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THE EFFECTS OF NOISE ON CHILDREN AT SCHOOL: A REVIEW

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ABSTRACT

This paper reviews research on issues relating to the effects of noise on children at school. Areas covered include factors affecting speech intelligibility in the classroom; the effects of environmental and classroom noise on children's academic performance; children's annoyance due to noise; and surveys of classroom noise levels. Consistencies and discrepancies between the results of various studies are highlighted. The paper concludes by outlining some current acoustic standards for classrooms.

1. INTRODUCTION

There has been a great deal of research in the past 30 years into the effects of noise on children’s learning and performance at school. This has been mainly concerned with the primary school age range (5 to 11 years), and has included studies of the effects of chronic exposure to different kinds of environmental noise and of other kinds of classroom noise. Many of these studies have examined the effects of noise on children's cognitive processing in a range of tasks and on their academic performance at school. In addition to the examination of the effects of noise on children's performance, a limited number of surveys have investigated the annoyance experienced by children in relation to their noise exposure at school.

A major effect of noise in the classroom is the reduction of speech intelligibility, and the hearing and understanding of speech by children of different ages in various noise and acoustic conditions is a related important research field.

In parallel with studies of the effects of noise at school, there have been several surveys of classroom noise and acoustics, and investigations into the way in which the acoustics of classrooms may be improved. Concern about the effects of noise on children’s learning, and how they may be mitigated, is reflected in current work towards improving standards for classroom acoustics.

2. GENERAL EFFECTS OF NOISE ON CHILDREN

In the past 30 years there have been many investigations examining the relationship between noise exposure of school children and their performance in various cognitive tasks. The earlier studies were concerned mainly with external environmental noise exposure of schools, but more recently the effects of internal classroom noise have been investigated. It is generally accepted that noise has a detrimental effect upon the learning and attainments of primary school children [1,2]. At the beginning of the 1990s there were two major reviews of previous work to date in this area [3,4], both of which concluded that chronic noise exposure of young children has a particularly detrimental effect upon their reading ability. More recently Picard and Bradley [5] have published a major review of issues related to speech intelligibility in classrooms, which covers many aspects of noise and acoustics in the classroom.

In investigating the effects of environmental noise on children a wide range of attainments and performance factors have been considered. These include literacy [6-11], attention [12-17], mathematics [7,11], and memory [18-21]. Tasks that involve language, such as reading, and those that have high cognitive processing demands involving attention, problem solving and memory appear to be those most affected by exposure to noise [4, 11, 20, 22] although such effects are not always evident [6, 7, 23-25].

In summary, it appears from this body of work that the general effects of chronic noise exposure on children are deficits in sustained attention and visual attention; poorer auditory discrimination and speech perception; poorer memory for tasks that require high processing demands of semantic material; and poorer reading ability and school performance on national standardised tests.

The types of noise which have been considered in these studies include aircraft noise [6, 7, 9, 22, 26, 27]; train noise [19, 28, 29], traffic and street noise [30, 31]. Many of these studies have focused on the effects of noise from a single source, although noise exposure in the classroom is likely to be due to a combination of internal and external sources. Despite this, there have been few studies in which the effects of irrelevant noise in the classroom have been considered. One such study is the large scale investigation by Shield and Dockrell [11] which examined, separately and in combination, the effects of environmental and classroom noise on children's perceptions of noise and performance.

3. SOURCES OF NOISE IN THE CLASSROOM

The noise in a classroom is made up of external noise which is transmitted through the building envelope, plus internally generated noise, so that children in school may be exposed to noise from a wide variety of sources. External noise is likely to consist of a range of environmental noise including noise from transportation sources, industrial noise, plant noise and the noise of people outside the school. An additional source of noise which is reputed to cause significant disturbance to teaching is the noise of rain falling on lightweight school roofs [32,33].

The predominant external noise source, particularly in urban areas, is likely to be road traffic [34,35] although aircraft noise may also affect many schools, with fewer schools exposed to railway noise.

A survey in 2000 by Shield and Dockrell [36] of noise sources outside schools in London found that the predominant sources were cars (outside 86% of schools), aircraft (54%), lorries (35%) and buses (24%), with 11% of schools exposed to railway noise. This distribution of sources agrees closely with the occurrence of sources recorded outside dwellings around the UK during the 2000/2001 National Noise Incidence Survey (NNIS) [34] (for example NNIS found 87% of dwellings exposed to road traffic noise, and 12% of dwellings exposed to railway noise.) It can therefore be assumed that these figures are likely to reflect the typical noise exposure of schools in industrial societies.

