 3 per average sized secondary school. There is a higher prevalence of children with EAL as shown in Figure 1. Children with temporary hearing loss account for up to 4 per average sized classroom (14). Clearly primary schools will also need to consider enhanced acoustic criteria which may apply to younger children who are more impacted by poor acoustics.

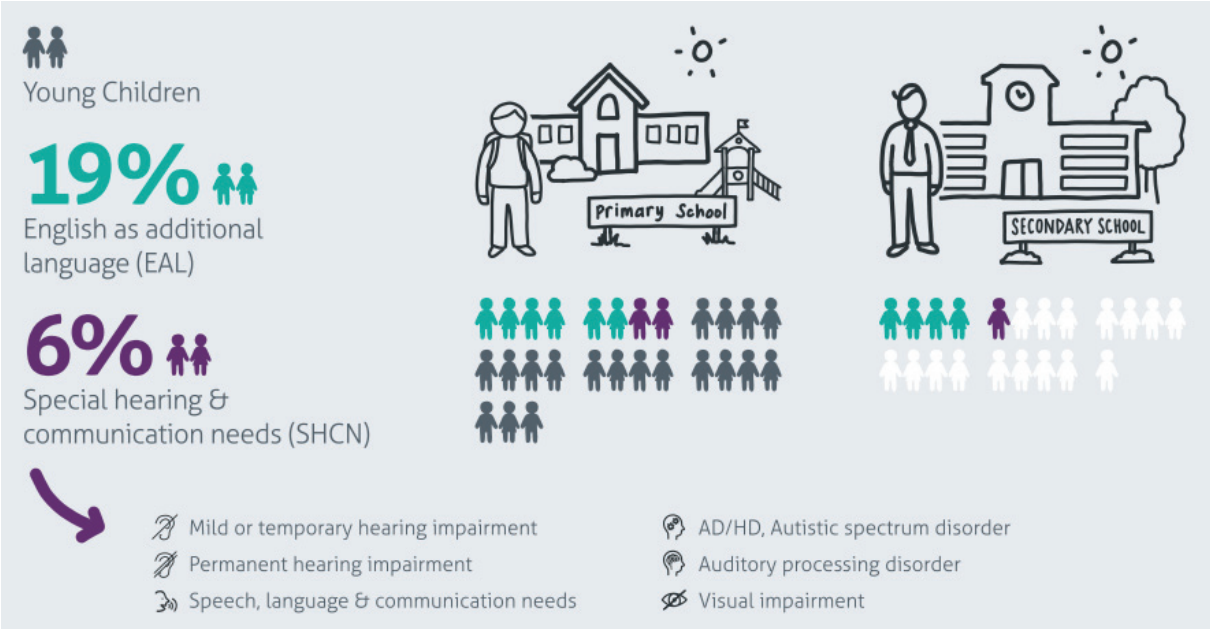

Figure 1 – Prevalence of SHCN in average size mainstream classrooms (primary and secondary)

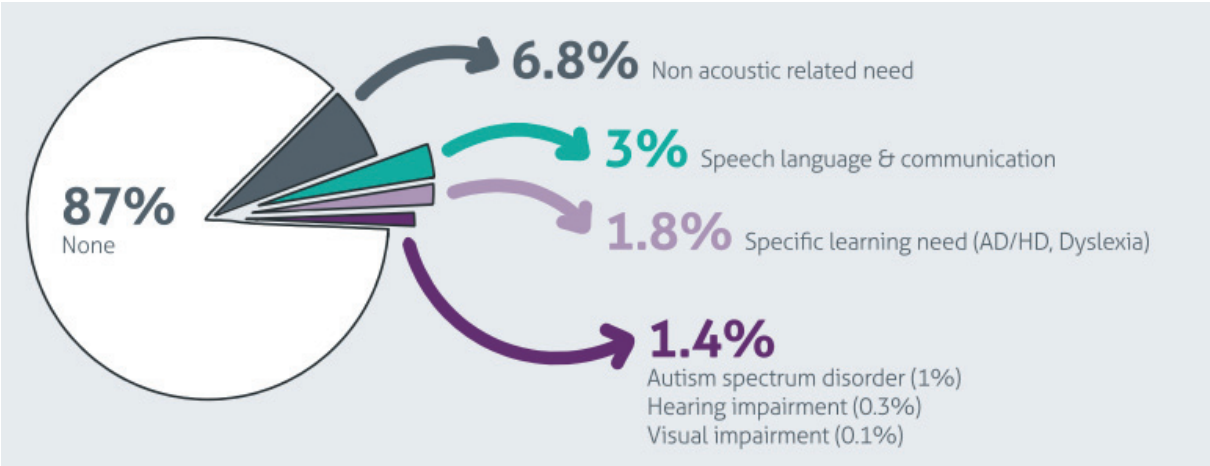

Figure 2 – Prevalence of SHCN in mainstream schools (by specific need)

