THE EFFECTS OF NOISE ON EDUCATION IN URBAN SCHOOLS

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1 INTRODUCTION

In the past 40 years there have been many studies which have considered the effects of noise upon children in school. Most of these studies have investigated the effects of exposure to high levels of environmental noise such as road traffic, aircraft and construction noise, the majority having been carried out in urban areas. Reviews of previous work show conclusively that chronic noise exposure of children has an adverse effect upon their performance in school[1-3]. It has also been found that, in the primary school age range, the academic performance of the older children is more affected than that of the younger children.

Typical effects caused by aircraft noise include reduced motivation, poorer long term memory and decreased reading comprehension[4-8]; these effects appear to be long term[9,10]. Railway noise and road traffic noise have also been found to affect reading ability, and to reduce attention in the classroom[11-15]. In addition to affecting children's performance both aircraft noise and road traffic noise have been found to cause annoyance to children and teachers[16,17]. Children have also been found to be affected by typical noise within the classroom caused by different classroom activities, and by the noise of other children[6,8,18-20].

This paper reports the findings of a recent study of the effects of chronic exposure to environmental noise in primary schools in London. The effects examined include annoyance of children and teachers; interference with listening in the classroom; and reduced overall school performance in standard assessment tests (SATs). The paper concludes by discussing the implications of identified effects of chronic noise exposure at school for the acoustic design of urban schools.

2 DESCRIPTION OF THE STUDY

Three London boroughs were selected for the study, one outer and two inner London boroughs. The boroughs were selected to be typical of Greater London in terms of academic achievements (as measured by overall SATs results for schools) and demographic characteristics (as measured by percentages of children in each school receiving free school meals; with English as an additional language; and with special educational needs). Boroughs in which aircraft are the predominant noise source were excluded from the study as there is already a considerable body of research concerning the specific effects of aircraft noise on schools. Thus the noise exposure of the schools included in this study is typical of that of schools in general urban areas.

In each borough an external noise survey of primary schools was carried out, the majority of primary schools in each borough being included in the survey. In the outer London borough a questionnaire survey of over 2000 children in years 2 and 6 (that is of average age 7 years and 11 years) was conducted to ascertain their perceptions of the noise environment at home and at

school, and of ease of listening in the classroom. A related questionnaire survey of the children's teachers was also carried out.

In the outer borough noise levels measured outside schools were compared with the children's questionnaire responses on annoyance and ease of listening. In all three boroughs the external noise levels were compared with the performance of each school in standardised assessment tests at Key Stage 1 (year 2) and Key Stage 2 (year 6).

3 EXTERNAL NOISE SURVEY

3.1 Method

In total noise levels were measured outside 142 primary schools of which 53 were in the outer London borough, and 50 and 39 respectively in the two inner boroughs.

Five minute samples of noise were measured outside each school using a hand held sound level meter. The environmental noise parameters $L_{Aeq,5min}$, $L_{A10,5min}$, $L_{A90,5min}$, $L_{A99,5min}$, $L_{Amax,5min}$ and $L_{Amin,5min}$ were recorded at each site. For security reasons measurements were made off the school premises, where possible outside the noisiest façade, at the kerbside of the nearest road. At many schools the measurement position was approximately four metres from the school façade. For consistency measurements at other schools were corrected to give the corresponding level four metres from the façade.

The 5 minute measurement period was chosen to be typical of the school day. For this reason rush hours, times when children were arriving at or being collected from school, and times when children were outside in the school playground were avoided. In all cases it was felt that the noise environment at the time of measurement represented, as far as possible, the general noise environment of the area.

In addition to measuring noise levels the noise sources which occurred during the five minute measurement period were noted.

The noise survey and results are described in full in reference [21].

3.2 Noise levels

The means and standard deviations of the various noise parameters for each borough and overall are shown in Table 1. Figure 1 shows the overall distributions of $L_{Aeq,5min}$ and $L_{Amax,5min}$ levels.

