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An investigation of classroom sound levels as a function of class size

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ABSTRACT

In their work as expert witnesses on acoustics for Special Education Needs and Disabilities Tribunals, the author and colleagues have measured in-lesson sound levels during different types of teaching and learning activity in both state schools and independent schools throughout England. The results have been analysed to investigate the relationship between class size and sound levels generated by teachers and pupils during different activities and types of teaching and learning activity. From this the author considers the acoustic justification for teaching pupils with special hearing and communication needs in smaller classes, and other, less measurable factors which influence noise lessons in classrooms at different schools.

1. INTRODUCTION

It is widely assumed that pupils with special hearing and communication needs should be taught in classrooms with low noise levels and short reverberation times. This conclusion is supported by research and publications too numerous to reference individually, and is supported by acoustic standards in several countries, including DfE Building Bulletin 93 and the associated guidance in the UK [1, 2]. Building Bulletin 93 sets different numerical standards for "Mainstream" classrooms and for those intended for teaching pupils with special hearing and communication needs (SHCN). These standards apply to new and refurbished schools under Building Regulation E4, which is partially enforced by local authority building control, and also nominally under the Schools Premises Regulations although there is no mechanism for enforcement under the SPRs. As discussed later, the regulations are in any case written in such a way as to invite delegations and alternative performance standards to reduce the cost of acoustic treatment.

There has been a great deal of research into the effect of room acoustics on the signal-to-noise ratio experienced by pupils. There is, however, less research into the effect of class size on absolute sound levels during lessons. This is important because many students with special needs are sensitive to high noise levels, either for psycho-acoustic reasons or because of the limited dynamic range of cochlear implants and other assistive devices [3].

Large-scale studies have shown clear statistical correlation between class size and sound levels in classes during lessons both in primary and secondary schools [4, 5] and in 2015 the DfE published the guidance document "Advice on standards for school premises for local authorities, proprietors, school leaders, school staff and governing bodies". This states:

> "Pupils with special needs may need to be taught in spaces with lower noise levels and shorter reverberation times than in mainstream classrooms and class bases. Special schools and SEN units in mainstream schools therefore require designing to a higher acoustic standard. Where pupils with these 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 in special units. Provision will usually be required to teach these pupils in smaller groups so that ambient noise from other pupils is lower and the distance between teacher and pupil is minimised."

The wording of this guidance might be described as rather timid; most people with knowledge of the subject would probably say that pupils with special needs "should be" taught in acoustically better conditions and it smaller groups, rather than that they "may need to be". Similarly indecisive wording is found in Building Bulletin 93, which identifies the need for shorter reverberation times and lower noise levels for pupils with special hearing and communication needs, but leaves a significant loophole by setting the standards for "teaching spaces *intended specifically* for students with special hearing and communication needs". Even this is qualified with a note that alternative performance standards are commonly required for these rooms and should be agreed by an acoustician and the School client body. As a result, new schools procured through the DfE frameworks generally contain few, if any, classrooms "intended specifically" for this use, although it is not rarely clear where pupils with special hearing and communication needs are to be taught or how this approach complies with the Equality Act.

Readers will not be surprised to know that the above wording was significantly altered from the more specific recommendations drafted by the acousticians who were the original authors of BB93. Unfortunately, the cost of providing good acoustic conditions for disadvantaged pupils is very much at odds with the cost-driven procurement systems for building and refurbishing state schools. It is known that every classroom is likely to contain at least one child with special hearing and communication needs at any time [6], but only a very small proportion of all classrooms are designed to the acoustic standards identified in BB93 for these pupils.

Even where the acoustic consultant persuades the client to design some classrooms to the SHCN standard, the additional acoustic treatment is commonly omitted either a result of "value engineering" (i.e. cost-cutting) or because other constraints make it difficult to provide enough acoustic absorption. These constraints include [6]:

- very stringent limits on capital cost per square metre;
- a requirement for exposed soffits for thermal stability, such that the conventional acoustically absorbent suspended ceiling is no longer viable;
- constraints on the ceiling area that can be covered by acoustically absorbent rafts or battles (at the time of writing, a maximum of 40% coverage was permitted under the latest DfE output specification;
- a lack of wall space for acoustically absorbent wall panels due to the need for natural cross ventilation, whiteboards, noticeboards, shelves and cupboards
- a reluctance on the part of many architects to include acoustic absorption on walls.