Whilst the attainment gap for hearing impaired students achieving expected grades is significant (15), it is smaller than for other forms of SHCN. National progress scores for English and Maths (16) reveal a gap of up to 10% for hearing impaired children, compared to 25% for ASD and 30% for Speech Language and Communication Needs. Whilst the use of averages should be treated with caution and prevalence will vary with individual school location and circumstances, the analysis reveals that the need to provide appropriate acoustic conditions for children with SHCN should be anticipated in every classroom. It also shows that, given the low prevalence of SHCN and the very low prevalence of children with hearing impairment, preferential seating and use of personal listening aids may be feasible classroom management strategies to help improve acoustic conditions and hence access to learning. Where there is a significantly larger proportion of children with SHCN in a school cohort, this may suggest the need for a Specialist Resource Provision or Designated Unit.

4. CLASSROOM MANAGEMENT & RESPONSIBILITY

The major effect of poor acoustics in classrooms is the reduction of speech intelligibility. Acoustics of Schools: A Design Guide (5) recognises that *'effective classroom management by the teacher is critical in ensuring that the pupils can have access to all that is spoken'*, but *'classroom management alone cannot ensure adequate speech communication'*. It identifies types of personal listening aids which may be used to ensure pupils with SHCN are able to hear the teacher and their peers. BATOD (10) also recognises the importance of classroom management and personal listening aids:

> *"personal listening aids enhance SNR,* ***reduce impact of unhelpful reverberation, particularly when a headset is used*** *by the speaker" IoA/ANC Design Guide (5)*

> *"****if ambient noise level*** **[SNR]** ***is controlled*** *then* ***high RT has a minimal effect*** *when a personal listening aid is in skilled use and set up properly"* BATOD *(10)*

It can be concluded that provision of good listening conditions for children with SHCN in mainstream classrooms is the combined result of the acoustic design, provision of personal listening aids and classroom management. In an attempt to identify acoustic design responsibility, the responsibilities for each listening mode (17) have been assigned in Table 2, together with common classroom management strategies. This exercise reveals that the primary responsibility of the acoustic design is to ensure teacher-to-student speech communication in quiet. Good control of noise and reverberation time (as required to support this listening mode for SHCN) will also help to control buildup of classroom activity noise to support other listening scenarios, and other non-spoken learning modes.

Table 2 – Proposed classroom design and management responsibility

Listening mode	Design responsibility?		Classroom management responsibility?
	Acoustic design?	Personal Listening Aid?	
Teacher speaking in quiet	✓	✓	support[a)]
Teacher facing away	support	✓	✓
Class is active/ others talking	support	support	✓[b)]
Teacher moving around	support	✓	✓[c)]
Other pupils answering	support	support	✓[d)]
Working in groups	support	✓	✓
Noise from multimedia (projector)	✓	support	support

Notes: a) Teacher to gather younger children on carpet/mat for critical listening scenarios; b) Teacher to use visual cues to quieten an active class before speaking; c) Address small groups/individuals and use roaming tactics around classroom. d) Teacher to repeat child's answer to secure speech intelligibility

5. REVIEW OF THE EVIDENCE

In order to help establish appropriate acoustic criteria for children with SHCN to ensure that the acoustic design of mainstream classrooms *does not place people with disabilities at a disadvantage*, a detailed review of the seminal research studies on speech perception has been undertaken. In a novel approach which seeks to quantify the *disadvantage*, it is proposed to examine the listening gap, ie the difference in average % speech perception scores between the impaired group and non-impaired group for each type of SHCN. This reveals the 'inherent gap' of the impaired groups (under ideal acoustic conditions), and the additional 'acoustic gap' caused by non-ideal acoustic conditions. It also helps to reveal consistencies between studies, as systematic errors/variations between studies are reduced. Significance tests between different groups and conditions are also examined, to help establish reasonably adjusted acoustic criteria for critical listening conditions in quiet which are robust, practicable and improve access to the mainstream classroom by disabled children.

The review was screened to include those studies which quantified speech perception by subjective testing in realisable acoustic conditions, to reflect speech perception for teacher-to-student speech communication in critical listening scenarios, when classroom management is well considered. Unfortunately, none of the screened studies examined listening performance via a personal listening aid, which is now commonplace.