Table 1. Means and standard deviations of external noise levels

Borough (N)	$L_{Aeq,5min}$		$L_{A10,5min}$		$L_{A90,5min}$		$L_{A99,5min}$		$L_{Amax,5min}$		$L_{Amin,5min}$	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Outer (53)	57.4	8.8	59.4	9.0	49.2	7.7	47.0	7.4	70.5	10.5	46.0	7.5
Inner 1 (50)	56.2	9.4	58.4	9.9	46.5	9.3	44.3	9.2	68.3	17.0	41.3	12.4
Inner 2 (39)	58.9	7.4	61.2	7.7	50.2	8.2	47.8	8.2	72.0	9.0	47.0	8.3
All (142)	57.4	8.7	59.6	9.0	48.5	8.6	46.3	8.6	70.1	12.9	44.6	10.0

It can be seen that the levels and distributions are reasonably consistent across boroughs. The first inner London borough displays the greatest variation in noise between schools, with L_{Amax} having a large standard deviation. In this borough, many schools were located in housing

estates and were shielded from the noise of road traffic by other buildings thus having lower noise levels than occurred elsewhere in the borough.

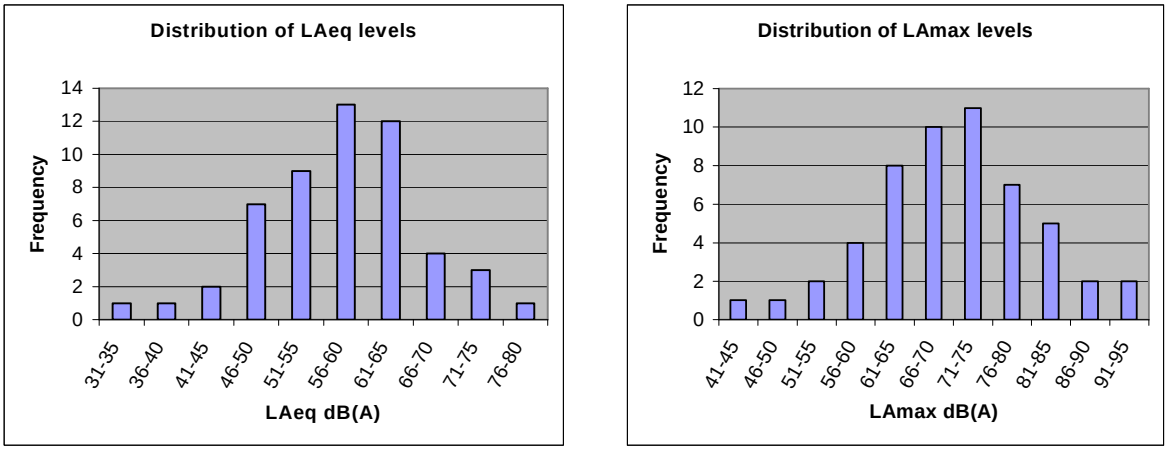

Figure 1. Distributions of L_{Aeq} and L_{Amax} levels outside schools

3.3 Noise sources

Figure 2 shows the distribution of the most common noise sources heard outside all schools.

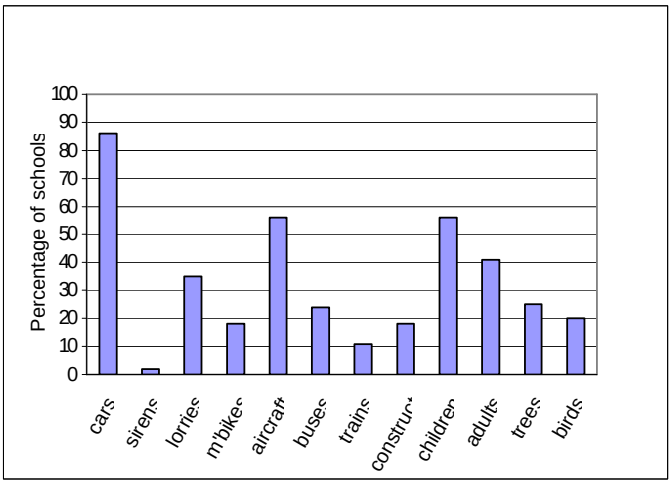

Figure 2. Distribution of noise sources heard outside schools

The most commonly occurring source was road traffic with cars being heard outside 86% of the schools measured, buses outside 24%, lorries outside 35% and motorbikes outside 18% of schools. Noise of trains was heard outside 11% of the schools