Studies of annoyance caused by noise heard in schools by Dockrell *et al* [37-39] suggest that certain occasional noise events such as overflying aircraft, trains or sirens may affect children and teachers disproportionately to their contribution to the overall noise environment of a school.

In addition to external noise transmitted through the building façade to a classroom, noise inside a classroom may include noise from teaching equipment (computers, projectors and so on), noise from building services in the classroom, and noise transmitted through the walls, floor and ceiling from other parts of the school. Shield *et al* [11, 36], however, in a survey of 140 primary school classrooms, found that the dominant source of noise in a primary school classroom is the noise generated by the pupils themselves as they take part in a range of classroom activities.

4. SPEECH INTELLIGIBILITY

A major effect of noise and poor acoustics in the classroom is the reduction of speech intelligibility. If children are unable to understand the teacher then the major function of a classroom in providing an environment that enables the transfer of information from teacher to pupil is impaired. In addition it is important, both for learning and for social interaction, that children are able to hear and understand their peers in the classroom.

4.1 Children's understanding of speech

There have been many studies of children's understanding of speech in different noise and reverberant conditions, some of which have paid particular attention to the acoustic conditions of classrooms. These studies have shown that young children are far more susceptible to poor acoustic conditions than adults. Nelson [40], in describing the development of the 2002 ANSI standard on classroom acoustics [41], gives a brief review of recent work in this area. It has been shown through research with children of differing ages that a child's understanding of speech in noise and reverberation does not reach an adult level until the late teenage years. Before this time, the younger the child the greater the detrimental effect of noise and reverberation [42-45], with children under about 13 years of age being particularly susceptible.

Children and adults who are hearing impaired are more seriously affected by noise and reverberation than those with normal hearing. It is estimated that at any one time up to 40% of children in a primary school class in the UK or USA may have some form of hearing impairment [40,46], due to either permanent damage to their hearing or a temporary condition such as a cold or ear infection. Furthermore, many children with permanent hearing impairments are now educated alongside their mainstream peers, in accordance with the principles of social inclusion and legislation such as the Americans with Disabilities Act [47] and the UK Disability Discrimination Act [48]. It is therefore particularly important to achieve good acoustic conditions in classrooms to meet the needs of these children.

There are other groups of children for whom understanding their teachers and their peers can be difficult in the classroom, for example children who are not being taught in their first language [40, 49], children with disorders such as attention deficit/hyperactivity disorder [50], and children with speech and language difficulties. These children may be easily distracted in poor acoustic conditions or may have general problems in processing language, which will be exacerbated in classrooms with poor acoustics.

4.2 Acoustic factors affecting speech intelligibility in classrooms

The room acoustic factors that affect speech intelligibility are background noise level and reverberation time. Both Bradley and Hodgson and their colleagues [51-56] have carried out experimental and theoretical studies to investigate the relationship between these factors and speech intelligibility in the classroom. A general conclusion of these studies is that noise is the more critical factor and that criteria for acoustical conditions in the classroom should be based upon speech intelligibility. In work with adults Bradley *et al* [51] found that noise, rather than reverberation, was the most significant factor in understanding speech and that the most important parameter for speech intelligibility is the signal (that is, speech) to noise ratio. As the levels of teachers' voices vary, this means that it is particularly important to reduce the background noise level in a classroom. Bradley [52], in an analysis of measurements of acoustical conditions and speech intelligibility in classrooms for 12 and 13 year old students, concluded that 30 dB(A) was an appropriate background noise level, with optimum reverberation times of 0.4 to 0.5 seconds. There is however some disagreement about the ideal value of the signal to noise ratio for classrooms. Finitzo-Hieber and Tillman [57] in 1978 recommended a signal to noise ratio of 12 dB for both normal hearing and hearing impaired students although others [58, 59] argued that a higher S/N value of 20 to 30 dB is required for the teaching of hearing impaired children. More recently Bistafa and Bradley [53], following a series of theoretical studies, recommended that the speech to noise ratio should be greater than 15 dB throughout a classroom, 25 dB being the ideal value and 20 dB an acceptable value 1 m in front of speaker. These values assume a reverberation time of less than 0.4 to 0.5 seconds. Signal to noise ratios of 15 or 20 dB are recommended for classrooms by the American Speech-Language-Hearing Association [60] and the British Association of Teachers of the Deaf [61] (see section 9).