The detrimental impact of noise on aspects of children's learning performance other than speech communication (for example reading ability, attention and memory tasks) in noisy conditions (typically 65 dBA babble) are well studied, and it is generally agreed that children with SEN are significantly more affected than their typically developing peers (18). Furthermore, occupied classroom noise levels of 50-70 dBA have been shown to be associated with higher average occurrences of repetitive behaviours by children with ASD, compared to quieter classrooms (19). Results of these studies are beyond the scope of this paper, which focuses on the impact of acoustics on children's speech perception in critical listening scenarios (quiet). However, they highlight the need to consider classroom management carefully when children with SHCN are working on tasks in mainstream classrooms.

5.1 Factors to consider

It is well known that the most important parameter affecting speech intelligibility is the signal-to-noise ratio (SNR), and that this parameter is more important than reverberation time, although both factors affect speech intelligibility (20,21).

Ambient noise level criteria are commonly derived based on the required SNR, and assumptions about the teacher's voice level and communication distance to the listener (21,22). However it is important to ensure these assumptions account for classroom management strategies and provision of personal listening aids. Recent analysis (14) has shown that the occupied critical listening activity noise levels (students quiet, attentive and listening to the teacher), in average sized classrooms achieving 40 dB indoor ambient noise level, are expected to be up to 44 dBA. All studies in the following review used multitalker babble (meaningful speech) as the noise source, which may represent worst-case noise masking, compared to stationary or environmental ambient noise sources.

The avoidance of very short reverberation times is necessary in real settings, where there is a balance to be achieved between control of reverberation time (to control activity noise levels as well as for good speech perception), and providing the early reflections necessary to support the teacher's voice level and hence reduce vocal effort. Near ideal conditions for speech perception can be achieved over the range 0.2-0.5 s (20) given sufficient SNR, with acceptable conditions for normal hearing children achieved in reverberation times up to 0.9 s. This must be balanced with minimum recommended reverberation times of around 0.5 seconds for unoccupied classrooms to support teachers' voice (14,21). Recent analysis (14) reveals 'Raised' vocal efforts equivalent to 65 to 67 dBA at 1 m are typical for teachers addressing a quiet and attentive class in classroom reverberation times of around 0.5 seconds (22, 33, 34), which equates to at least 59 dBA at a typical worst-case listening distance of 6 m in secondary schools, indicating that +15 dB SNR is achievable throughout a typical classroom with a 40 dB ambient noise level, and +20 dB SNR is achievable at preferential seating

locations of up to 1.5 m.

Control of reverberation time at low frequency is also cited as being important for hearing impaired listeners (5, 10) who may be reliant on their residual hearing at low frequency and more affected by upward spread of masking. However even after consulting educational audiologists and BATOD who informed the BB93 criteria, it has proved difficult to find experimental speech perception evidence which examines the variation of low frequency reverberation time in isolation to support this, or quantifies the importance of low frequency room reverberation when a personal listening aid is in skilled use.

5.2 Quality of Evidence

The majority of speech perception studies which met the screening criteria (22-28) examined the listening disadvantage of children with hearing loss (minimal-to-moderate n = 4, severe to profound n = 2), and only two of these 6 studies looked at variation of reverberation time in addition to SNR. However children with hearing loss represents just 0.3% of the mainstream school population. One study looked at EAL children (19% of mainstream population) but only examined SNR under anechoic conditions (however inferences have been made from the hearing impaired studies which examined both SNR and RT, to obtain a recommended signal-to-noise ratio for ideal reverberation times). One study looked at effects of both reverberation time and SNR on age of pupils (for realistic acoustic conditions typical of a modern compliant acoustic design), which is applicable to primary school populations.

Many studies tested at low signal-to-noise ratios, not representative of teacher-to-student communication in well managed critical listening scenarios, and focused on longer, non-compliant reverberation times. Not surprisingly, test conditions of 0.9-1.2 seconds RT revealed average word-recognition deficits (compared to listening under 0.3-0.4 s RT) of 15-20% for hearing impaired children. Normal hearing children were similarly affected when listening to individual word tests, but there was no significant disadvantage to listening at 0.9 s RT when they listened binaurally to test sentences at good SNRs. This suggest that reverberation times of around 1.0 s and above are unsuitable not only for hearing impaired children, but also for normal hearing children with lower language acquisition skills who may not be familiar with the speech material and are unable to make use of the redundancy in sentential speech (for example young children or children with EAL or APD).