4 CHILDREN'S QUESTIONNAIRE SURVEY

4.1 Method

Although there have been few studies of noise annoyance among children, a previous study found high levels of annoyance due to aircraft noise[22] and, importantly, demonstrated the validity of children's questionnaire responses related to annoyance caused by noise.

In the current study a questionnaire survey of primary school children was carried out to assess the children's awareness of, and annoyance caused by, noise from different sources at school, and to determine their ability to assess the listening conditions in their classrooms[23]. Results from the questionnaire survey were compared with noise levels measured outside the schools.

The questionnaire was distributed to all children in year 2 (age 7) and year 6 (age 11) classes in 43 schools in the outer London borough. In total 2036 children completed the questionnaire.

In the first section of the questionnaire the children were presented with a range of noise sources and asked to indicate whether they heard the source in their classroom and at home, and, if so, whether they were annoyed by it. The second section examined how well the children heard their teacher or a classmate in nine different classroom listening situations such as when the child could not see the teacher's face or when children were making a noise outside the classroom.

The questionnaire survey and results are described fully in reference [23].

4.2 Children's noise awareness and annoyance

Figure 3 shows the noise sources reported being heard by all the children at home and at school. The figure provides evidence of the validity of the children's responses by showing significant differences between home and school for most sources. This is further confirmed by close agreement between the teachers' and children's reports of hearing the different sources while at school.

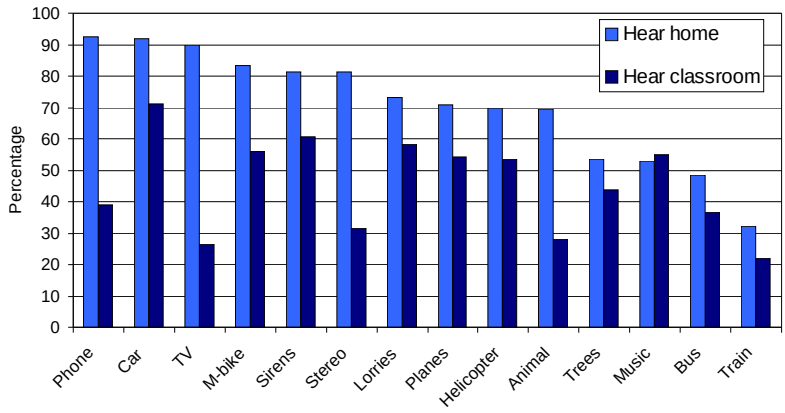

Figure 3. Noise sources heard by children at home and at school

In general more of the older children were aware of external noise sources while at school, but more of the younger children were annoyed if they heard the noise. Over all children the most annoying sources if heard were trains (63%), motorbikes (60%), lorries (59%) and sirens (58%).

In order to compare hearing and annoyance with external noise levels, for each school an average 'hearing score' and an average 'annoyance score' were computed, together with an

average 'child annoy score' representing the proportion of children who reported hearing a sound and were annoyed by it[23]. It was found that the 'hearing score' was significantly correlated with the background (L_{A90} and L_{A99}) external noise levels while the 'annoyance score' was significantly correlated with L_{Amax}, L_{A90} and L_{Aeq} levels. The 'child annoy score' was significantly related to L_{Amax} levels. Thus, children in schools with higher background external noise levels report hearing more external noise sources. Annoyance caused by noise however is related to all aspects of the noise environment, and annoyance of particular sources to the maximum levels.

4.3 Ease of listening in the classroom

Children's scores of their ability to hear in different contexts in the classroom, on a scale of 1 to 5 (1 = 'very well', 5 = 'not at all'), are shown in Table 2. Significant differences between the year groups are highlighted.