When this happens, instead of developing a coordinated design which provides the best possible acoustic conditions within those constraints, some acoustic consultants are persuaded to propose an alternative performance standard (APS) which is merely the minimum legal standard required for mainstream classrooms, i.e. a mid-frequency reverberation time of 0.6 seconds in primary schools and 0.8 seconds in secondary schools. This approach generally meets the approval of the contractor and quantity surveyor, but at the expense of the ultimate users of the classrooms.

Most of our state school classrooms are therefore not designed to a good or desirable standard, but to the minimum legal standard required under building regulations, although this is known to be inadequate for children with special hearing and communication needs (which are defined in BB93 as including hearing impairment, visual impairments, conductive hearing loss, attention deficit hyperactivity disorders, auditory processing disorders or difficulty and being on the autistic spectrum).

In state schools, he vast majority of children with special hearing and communication needs still spend most of their school time in mainstream classrooms with classes of up to 30 pupils. Some of them may spend, typically, 10% of their time receiving one-to-one tuition in a hearing-impaired unit or receiving remedial teaching in smaller groups, but this is of limited value if they have difficulty following lessons in the mainstream classes where they spend most of their time.

As a result, an increasing number of parents are using the tribunal system to force education authorities to fund their children's fees at independent schools which do not have the same cost constraints and are therefore likely to have classrooms with better acoustics and, perhaps more importantly, fewer pupils in each class.

2. ACOUSTICS AND SEND TRIBUNALS

Parents who believe that their child is disadvantaged at school through inadequate provision can apply to a SEND (Special Education Needs and Disability) Tribunal which can, effectively, instruct the education authority to fund the cost pf educating that child at another school nominated by the parent. This may be a specialist school which caters specifically for the child's special need, such as a school for deaf children, or it may be an independent school which the parents feel meets the child's needs because, among other things, the class sizes in independent schools tend to be significantly smaller. Classes in independent schools are typically between 12 and 24 pupils in core subjects, and often fewer than 10 pupils in other subjects, especially in later years.

The tribunal process is rather limited in scope; for example, it does not set out to find an ideal school for a given pupil but merely decide which is the better of the single school proposed by the local education authority and the single school nominated by the parents. In cases where the pupil has a significant hearing loss or auditory processing difficulty, an expert witness on acoustics may be appointed to assess the acoustics of the two schools and to advise on which of them is likely to be acoustically better for the child. This work is generally separate from that of the educational audiologist who advises on the degree of hearing loss and its likely implications for the child. Reference [7] describes the SEND Tribunal Process is described in more detail.

3. METHODOLOGY

The question that we have to address is which school better provides an acoustic environment in which the pupil in question can hear and communicate with teachers and other pupils. We therefore measure acoustic parameters in typical conditions and in a typical selection of classrooms likely to be used by the pupil. We normally take three types of measurement: room acoustics, internal ambient noise level in the unoccupied rooms, and sound levels during classes. We also consider sound insulation, but we do not necessarily measure this unless it is so poor that noise transmitted between rooms is clearly audible and disturbing. This occurs surprisingly rarely, most frequently where classrooms are divided by folding partitions, or are linked by single doorsets in the separating walls.

Measurements of reverberation time and Internal Ambient Noise Level (IANL) in unoccupied classrooms are taken in accordance with the Association of Noise Consultants' Good Practice Guide [8] and need not be described in detail here. Measurements of sound levels during lessons are taken using a pragmatic approach developed to provide a simple and reproducible means of comparing values in different classrooms, while minimising disruption to teaching. It is gratifying, but not surprising, to find that our methodology is virtually the same as that developed by Shield et al in their surveys of noise levels in school classrooms [4,5]. We use a hand-held sound level meter, normally located at the back of the classroom, at a distance of between 5 and 7 metres from the teacher's normal speaking position. We measure and observe the overall LAeq value, the duration of each measurement generally being between 30 seconds and five minutes, depending on changes in activity during the measurements. The start and stop time of each measurement is chosen to coincide with changes in the type of activity, using similar activity types to those used by Shield et al. in their survey of secondary school classrooms [5] i.e.

a) Plenary, i.e. teachers talking to the whole class, reading out loud, or question and answer session with only one person talking at a time.
b) Individual work - pupils engaged in quiet study, doing a test or exam, or otherwise working individually without significant sound from discussion between pupils. Frequently includes sound from the teacher moving around and talking to individual pupils.
c) Group work - typically, pupils working in groups of 4 to 6 around a table and talking within their groups, often with contributions from the teacher talking to one group of pupils at a time.
d) Watching/listening to a video or audio recording.