It is usual to assume that speech intelligibility will increase as reverberation time decreases to zero [62]. Although it is generally accepted that, to maximise speech intelligibility, it is necessary to have a relatively short reverberation time, Hodgson and Nosal [54] argue that, when the noise inside a classroom is taken into account, longer reverberation times are possible without compromising the speech intelligibility. When accounting theoretically for noise of equipment and occupants in a classroom, they predicted that it was possible to achieve high speech intelligibility with reverberation times of up to 1 second, depending on the size of the room. However, the authors concede that their results may not be appropriate in the case of younger and hearing-impaired listeners.

Picard and Bradley, in a major review of research on speech intelligibility in classrooms [5], compared measured noise levels and teachers' voice levels from a range of studies. They estimated that in reality the speech to noise ratio varies from 3 dB in a kindergarten to almost 7 dB in university classrooms.

5. EFFECTS OF ENVIRONMENTAL NOISE

The majority of the research into the effects of noise on children's performance in the classroom has examined the issue in one of two ways. Either the performance of children exposed long term to significant levels of environmental noise has been compared with that of children with low noise exposure; or the effects of a reduction in environmental noise on children's performance in the classroom have been studied.

Much of the published work on the effects of external noise has concerned pupils in schools exposed to aircraft noise. In the early 1970s Crook and Langdon [63] found that in schools around Heathrow aircraft noise had a significant impact on teaching by interfering with speech and causing changes in teachers' behaviour in the classroom. Two major studies around airports in the 1980s and 1990s involving children aged from 8 to 12 found impaired performance in noise exposed children [4, 6, 7, 64]. In these studies high noise exposure was associated with poor long term memory and reading comprehension, and decreased motivation in school children. Typical levels of aircraft noise to which the schools were exposed were 95 dB L_{peak} [6,7]. A recent study of children in schools affected by aircraft noise from Heathrow Airport, in which children in schools within the 63 dB(A) $L_{Aeq,16hour}$ aircraft noise contour were compared with children in schools outside the 57 dB(A) contour [10, 65, 66] also found that noise affected reading ability for the hardest items.

The effects of chronic exposure to aircraft noise appear to be long term. Cohen *et al* [7] found that reducing the noise inside a school by 16 dB(A) had little effect on children's performance. More recently Hygge [64] found that even when the noise source is removed, as in the closure of an airport, it takes several years for the detrimental effects of noise exposure to cease.

Other studies have examined the effects of school exposure to train and road traffic noise. Bronzaft and McCarthy [29] found that children on the quieter side of a school next to an elevated railway had reading scores higher than children on the side exposed to the train noise, at levels of up to 89 dB(A). A noise abatement programme reduced the train noise inside the school by 6 to 8 dB(A), after which no difference was found between the reading scores on the two sides of the school [67].

In the UK road traffic noise has been found to cause dissatisfaction with the classroom environment among teachers; Sargent *et al* [68] found that there was a greater incidence of complaints about noise at levels above 60 dB(A) L_{A10}. Lukas *et al* [69] found that exposure to traffic noise had a detrimental effect upon children's reading ability. More recently tests in both primary and secondary schools exposed to noise from road traffic have found that noise has a detrimental effect on children's attention [70, 71]. The levels of road traffic noise in these studies were around 70 dB(A) on average.

Hygge [20] investigated the effects of noise from various transportation sources on children aged between 12 and 14. Noise of different sources was played at 66 dB(A) in the classroom. Aircraft and road traffic noise were found to affect long term recall whereas the noise from trains had no effect.

Shield and Dockrell [35] compared external noise levels at over 50 London schools with the schools' scores in standardised assessment tests (SATs) of children aged 7 and 11. There were significant relationships between external noise levels and SATs scores, the relationships being stronger for the older children. The noise parameter that had the highest correlation with SATs results was L_{Amax}, suggesting that it is the noise of individual events, or acute exposure, which may have the most significant effect. In contrast to other studies, the subjects most affected were mathematics and science. The significant relationships were maintained when the data was corrected for school socio-economic factors such as percentages of children for whom English is not the first language and percentages of children receiving free school meals. Similarly, Haines *et al* [72] found that chronic exposure to aircraft noise was significantly negatively related to performance in the standardised mathematics tests of 11 years olds, although the relationship was not statistically significant when the data was corrected for socio-economic status.