Table 2. Average ease of listening scores for year 2 and year 6 children

Classroom situation	Sig diff?	Year 2		Year 6	
		Mean	sd	Mean	sd
Cannot see teacher's face		1.93	0.84	2.34	1.02
Teacher talking and moving around	Yes	2.29	0.83	1.96	0.95
Working in groups		2.44	0.93	2.39	1.11
No noise from outside classroom	Yes	1.90	0.93	1.68	1.10
Children making noise outside classroom		2.70	1.08	3.01	1.06
Doing a test	Yes	1.87	0.89	1.53	1.04
During PE in playground	Yes	2.79	1.05	2.62	1.09
No noise at all	Yes	1.46	0.83	1.24	0.79
Hearing classmate who is speaking to teacher	Yes	2.47	1.00	2.15	1.00

Table 2 shows that, in general, the younger children reported more difficulty hearing in the classroom than the older children. However the older children found more difficulty when they could not see the teacher's face and when other children were making a noise outside the classroom. There were statistically significant differences between the scores for the different contexts[23], the best conditions overall being when there was no noise outside the classroom and in test conditions, and the worst when other children were making noise outside the classroom.

Listening scores were compared with external noise levels. There were no significant relationships between ease of listening and external noise in eight of the nine conditions assessed. However, ease of hearing the teacher when there was no noise outside was significantly correlated with the external noise measurements. The higher the external noise level the less likely the children were to report being able to easily hear the teacher. All noise parameters measured were significantly correlated with ease of listening in this condition, the highest correlation occurring for L_{A90} ($r = 0.376$, $p<0.05$).

5 TEACHERS' QUESTIONNAIRE SURVEY

5.1 Method

At the same time as the questionnaire survey of the children in years 2 and 6 in the outer London borough was carried out, a related survey of their teachers was conducted. The teachers' questionnaire was completed by 51 teachers in 34 schools. The questionnaire aimed to obtain teachers' views on issues such as noise exposure and noise policy at school, and the

impact of noise on the children and on their own teaching style[24]. It also included questions relating to their teaching experience and their general health during their teaching career.

5.2 Teachers' health

Twenty per cent of the sample reported ear problems, in all cases these were ear infections. In contrast, 77.4% of the teachers reported problems with painful throat, hoarseness, voice loss and throat infection, while a further 12% mentioned only painful throat. Only four teachers (7.8%) reported no health problems at all. In general, this group had taught for a shorter period of time (less than five years), were in schools which they described as quiet or very quiet, and tended not to raise their voice to control noise levels.

5.3 Effects of noise on children's concentration

Overall, 90.2 % of the teachers responding considered that outside noise affected the children's concentration. Many teachers believed that children with special educational needs were more affected than their mainstream peers (68.6%).

Table 3 shows the percentages of teachers reporting effects on concentration by the most common environmental noise sources.

Table 3. Impact of environmental sound source on children's concentration

Sound source	% teachers reporting effects
Helicopter	81.8
Sirens	69
Bus	50
Lorries	46.2
Cars	43.3
Trains	42.9
Motorbikes	37.5
Planes	27.8

Teachers often attempted to militate against the distracting effect of external noise by arranging quiet times (60.8%). Although many teachers felt that noise levels impacted on most class activities (39.2%), an identical proportion felt the key effects were primarily on language based activities (39.2%). Teachers had a limited range of classroom strategies to combat the effect of external noise sources. These included raising voices (33.3%), specific attention gaining strategies (21.6%), stopping teaching (17.6%) and ignoring the situation (3.9%). Nearly one-fifth of the respondents (17.6%) reported no specific strategies at all.

6 EFFECTS OF CHRONIC NOISE EXPOSURE ON CHILDREN'S ACADEMIC PERFORMANCE

6.1 Method

The effects of environmental noise on children's academic achievement were examined by comparing schools' external noise levels with school SATs scores at Key Stage 1 and Key Stage 2. The SATs data used were the percentages of children in each school achieving the appropriate standard in Reading, Writing, Spelling and Mathematics at Key Stage 1 and in

English, Mathematics and Science at Key Stage 2. The published averaged school scores at each stage were also used. The SATs scores were compared with all the measured environmental noise parameters.