There is a distinct lack of speech perception evidence for children with other needs (SLCN, AD/HD, ASD, APD, visual impairment) (14) and therefore detailed results for these needs cannot be reported as part of this review. Studies for these groups (19, 29-32) tend to focus on benefits from using personal listening aids, and the few studies which do address acoustic conditions have carried out experiments in low SNR conditions (-5 to + 5 dB) and have not considered variation of reverberation time. There is some evidence (30) that high functioning students with ASD or Asperger's syndrome require up to 3.5 dB higher SNR to achieve equal speech perception and therefore the inference is to target a classroom SNR of at least +15 dB for this group. The general lack of evidence for these needs is a concern, considering that they form the vast majority of the SHCN population in mainstream schools.

5.3 Results

Detailed results of the review are discussed in a previous paper (14). The summary in Figure 3 presents the total listening disadvantage as the inherent % gap (ideal near anechoic, quiet acoustic conditions), and additional acoustic % gap (for the recommended acoustic condition). As expected, groups with minimal hearing loss, EAL, and younger learners exhibit the smallest inherent listening gap of less than 5%, which is not considered significant, since this gap was comparable to the standard deviation reported within the group. However children with a significant hearing impairment were more severely disadvantaged. Children with severe-to-profound hearing loss (listening without a personal aid) experienced the greatest disadvantage compared to their typical hearing peers, with an inherent listening gap of up to 12% and a total listening disadvantage of 30% or more when reverberation times were 0.6 seconds or greater (14, 24).

Despite variations in the experimental studies and presentation of the speech testing material, results are remarkably consistent between the studies which examined the same need. An inherent gap of 6-7% was obtained for children with mild-to-moderate hearing loss. An inherent gap of 9-12 % was obtained for children with severe-to-profound hearing loss.

Whilst the ideal acoustic conditions associated with the inherent listening gap may not be reproducible naturally throughout a room, use of personal listening aids with close microphone technique may help to approach these conditions by capturing direct sound in the near field (excluding reverberation) and amplifying to achieve +20 dB SNR. According to Finitzo-Hieber & Tillman's 1978 study (23) the 'acoustic gap' under 0.3-0.4 s RT and +20 dB SNR is an additional 7%, however it is possible that this gap would reduce with the benefit of modern digital hearing aids, binaural listening, and using sentential speech (rather than individual words) as test material. For the more recent studies of children with severe-to-profound loss who benefitted from these advantages, no acoustic gap was apparent, provided that +20 dB SNR and 0.3 s RT was maintained.

Type of need n studies (test material)	Inherent Gap % (anechoic, quiet)	Acoustic Gap %	 RT condition	Required SNR
minimal hearing loss n=1 (sentences)	4%	up to +4% (less if >12 dB SNR achieved)	Not tested, 0.4 s implied	+6 dB for anechoic, +12 dB for 0.4 s
mild-to-moderate hearing loss n=3 (words)	7%	+7% - mitigated by modern hearing aids, binaural listening, sentential speech	0.4 s	+20 dB or +15 dB if RT <<0.4 s
Severe-to-profound loss n=2 (sentences)	9-12%	N/A provided RT and SNR maintained	0.3 s	+20 dB
EAL n=1 (sentences)	1-4%	N/A provided RT and SNR maintained	Not tested, 0.4 s implied	+6 dB for anechoic, +12 dB for 0.4s
Age n=2 (words)	N/A	11 yrs: 4% 8 yrs: 3% 6 yrs: 4%	0.4-0.5 s	11 yrs: +9 dB 8 rs: +13 dB 6 yrs: +15 dB

Figure 3 – Summary results of speech perception evidence review (14)

6. CONCLUSIONS

This review was undertaken to explore how classroom acoustics criteria might be reasonably adjusted to ensure children with SHCN are not placed at a disadvantage in mainstream classrooms. On average, all mainstream primary and secondary classrooms, need to anticipate the presence of children with SHCN, who require improved acoustic conditions to avoid being placed at a disadvantage.

On balance, a reasonably adjusted criterion for reverberation time (to protect teachers' voice level whilst achieving good speech intelligibility for SHCN) is considered to be 0.5 seconds unoccupied, corresponding to around 0.45 seconds occupied, in combination with +15 dB SNR. This criterion is practicably achievable in BB93 compliant naturally ventilated typical mainstream classrooms with an ambient noise level of up to 40 dBA. Pupils with hearing impairment will benefit from even shorter effective reverberation times and boosted +20 dB SNR via skilled use of a personal listening aid.

The reasonably adjusted acoustic criteria for mainstream classrooms proposed in this paper should be further developed by carrying out further research into the impact (or otherwise) of low frequency reverberation time in rooms when a personal listening aid is being used, and addressing the lack of speech perception evidence for under-studied SHCN needs beyond hearing impairment.

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