While it appears from all these studies that both chronic and acute exposure to environmental noise may adversely affect children's academic performance, there are many other factors, often unreported, that may influence performance and interact with the effects of noise. These include child based factors such as ability, language or social deprivation. In their study of London schools, Shield and Dockrell [35] found that there was a high correlation between a school's external noise level and the percentage of children having free school meals at the school, the latter being a recognised indicator of social deprivation in an area [73,74]. This suggests that deprived children already living in noisy areas attend schools where their exposure to environmental noise may additionally negatively affect their academic performance.

6. EFFECTS OF CLASSROOM NOISE

There has been less research in the past into the effects on children of noise in the classroom, than of environmental noise. However, research in this area is increasing, several recent studies having investigated the effects of internal noise on children's reading, numeracy and overall academic performance [11, 75-77].

Hetu *et al* [3] found a significant drop in children's performance, particularly in learning to read, when the background noise level interfered with speech. Mackenzie [75] compared the performance of children in primary school classrooms that had been acoustically treated, thereby reducing background noise levels and reverberation times, with children in untreated classrooms. Children performed better in word intelligibility tests in the acoustically treated rooms, the improvement being particularly marked when other pupils were talking in the classrooms. Similar results were obtained by Maxwell and Evans [76] in a study of pre-school children who had been exposed to levels in the classroom of 75 dB(A). Following acoustic treatment to reduce the noise the children's performance improved in letter, number and word recognition. In contrast, in a study of older children, aged 13 and 15, working in levels of 58 to 69 dB(A) during mathematics classes [77] there was poor correlation between sound level and standard of work; however, there was a significant relationship between annoyance and the effect of noise on schoolwork (see section 8 for further discussion of annoyance).

Shield and Dockrell [78] in comparing standardised assessment test scores with internal noise levels in 16 schools found significant relationships between background (L_{A90}) levels in classrooms and test scores for several subjects. The test which showed the strongest association with noise was the English test of the older (age 11) children, the relationship still holding when the data was corrected for socio-economic factors. A possible explanation of this result is that background speech in the classroom interferes with general processing of language.

7. REASONS FOR THE EFFECTS OF NOISE ON CHILDREN

There is a need for further work to examine the reasons for the effects of noise on children's performance, in particular what aspects of their cognitive processing are affected by different types of irrelevant noise. A number of possible explanations have been proposed. These include cognitive coping [23] and level of arousal [4,79]. The cognitive coping hypothesis suggests that children deal with excessive levels of environmental sound by tuning it out. This, it is argued, results in indiscriminate tuning out of all stimuli resulting in generalised poor attention [9]. This explanation would imply that a full range of cognitive tasks would be affected, and this is not what appears to happen. In contrast increased arousal could have the effect of increasing performance on tasks where irrelevant items are screened, but continued high levels of arousal may result in an inability to concentrate. More recently the effects of environmental noise have been conceptualised by Evans *et al* [26] in terms of ‘helplessness’. However, both the arousal and the learned helplessness hypotheses fail to make clear predictions about the ways in which environmental noise will differentially affect cognitive skills.

A criticism of studies of the effects of irrelevant noise on adults is that they have mainly involved the performance of simple laboratory tasks in background noise or speech [80]. A marked exception to this is the work of Banbury and Berry [80,81] who examined the disruption of office related tasks by speech and office noise, and confirmed the negative effect of noise exposure on more complex cognitive tasks. However, results obtained with adults cannot necessarily be generalised to children as children’s cognitive and linguistic skills are less developed than those of adults. Shield *et al* [11] carried out a series of experimental investigations in schools to examine the ways in which different irrelevant sound sources interfered with children’s processing of verbal and non-verbal tasks. They found that children's talk in the classroom had a detrimental effect upon the verbal (reading) task but that the addition of random environmental noise events improved performance on this task. A non-verbal (speed of processing) task was detrimentally affected by both classroom talk and environmental noise individually, the worst performance occurring in a combination of these two sounds.