It is known that social deprivation has a negative effect upon children's performance at school[25,26]. It is therefore necessary in any analysis of noise and school performance to eliminate the confounding effects of social or economic factors which might be related to poor academic achievement. For each school the following socio-economic data was obtained: the percentage of children receiving free school meals (FSM) and the percentage of children with English as an additional language (EAL). The percentages of children receiving free school meals in schools has been shown to be a reliable indicator of social disadvantage in an area[27,28]. Partial correlation was carried out to eliminate the effects of FSM and EAL in comparing noise and SATs scores.

6.2 Results

Different results were observed for the outer and inner London boroughs. Therefore they are considered separately in the following discussion.

6.2.1 Outer London borough

There were significant negative correlations between all noise parameters and all SATs scores, showing that the higher the external noise level at a school the poorer the academic performance as demonstrated by SATs results. The correlations were stronger for Key Stage 2 test scores than for those at Key Stage 1, suggesting that noise has more of an effect on the older children. This is consistent with the results of previous research[1-2]. The noise parameter which showed the strongest relationship with test scores at Key Stage 2 was L_{Amax}. This suggests that it may be the noise of individual events which has the greatest impact upon the children's performance. In contrast, at Key Stage 1 the background levels L_{A90} and L_{A99} had the highest correlation with test scores. The correlation coefficients between $L_{Amax,5min}$ and $L_{A90,5min}$ and all SATs scores are shown in Table 4.

Table 4. Outer London borough: correlation coefficients

Test score	L_{Amax}	L_{A90}
KS1 Average	-.322*	-.402**
KS2 Average	-.454**	-.430**
KS1 Reading	-.312*	-.365*
KS1 Writing	-.293*	-.343*
KS1 Spelling	-.311*	-.378**
KS1 Maths	-.267	-.429**
KS2 English	-.391**	-.404**
KS2 Maths	-.456**	-.400**
KS2 Science	-.450**	-.419**

** significant at 1% level
*significant at 5% level

Table 4 shows that the subject scores most strongly related to noise is Key Stage 2 Mathematics

To illustrate the relationships between noise and SATs scores, Figure 4 shows scatter diagrams of L_{Amax} plotted against average Key Stage 2 and Key Stage 2 Mathematics scores.

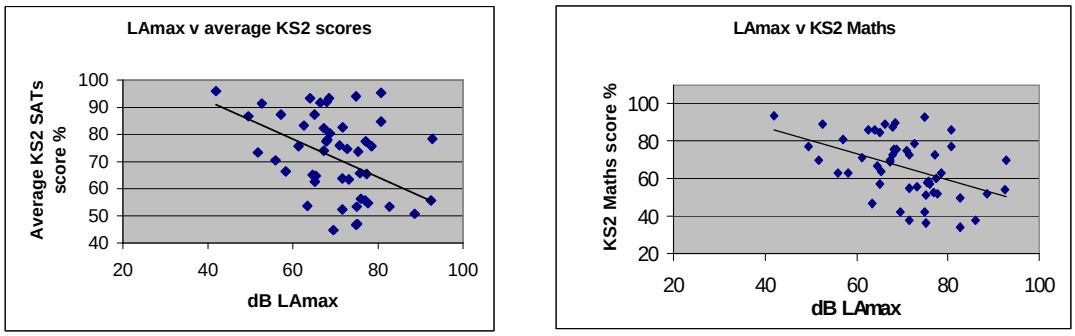

Figure 4. Relationships between L_{Amax} and Key Stage 2 SATs scores

Significant negative correlations were maintained when the data were controlled to eliminate the effects of socio economic factors. When controlling for the effects of free school meal data significant relationships were found only at Key Stage 2, and only for ambient (L_{Aeq}) and maximum (L_{Amax}) noise levels. The highest correlations were again with L_{Amax} levels, for example for the average Key Stage 2 SATs score $r = -0.440$ ($p<0.05$). When correcting for the effects of English as an additional language, there were significant negative correlations between all noise parameters and both Key Stage 1 and Key Stage 2 results, L_{Amax} being significantly negatively correlated at the 1% level with scores for all subjects at Key Stage 2. For example the correlation coefficient between L_{Amax} and the average KS2 score is $r = -0.532$ ($p<0.01$).