Where parents request, we may also measure levels in non-core subjects such as music, drama or art, but room sizes and acoustics vary so widely between these rooms that meaningful comparisons cannot always be made and we have therefore excluded these from our overall analysis.

4 SIGNAL, NOISE AND SIGNAL-TO-NOISE RATIO.

The criteria for internal ambient noise levels and reverberation times in classrooms are developed from consideration of signal-to-noise ratio at the area of the pupil, with a higher signal-to-noise ratio being required for pupils with special hearing and communication needs [6]. Signal-to-noise ratio, however, is practically impossible to measure in a survey of this type, and in any case what is signal and what is noise varies between the activities listed above:

a) In plenary activities, the signal is the teacher's voice or the voice of a pupil answering a question. Any other sound generated by the pupils or other sources inside and outside classrooms is noise.
b) In individual work, any sound at all might be considered as noise for all pupils, except that if the teacher is talking to an individual pupil, the teacher's voice is signal rather than noise for that pupil.
c) In group work, the sound from a pupil talking within a group is signal within that group, but is noise to people in other groups. The sound from the teacher talking may similarly be signal to one group but noise to another.
d) When listening to a video or audio recording, anything other than the audio is likely to be noise.

Consequently, any simplified analysis such as the difference between L_{Aeq} and L_{A90} is unlikely to be helpful except as a comparison between classrooms with identical activities taking place. Even in those cases, there is no evidence for a clear relationship between (L_{Aeq}-L_{A90}) and signal-to-noise ratio as related to speech intelligibility. In any case, we also have to think carefully about the duration over which we would measure signal-to-noise ratio. The intelligibility of a single word will depend on the signal-to-noise ratio during the second or fraction of second when that word is said. Both signal and noise, however, fluctuate from second to second. It is therefore not clear over what period signal-to-noise ratio should be measured, although it seems obvious that an averaging time of more than a few seconds is unlikely to give any valuable information unless both the signal and the noise are reasonably constant over that period.

While the acoustic parameters that we consider have been derived from consideration of signal-to-noise ratio, we can only measure much simpler parameters such as reverberation times and sound levels averaged over several minutes. Fortunately these have been shown over a very large number of measurements by many researchers to have empirical relationships to speech intelligibility in classrooms for pupils with and without special hearing and communication needs [6].

5 MEASUREMENT RESULTS AND DISCUSSION

It must be remembered that the reason for our measurements was not to collect data for a large-scale study (as was the case in references 5 and 6) but simply to provide a comparison of conditions in two schools for each SEND Tribunal. Tribunals do not generally encourage a high level of technical complexity and a very simple form of analysis is therefore required. Our usual presentation of classroom noise levels is therefore in terms of a simple table of results, a comparison of the mean classroom noise levels, a professional opinion and in some cases a very simplified graphical presentation.

It should also be pointed out that the rules relating to expert witnesses at tribunals are the same as those in civil courts. The expert is required to advise the tribunal independently of the interests of the instructing party, so that there should be no bias in the evidence presented.

Figure 1 shows one type of very simple analysis as presented to a tribunal, in which all of the measurements taken into schools are arranged in ascending order on a single graph, as shown in figure 1.