8. CHILDREN'S PERCEPTIONS OF NOISE AT SCHOOL

The most widespread and well documented subjective response to noise is annoyance. However, while there have been many studies concerned with annoyance caused to adults by different types of noise, including ones which have established dose response relationships between noise and annoyance, children's annoyance due to noise is a relatively under researched area. Yet children's annoyance may be a important factor in determining the effects of noise; indeed Lundquist *et al* [78] found that there was a stronger relationship between school performance and annoyance than between sound level and performance.

Some of the studies of the effects of noise on children already discussed have also considered children's perceptions of sound. Children at school have consistently been found to be annoyed by chronic aircraft noise exposure [22,65]. In their study of the effect of high levels of aircraft noise Haines *et al* [65] demonstrated that annoyance levels due to aircraft noise were significantly higher among children in schools exposed to high levels of aircraft noise compared with schools with lower exposure levels. In contrast, levels of annoyance due to road traffic noise both at school and at home did not differ significantly across the high and low aircraft noise schools.

Children may be aware of noise without necessarily being annoyed by it. A recent survey by Dockrell and Shield [37-39] of over 2000 London primary school children aged 7 and 11 years, in schools exposed to a range of environmental noise sources, found that children were aware of, and some were annoyed by, specific noise sources. The older children were more aware of the noise, while the younger children found noise more annoying. The most annoying noise sources were trains, motorbikes, lorries and sirens, suggesting that it is intermittent loud noise events which cause most annoyance to children while at school.

9. CLASSROOM NOISE LEVELS

Despite the body of research into the effects of poor speech intelligibility and noise on children in the classroom, there is relatively little published data on typical noise levels in classrooms. Furthermore, owing to changes in instrumentation, measurement techniques and parameters over the past 30 years, the data that is available is limited in scope and often difficult to interpret in terms of current noise parameters and methodologies. The reported levels have on the whole been presented as single figure ratings, either in dB(A) with no explanation of which acoustic parameter was measured, or in terms of L_{Aeq} without reference to time or classroom activity. In a review of classroom noise data published between 1977 and 1991, Hodgson *et al* [82] report that in most cases it is difficult to determine precisely how the measurements were obtained and in what classroom conditions. Picard and Bradley, in a recent large scale review of classroom noise levels also note the lack of detailed data on noise in classrooms [5]. However, with increasing interest world wide in school and classroom acoustics, the rate of publication of classroom and school noise data is increasing. For example, the UK government has recently funded several large scale studies of classroom noise and the effects of noise on children [9,11,83], and similar work is currently being undertaken on a European wide basis [84].

Published data include measurements of teachers' speech levels, background levels in empty classrooms and levels due to student activities in the classroom. However, previous surveys have shown a wide range in noise levels in classrooms, as discussed below.

9.1 Teachers' speech levels

The review by Hodgson *et al* [82] found that data on teachers' speech levels ranged from 40 to 80 dB(A). Picard and Bradley [5] also note the wide range in reported speech levels, the variation being due to different measurement methods and microphone positions. From the published data they estimate that the average speech level in a classroom, 2 metres from the teacher, is 60.1 dB(A).

9.2 Background levels in empty classrooms

In empty classrooms the noise is likely to be due to sources within the classroom such as ventilation system noise, plus noise transmitted from other areas in the school and from external sources. The review by Hodgson *et al* [82] found measured levels of ventilation noise in classrooms ranged from 23 to 55 dB(A).

Other surveys have included data on noise levels in empty classrooms, without the noise sources being specified. A survey of empty classrooms in elementary schools in Istanbul [85] shows a range of measurements from 35.7 to 60.6 dB(A); from the data presented the average can be calculated as 47.8 dB(A). Empty classrooms have been measured in several of the surveys of classroom noise in the UK. A survey of seven primary school classrooms by Hay in 1995 [86] found that the background noise levels in empty classrooms ranged from 35 to 45 dB(A) L_{Aeq}. In a survey by Moodley [87] of 40 nursery, primary and secondary schools in Lincolnshire, the average level for empty classrooms was 44.8 dB(A). Airey and MacKenzie [88], in a comparison of acoustically treated and untreated classrooms found average background noise levels in the treated classrooms of 40.1 dB(A), compared with 44.7 dB(A) in untreated rooms. The survey of primary schools in London by Shield and Dockrell [36], found an average of 47 dB(A) L_{Aeq} in empty classrooms. Considering that these surveys include schools in urban (in both the UK and Turkey), suburban and rural areas, the results are surprisingly consistent, the larger surveys showing average noise levels in empty classrooms of 45 to 48 dB(A) (assuming no acoustic treatment).