6.2.2 Inner London boroughs

A different pattern emerges when considering the data for the inner London boroughs, with no significant relationships between noise and SATs scores when all schools are considered. However, if only those schools with external level greater than 60 dB L_{Aeq} (the maximum external level recommended by Building Bulletin 93[29]) are considered then significant negative correlations between noise and SATs results are found. The total number of schools for which the external level is greater than 60 dB L_{Aeq} is 34, 16 in one borough and 18 in the other.

If the two boroughs are considered separately the patterns of correlation coefficients for each are very similar. As with the outer London borough the strongest correlations occur for Key Stage 2 scores, L_{Amax} again being the parameter which is in general the most closely associated with test scores. Table 5 shows the correlation coefficients between $L_{Amax,5min}$ and $L_{A90,5min}$ and SATs scores when considering all 34 schools together.

Table 5. Inner London boroughs: correlation coefficients

Test score	L_{Amax}	L_{A90}
KS1 Average	-.309	-.122
KS2 Average	-.389*	-.242
KS1 Reading	-.403*	-.223
KS1 Writing	-.255	-.120
KS1 Spelling	-.332	-.065
KS1 Maths	-.090	-.027
KS2 English	-.431**	-.366*
KS2 Maths	-.305	-.151
KS2 Science	-.358*	-.146

** significant at 1% level
*significant at 5% level

As for the outer borough significant relationships were still found when the data were corrected for free school meals and English as an additional language. For all subjects except Key Stage 1 Mathematics L_{Amax} was the parameter most strongly related to test scores. In general scores at Key Stage 2 were more closely related to L_{Amax} than scores at Key Stage 1. When correcting for FSM statistically significant correlation coefficients between L_{Amax} and test scores were as follows: KS1 Reading r = -0.403 ($p<0.01$); KS2 English r = -0.454 ($p<0.01$); KS2 Science r = -0.349 ($p<0.05$); average KS2 score r = -0.408 ($p<0.05$). When correcting for EAL statistically significant correlation coefficients between L_{Amax} and test scores were as follows: KS1 Reading r = -0.405 ($p<0.05$); KS2 English r = -0.456 ($p<0.01$); average KS2 score r = -0.407 ($p<0.05$).

6.2.3 Summary of impact of environmental noise on SATs scores

It is not clear why there is a difference in the pattern of relationships between noise and SATs scores in the outer and inner London boroughs. It is possible that it is caused by variations in the distributions of socio economic factors or noise levels, or by ceiling effects.

However, if only those schools with noise levels above 60 dB L_{Aeq} in the inner London boroughs are considered the results are consistent with those for the outer London borough. Thus correlation analysis of noise levels and SATs scores in all three boroughs shows that noise has a significant detrimental impact upon children's performance. The SATs scores most affected by noise are those at Key Stage 2. The noise parameter most closely related to SATs scores is L_{Amax} which suggests that it is the noise of individual external noise events which has the greatest impact upon test results. These relationships persist when the data is corrected to allow for socio economic characteristics of the schools.

7 DISCUSSION OF RESULTS

The various phases of the study reported here provide consistent and converging evidence that noise has a detrimental impact upon children and teachers in primary schools in urban areas. These conclusions agree with, and extend, the results of previous research which has investigated the effects of different types of noise on children at school.

The noise survey showed that there is a wide range of external noise levels to which schools across London are exposed. Building Bulletin 93[29] recommends a maximum external level of 60 $L_{Aeq,30min}$ at the school façade; a level of 60 $L_{Aeq,5min}$ was exceeded at 40% of the schools measured. The level recommended by the World Health Organisation[30] and by Building Bulletin 93 for outdoor playgrounds, arising from external noise sources, is 55 dB(A) L_{Aeq}; this level (in terms of $L_{Aeq,5min}$) was exceeded at 65% of schools.