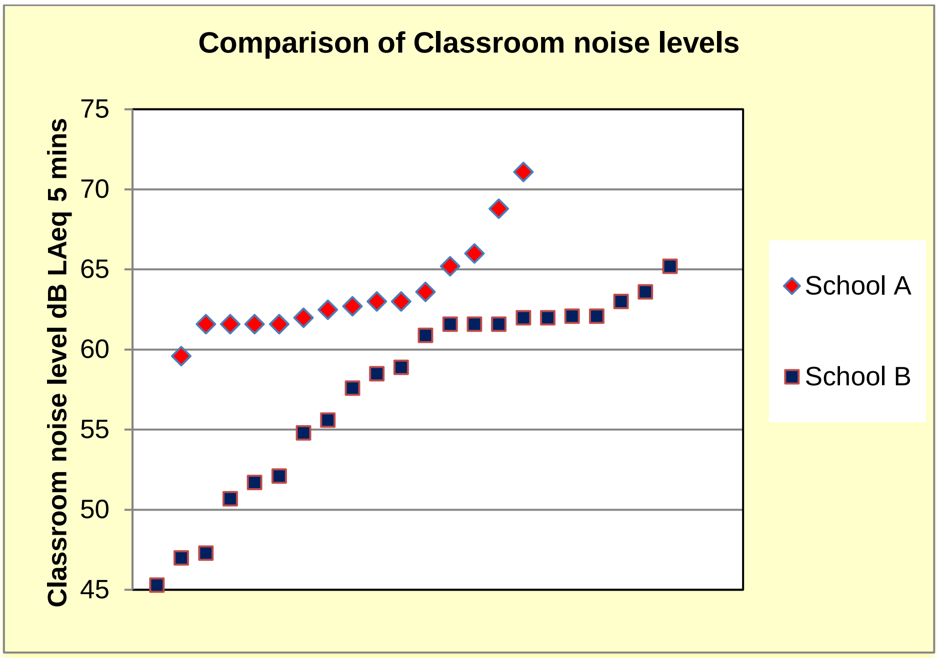

Figure 1: Graphic comparison of data for SEND Tribunal.

This type of presentation can only be claimed to be valid if the measurements taken any school are directly comparable, and every effort is made to ensure that this is so. In this case, all of the measurements were taken in mainstream classrooms in core subjects, in classrooms which would have been used by the pupil in question, so that the only variables were the classroom itself, the number of pupils and the behaviour of those pupils.

Pupil behaviour strongly influences noise levels in classrooms, but is not generally referred to in large-scale studies. Figure 1 shows two data points for school A which are close to 70 dB LAeq. These were measured in a humanities class of 26 year seven pupils, nominally undertaking individual work but in fact talking very loudly among each other with no intervention by the teacher. The equivalent activity in other classrooms with the same class size at the same school was around 63 dB LAeq. In School B the equivalent activity in a classroom with a slightly longer reverberation time but the class size of 21 pupils was around 51 dB LAeq. While there is a clear correlation between the sound levels and the class size, the conclusion in our report to the tribunal was that the difference in noise levels was due to a difference in classroom behaviour rather than of class size.

Classroom behaviour is a very fundamental issue which drives not only classroom noise levels but also a number of other factors which influence parents in their choice of school. In nearly all cases, the local authority names a local state school whereas the parents nominate either a special school or an independent school. While some state schools expect and achieve a very high standard of behaviour in classrooms, they do not have a selective policy which allows independent schools to exclude children who are noisy or badly behaved. Independent schools may also be able to select teachers who are dated capable of maintaining class discipline than some state schools. Many of us, thinking back to our own schooldays, will remember that different teachers teaching the same class achieved very different results in terms of classroom discipline and hence noise levels.

Figure 2 shows a comparison of raw data measured across 32 schools, of which 50% were state schools and 50% were independent. This shows the results for a very wide range of class sizes and for mid frequency reverberation times ranging from less than 0.4 seconds to, in one case, as much as 1.2 seconds. The data is limited to core subjects taught in conventional classrooms with floor areas varying between 50 and 100 m². It should be noted that in many cases, because of the age of buildings in many independent schools, classroom dimensions were larger and the reverberation times longer in independent schools than in state schools. It is clear, however, that there is a trend towards higher sound levels in the larger classes which tend to occur in state schools.