9.3 Noise levels in occupied classrooms

Several studies [36, 75, 89] have found that, even when students are silent in a classroom, their presence significantly increases the noise level above that of the unoccupied condition. As with empty classrooms, the noise levels measured in occupied classrooms with students or pupils engaged in quiet activities are remarkably consistent between studies, regardless of the age of the students. In a survey of university classrooms Hodgson [89] found that a typical background noise level of 35 dB(A) in an empty classroom increased to 56 dB(A) when students were present. MacKenzie [75] in a survey of primary school classrooms found that the average level when pupils were silent was 56 dB(A) in acoustically untreated classrooms, although this dropped to 46.5 dB(A) in treated rooms. The average L_{Aeq} level measured by Shield and Dockrell [36] when pupils were quiet was 56.3 dB(A). It would appear from these studies that, regardless of the noise levels when the room is empty, or of the age of the students, the presence of students, even when quiet, increases the noise level in a room to around 56 dB(A).

The published data on noise in occupied classrooms, with students engaged in teaching and learning activities, display a wide range. The review by Hodgson *et al* [82] found that reported levels ranged from 40 to 70 dB(A); in the review by Picard and Bradley [5] occupied levels in a full range of classrooms from kindergarten to university varied from 42 to 94 dB(A). However, it is possible to observe some patterns among the published data.

Shield and Dockrell [36] found that the ambient noise level in an occupied primary school classroom was closely related to the pupil activity. The measured activity levels ranged from 56 dB(A) (silent activity) to 77 dB(A) L_{Aeq} when the pupils were engaged in noisier activities involving group work and movement around the classroom. The level for the most common activity, children sitting working at their tables with some interaction between them, was 65 dB(A) L_{Aeq}, while the average overall level of all occupied classrooms in this study was 72 dB(A).

An average occupied level of 65 dB(A) was also measured in both primary and secondary school classrooms by Moodley [87]. Similar levels, from 58 to 72 dB(A), were measured by Hay [86] in her survey of seven occupied primary school classrooms with the children talking and working. These three surveys suggest that a representative value for typical classroom activity in UK primary schools is 65 dB(A) L_{Aeq}.

However, the figures given by Mackenzie [75] for occupied classrooms are higher: 70.1 dB(A) (acoustically treated) and 77.3 dB(A) (untreated). These figures refer to 'pupils working' with no indication of the particular activity, and it is interesting to note that 77 dB(A) was the level recorded by Shield and Dockrell [36] for the noisiest classroom activity.

9.4 Factors affecting classroom noise levels

It is assumed that noise levels inside classrooms are affected by external noise. However, while external noise might act as a 'distractor' to pupils there is little evidence on the relationship between internal and external noise levels. The only study to address this issue in detail is that of Shield and Dockrell [36]. They found that external noise had an effect on the internal noise level only when pupils were engaged in quiet activities. Furthermore, it appeared to be external background noise levels (L_{Amin}, L_{A99} and L_{A90}) that were related to internal ambient L_{Aeq} levels.

There is conflicting evidence as to whether or not noise levels are affected by the age of the children. The data examined by Picard and Bradley [5] suggest that classroom noise levels decrease as the age of the children increases; however, this trend was not evident in the data collected by Shield and Dockrell in primary schools [36]. The levels measured by Moodley [87] in nursery schools are considerably higher (75 dB(A) on average) than those measured in primary and secondary schools, although the average levels for the last two categories are the same (65 dB(A)). Shield and Dockrell did however find that the noise levels in primary school classes were related to the number of children in the class; this could possibly account for some of the effects of age observed in other studies.

Hay [86], in her survey of 7 schools, related measured noise level to the experience of the teachers and found that the lower levels were measured in classes with an experienced teacher, and the higher levels when a trainee teacher was taking the class.