Comparison of external noise levels and SATs results showed that the aspect of noise which has the most marked effect upon academic performance is the maximum level occurring outside schools. This could be because children are distracted by the noise of individual loud events occurring outside the school. This explanation is consistent with the findings of the children's questionnaire survey which showed that children are aware of, and annoyed by, external noise. Annoyance was also found to be related to maximum noise levels outside schools. As found in previous research it was the older children whose performance in SATs appeared to be more affected by external noise, although the younger children reported more annoyance than the older.

In addition to being aware of, and annoyed by, external noise children recognised difficulties in hearing in the classroom which were caused by noise. In the absence of additional noise ease of listening was related to background levels of environmental noise outside the schools.

The analysis of questionnaire data, SATs data and noise levels confirmed the teachers' views that external noise affects children's concentration. Teachers also believe that children with special educational needs are more affected by noise than their mainstream peers, particularly in language based tasks. This latter view was corroborated by a related experimental study carried out by the authors which found that children with special needs were more affected by classroom noise, particularly in reading and spelling tasks, than their peers[31].

8 IMPLICATIONS FOR ACOUSTIC DESIGN OF URBAN SCHOOLS

The results of this and previous studies have implications for the acoustic design of schools in urban areas. It has been shown that noise at levels typical of urban environments and caused by sources common in urban areas has a detrimental effect upon children's concentration and academic achievements in primary schools. It is therefore important that schools are designed to provide adequate sound insulation to prevent the intrusion of external noise.

Many children in schools in urban areas are particularly vulnerable to the effects of noise. As discussed above the percentages of children receiving free schools meals in a school is a reliable indicator of social deprivation in an area[27]. Furthermore, social deprivation has been shown to be strongly negatively related to educational achievement[26,32]. By comparing school external noise levels and free school meal data the authors have shown that the areas in London with the higher noise levels are those areas associated with greater social deprivation[33]. Thus in cities children from socially deprived families are likely to attend the schools with the higher external noise levels, and are therefore doubly disadvantaged academically.

There is also evidence of a relationship between poverty and the level of special educational needs in a school[26], which suggests that schools in deprived inner city areas are likely to have greater numbers of children with special needs. Research by the authors has shown that noise at school has a greater negative effect upon such children than upon their peers[31]; this is also the view of many primary school teachers.

Thus urban schools, which are exposed to high levels of external noise, are likely to have relatively high numbers of pupils who are particularly susceptible to the negative effects of noise upon their academic performance. It is therefore of particular importance that noise levels in such schools are kept to a minimum though appropriate acoustic design.

It is not only children who are adversely affected by noise at school. The impact of noise on teachers' efficiency and health also needs to be avoided. There is a considerable body of evidence of high levels of throat and voice problems among teachers, in addition to the evidence provided by the questionnaire survey of teachers discussed above[34-36]. Good acoustic design of a school is therefore required to minimise the risks to teachers' health and to disruption of teaching due to teacher absence.

9 CONCLUSIONS

This study has shown that the typical noise environment of schools in an urban area has a detrimental effect upon the children's academic performance and may also affect teachers' health. The study has only concerned the performance of children and teachers in primary schools. However, previous research suggests that similar effects will be experienced in secondary schools.

In the UK many new schools are currently being built or planned, and the government has recently pledged funding for refurbishment of the majority of existing schools. Concern is

already being expressed in educational circles at the current design trends for new schools, particularly city academies, one problem cited being that these state-of-the-art buildings are constructed of materials that cause too much noise[37].

It is therefore important that architects and acoustic consultants design new school buildings to meet the requirements of Building Bulletin 93 in order to minimise noise levels in schools. This is particularly true of schools in urban areas where external noise levels are likely to be high, and whose pupils are likely to be particularly vulnerable to the effects of noise.

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