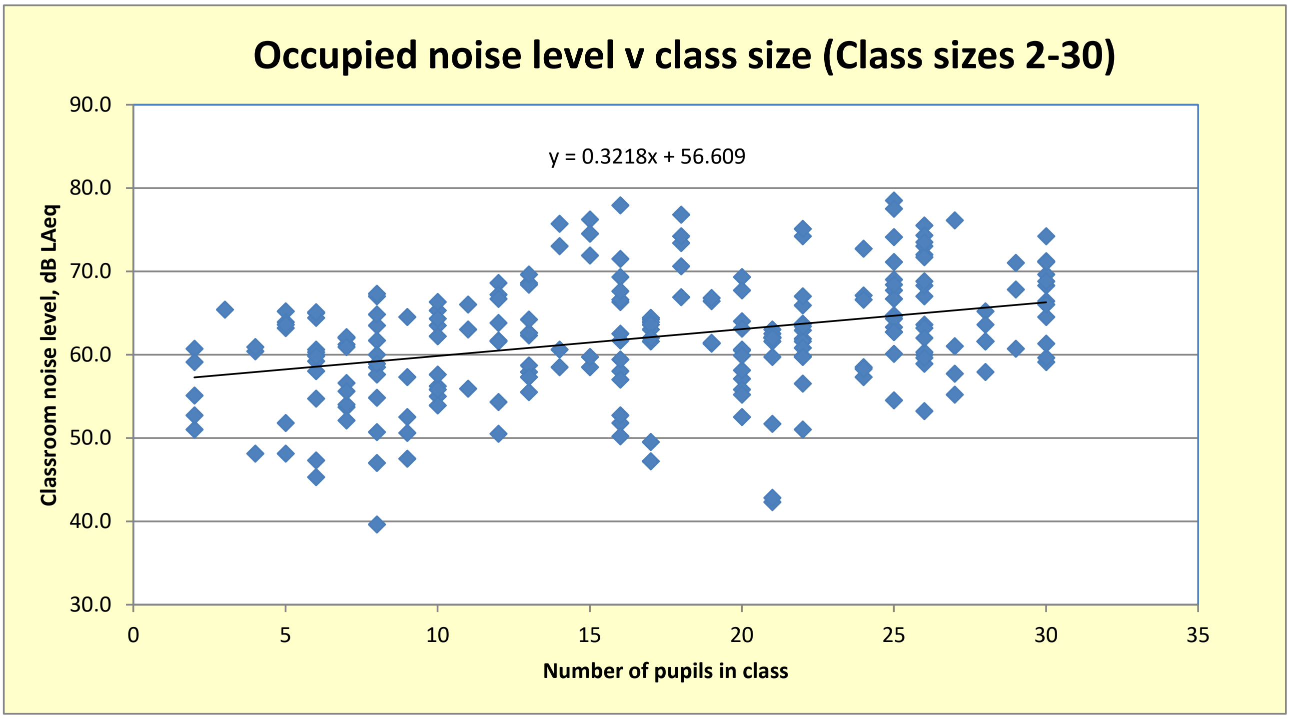

Figure 2: Comparison of results uncorrected for reverberation time

At this level of analysis there is no indication of a "breakpoint" at which classroom sound levels increase sharply, as happens in other spaces as a function of occupancy. It is therefore not clear that there is an equivalent of the Lombard effect in classrooms. Because of the nature of our work for SEND Tribunals, we have not had had the opportunity to measure different class sizes with the same age of pupils and with the same teacher in identical classrooms, which we believe would be necessary to identify an equivalent to the Lombard effect if this, indeed, occurs.

There are a few other observations to be made on the above data:

- Unusually low noise levels (around 40 dB LAeq) occurred in two cases, one with a class size of eight and another with class size of 21. In both cases these were during quiet individual study at a time shortly before GCSEs or A-levels. Measured levels below 50 dB LAeq did not, otherwise, occur in class sizes of more than 17 pupils.

- There were a few values approaching 80 dB LAeq and in these cases our notes during the measurements recorded that these were uncomfortably high and clearly incompatible with teaching or learning. In some cases these were during end-of-term activities including “revision games”, and we were informed by the teacher that these no way represented normal teaching activity. Nonetheless these are included for completeness. The very highest noise levels, however, were recorded in two core subject classes where the teacher clearly had no control over the class, and where it was clear that no meaningful learning could take place.