10. CURRENT STANDARDS FOR CLASSROOM ACOUSTICS

In recent years there has been considerable debate about the acoustic design of classrooms, although research in this area has been limited mainly to the work of Bradley and Hodgson and their colleagues [51-56, 82, 90-92]. Many countries have developed new or revised standards for classroom design (see Vallet [93] for a review of European standards), and the World Health Organisation includes recommendations for schools in its Guidelines for Community Noise [94], see below.

Most standards include guidance on some or all of the following: ambient noise levels in various types of school room (for example, classrooms, libraries, dining halls); reverberation times; sound insulation of the school façade; sound insulation between rooms; and background noise from building services. The two most recently published guidelines on classroom acoustics are the ANSI standard S12.60-2002 [41] in the USA and Building Bulletin 93 [32] in the UK, both of which are summarised below.

10.1 WHO Guidelines

The WHO guideline values for schools [94] are summarised in Table 1.

Table 1. WHO guidelines for maximum noise levels and reverberation times in schools

	Noise level, dB L_{Aeq}	Reverberation time, seconds
Classrooms	35	0.6
Halls and cafeterias	-	< 1
Outdoor playgrounds	55	-

The background noise level of 35 dB(A) L_{Aeq} in classrooms is based upon the assumption of 55 dB(A) for a typical teacher's voice level at a distance of 1 m, and of the need for a signal to noise ratio of 15 dB. It is not clear whether the reverberation time requirements apply to occupied or unoccupied rooms. The guidelines state that both background noise level and reverberation time should be lower for hearing impaired children. The maximum noise level of 55 dB(A) in outdoor playgrounds is chosen to be the same value as for outdoor residential areas in daytime, in order to prevent noise annoyance.

10.2 ANSI S12.60-2002

The American National Standard S12.60-2002 'Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools' [41] was published in 2002 and provides design criteria and guidelines for new and refurbished classrooms and other learning spaces. The standard specifies limit values for background noise levels and reverberation times in 'core learning spaces' (that is teaching spaces including classrooms, conference rooms, libraries, music rooms and so on) which are classified according to their volume, see Table 2. The spaces are assumed to be furnished but unoccupied.

Table 2. ANSI S12.60-2002: Maximum background noise levels and reverberation times in learning spaces

Volume of space	Background noise level, dB $L_{Aeq,1hour}$	Reverberation time, seconds
< 283 m^2	35	0.6
> 283 m^2 and ≤ 566 m^2	35	0.7
> 566 m^2	40	-

The standard also includes sound insulation requirements, expressed as STC ratings, between core learning spaces and adjacent areas. For example, the minimum STC between two core learning spaces is 50, between a core learning space and corridor 45, and between a core learning space and cafeteria 60.

The standard includes annexes which give the rationale for the setting of the criteria; advice on noise control, control of reverberation and sound insulation; and recommendations for good practice to verify conformance to the standard.

10.3 Building Bulletin 93

In the UK, although there has been guidance available on the acoustic design of schools since 1975 [95, 976], there have up to now been no legal requirements for compliance with the standards. However from July 2003, the acoustic design of schools is to be regulated under amendments to the Building Regulations. The standards, which will have to be met by both new and refurbished schools, are contained in Building Bulletin 93 'Acoustic Design of Schools', published by the Department for Education and Skills [32].

Building Bulletin 93 replaces Building Bulletin 87 'Guidelines for Environmental Design in Schools' [95] which gave advice on heating, lighting, ventilation and acoustics in schools. James [96] discusses the background to the writing of Building Bulletin 93.

Building Bulletin 93 is a comprehensive document specifying indoor ambient noise levels, reverberation times and sound insulation requirements for over 30 types of teaching and learning spaces in schools. It also includes guidance on noise control, design of rooms for speech and music, the needs of and technology available for hearing impaired children and case studies of good and bad examples of school and classroom design.

Examples of the performance standards for maximum indoor ambient noise levels, in terms of $L_{Aeq,30min}$, and reverberation times are shown in Table 3. Both noise levels and reverberation times are for unoccupied and unfurnished rooms. The reverberation time is the mean of the values at 500 Hz, 1000 Hz and 2000 Hz. Figures in brackets in Table 3 are the corresponding values from Building Bulletin 87, where a direct comparison is possible. (Note that the background noise level in Building Bulletin 87 was expressed as a 1 hour L_{Aeq} and the reverberation time was the mean of the 500 Hz and 1000 Hz values.) In general, the requirements of Building Bulletin 93 are more stringent than those of Building Bulletin 87, to reflect increased awareness of the effects of noise and reverberation on children, and in particular the needs of hearing impaired children.