6 CORRELATION, CAUSATION AND CONCLUSIONS

Correlation, of course, does not imply causation [9]. A correlation between the variables A and B does not mean that A causes B or vice versa. It is equally possible that both A and B are related to another factor C which is correlated to both. As discussed above, one such factor C is classroom behaviour, which in turn is affected by the ethos or behavioral expectation of the school and which, for understandable but regrettable reasons, tends to be better in independent schools which also tend towards smaller class sizes. It is hardly surprising that when selecting a preferred school, most parents choose an independent school which they have visited and where they have witnessed, among other things, small class sizes and a good standard of behaviour among pupils. This is not to say that good behaviour is limited to independent schools - we have taken measurements in state schools which have higher standards of behaviour than some independent schools - but it cannot be denied that on average, the standard of classroom behaviour as affecting classroom noise levels tends to be better in independent schools.

A further complication is that many of the sound levels measured are dominated by the speech level of the teacher. It is well known that people talking to or within a group adjust their vocal level to take account of the ambient noise level; that is, after all, the whole basis of the Lombard effect. In addition, a person addressing a room full of people will naturally tend to speak more loudly in a larger room and to a larger group of people. It is hardly surprising, therefore, that there is a relationship between vocal effort (and therefore speech level) and class size. In fact what the speaker is doing is attempting to maintain the same signal-to-noise ratio by increasing vocal effort as the noise level rises.

To further complicate matters, the noise level in classrooms is also affected by the teacher’s vocal effort. A common technique for teachers to silence a no at the beginning of the lesson is to start talking relatively loudly and once they have the classes attention, to reduce the vocal effort. This is a technique which have been witnessed on many occasions during our measurements in schools.

Rather than assume a direct correlation between sound level and class size we would suggest the following hypothesis:

- The underlying sound level caused by a class for a given activity increases with the number of people in the group, whether this is a relatively low sound level as a result of pupils sitting relatively quietly while the teacher is talking or as a result of pupils talking among each other during group work.

- The teacher will tend to increase vocal effort so as to maintain, as nearly as possible, an adequate signal-to-noise ratio. What this does is increase the overall sound level in the class, and what is really desirable in the class is for pupils to be able to understand the teacher at relatively low sound levels. This provides a less stressful environment for both teachers and pupils, even if they do not have special hearing and communication needs.

- Many pupils with special hearing and communication needs have a relatively low tolerance of high noise levels. This may be due to medical, psychological or psychoacoustic reasons (e.g. in pupils with Asperger's, Acoustic Spectrum Disorder and ADHD) or for purely acoustically reasons for pupils with personal listening aids or cochlear implants which reduce the effective dynamic range of the user's hearing.

- Our aim should therefore be to achieve the necessary signal-to-noise level while keeping the signal level as low as possible - and hence keeping the noise level as low as possible. As it is established that both signal and noise level increase with class size, it is clear that limiting class size will help to achieve this.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Department for Education England and Wales, Building Bulletin 93 - Acoustic design of schools: performance standards (2015)
2. Institute of Acoustics and the Association of Noise Consultants, Acoustic design and equipment for pupils with special hearing requirements, Chapter 6 of Acoustics of Schools – a Design Guide (2016)
3. Iglehart, F. (2016). Speech perception in classroom acoustics by children with cochlear implants and with typical hearing. American J. Audiology 25, 100-109.
4. Shield, B. and Dockrell, J. (2004). External and internal noise surveys of London primary schools. J. Acoustical Society of America 115 (2), 730-738.
5. Shield, B.., Conetta, R., Dockrell, J., Connolly, D., Cox, T. and Mydlarz, C. (2015). A survey of acoustic conditions and noise levels in secondary school classrooms in England. J. Acoustical Society of America 137 (1), 177-188.
6. Greenland, E and Shield, B, towards accessible acoustic criteria for inclusion in mainstream classrooms. Proceedings of the international congress on acoustics, 2019.
7. James, A, Acoustics and SEND Tribunals, BATOD (British Association of Teachers of the Deaf) Magazine (2013).
8. Association of Noise Consultants, 'Good Practice Guide – Acoustic Testing of Schools', 2015.
9. Altman, N, Krzywinski, M. Association, correlation and causation. Nature Methods, 2015.