Table 3. Building Bulletin 93: upper limits for indoor ambient noise levels and reverberation times for a selection of school rooms

	Indoor ambient noise level, dB $L_{Aeq,30min}$	Reverberation time, seconds
Primary school classrooms	35 *(40)*	<0.6 *(0.5-0.8)*
Secondary school classrooms	35 *(40)*	<0.8 *(0.5-0.8)*
Large (> 50 people) lecture room	30 *(35)*	<1.0
Classrooms specifically for hearing impaired pupils	30	<0.4
Library study area	35 *(40)*	<1.0 *(0.5-1.0)*
Assembly halls	35 *(35)*	0.8-1.2
Science lab	40 *(40)*	<0.8 *(0.5-0.8)*
Gymnasium	40	<1.5 *(1.0-1.5)*
Dining rooms	45 *(50)*	<1.0 *(0.5-0.8)*

Values in parentheses are corresponding values from Building Bulletin 87 [96]

Building Bulletin 93 also specifies the required sound insulation between the various different kinds of teaching spaces. The sound insulation requirements are based upon the classifications of the rooms according to their 'activity noise' (low, average, high or very high) and their 'noise tolerance' (very low, low, medium, high). The sound insulation is specified in terms of a weighted standardised level difference $D_{nT(Tmf,max),w}$ where the reference reverberation time is the upper limit of the specified RT for the receiving room. The required values of $D_{nT(Tmf,max),w}$ range from 30 dB for the insulation between a source room with low activity noise (eg study room) and a receiving room with a high tolerance level (eg dining room) to 60 dB between a source room with very high activity noise (eg music classroom) and one with very low tolerance (eg drama studio). The impact sound insulation of floors is specified in terms of the weighted standardised impact sound pressure level $L'_{nT(Tmf,max),w}$, which is is also defined by reference to the maximum RT of the receiving room. The required values of $L'_{nT(Tmf,max),w}$ range from 55 dB for rooms such as music classrooms and large lecture rooms to 65 dB for science laboratories, sports hall, dining rooms and so on.

Building Bulletin 93 also contains standards for open plan spaces, which are specified in terms of the speech transmission index, STI. The performance standard is that any open plan teaching or study areas should be designed so that the STI is greater than 0.6.

10.4 Standards for hearing-impaired pupils

Organisations concerned with the needs of deaf and hearing-impaired people also provide guidance on the acoustic requirements of classrooms. Examples include the position paper on acoustics in educational settings of the American Speech-Language-Hearing Association (ASHA) [60], published in 1995, and the recommended standards for classroom acoustics published in 2001 by the British Association of Teachers of the Deaf (BATOD) [61]. The recommendations of both of these organisations include unoccupied ambient noise levels, reverberation times and signal to noise ratios, as shown in Table 4.

Table 4. Recommendations of ASHA and BATOD for classrooms

	ASHA (1995)	BATOD (2001)
Background noise levels	30 - 35 dB(A)	≤ 35 dB(A)
Reverberation time	≤ 0.4 s	≤ 0.4 s, 125 Hz to 4000 Hz
Signal to Noise ratio	≥15 dB	>20 dB, 125 Hz to 750 Hz >15 dB, 750 Hz to 4000 Hz

In 2002 ASHA published a further report on appropriate facilities for students with speech-language-hearing disorders [97], the major part of which is concerned with the acoustics of classrooms.

11. CONCLUSIONS

The research evidence shows that noise does have an effect on children's performance at school, with older children in the primary school age range appearing to be the most affected by noise. Children are also annoyed by noise at school. Measurement surveys of classrooms show that classroom noise levels can be high, particularly in classrooms without acoustic treatment, and that this is often due to the noise of classroom activity. One cause of the detrimental effect of noise is the degradation of speech intelligibility in the classroom. The precise nature of the effects of noise upon the cognitive processes of children, however, is as yet not fully understood.

There is increasing awareness among the architectural, educational and acoustical professions about the effects of noise on children and the need to create good acoustic conditions in the classroom. This is being reflected in current national and international standards on classroom acoustics.

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