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THE EFFECTS OF ENVIRONMENTAL NOISE ON CHILDREN'S ACADEMIC ATTAINMENTS

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1 INTRODUCTION

Noise surveys have been carried out in and around 142 primary schools in three London boroughs, as part of an investigation into the effects of noise on the attainments and cognitive performance of primary school children[1]. The surveys have provided descriptive data on the noise climate around London primary schools; and have allowed the influence of external noise on internal classroom noise levels to be assessed[2]. The noise data have also been compared with children's and teachers' perceptions of their noise environment, as reported in questionnaire surveys[3,4].

The effects of noise on children's academic performance at school have been investigated in two ways: the measured internal and external noise levels have been compared with standardised test scores for schools; and children have taken part in experimental tests in artificially generated noise conditions which reflect their typical noise exposure at school. This paper reports the analysis of the relationship between external environmental noise and children's academic attainments as reflected by the results of the standard assessment tests which are taken by all primary school children in England and Wales.

The scores in the standard assessment tests (SATs) for individual schools have been correlated with the external noise levels measured outside the schools. A negative correlation between noise and SATs score would suggest that noise has a detrimental effect upon academic performance, higher noise levels being associated with lower SATs scores. However, performance at school is strongly influenced by social disadvantage. It is therefore necessary in any analysis of the effects of noise upon academic performance to consider the influence of socio-economic school factors.

The analysis reported here focuses on one outer London borough, where, in addition to an external noise survey of every primary school, a questionnaire survey of over 2000 children was also carried out to examine their perceptions of the noise environment while in school[3,4].

2 PREVIOUS RESEARCH INTO EFFECTS OF NOISE ON PRIMARY SCHOOL 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. It is generally accepted that noise has a detrimental effect upon the cognitive development of primary school children, and that older children in this group appear to be more affected than younger children[5,6]. At the beginning of the 1990s there were two major reviews of previous

work in this area[7,8], both of which concluded that chronic noise exposure of young children has an adverse effect upon their reading ability.

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[9] found that in schools around Heathrow aircraft noise had a significant impact on teachers 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 [8,10-12]. 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}[10,11]. A recent study of children in schools affected by aircraft noise from Heathrow Airport[13-14] also found that noise affected reading ability. In this study children in schools within the 63 dB(A) aircraft noise contour were compared with children in schools outside the 57 dB(A) contour.

The effects of chronic exposure to aircraft noise appear to be long term. Cohen et al[11] found that reducing the noise inside a school by 16 dB(A) had little effect on children's performance. More recently Hygge *et al* [12] 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[15] 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 – 8 dB(A), after which no difference was found between the reading scores on the two sides of the school[16].

In the UK road traffic noise has been found to cause dissatisfaction with the classroom environment among teachers; there was a greater incidence of complaints about noise at levels greater than 60 dB(A) L_{A10}[17]. Lukas *et al* [18] found that exposure to traffic noise had a detrimental effect upon reading. 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[19,20]. The levels of road traffic noise in these studies were around 70 dB(A) on average.

The majority of the previous studies have compared the performance of children exposed long term to significant levels of environmental noise with that of children with low noise exposure, or have examined the effects of noise reduction on children's performance. There have been few studies, apart from that of Green *et al* [21] who developed a dose/response relationship between noise and reading ability, in which the effects of varying levels of noise have been examined. Thus there is little evidence for determining threshold levels at which adverse effects occur, which in turn makes it difficult to establish specific guideline values to prevent such effects[22].

In the present study measured external noise levels at schools, as indicated by various noise parameters, were compared with SATs data for those schools. This enables the outcome of varying exposures to noise to be examined. In addition, it allows the most important property of the noise (for example its background or ambient level) in relation to performance to be determined, an aspect that has not been considered in previous studies.

3 EXTERNAL NOISE SURVEYS

3.1 Method

Noise levels were measured outside 53 schools in an outer London borough.

Five minute samples of noise were measured outside each school using a Bruel and Kjaer hand held sound level meter, Type 2236. 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. In many cases the measurement position was at approximately 4 metres from the school façade. For consistency measurements at other positions were corrected to give the corresponding level 4 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

3.2 Noise levels

The means and standard deviations of the measured noise parameters are shown in Table 1; Figure 1 shows the distributions of L_{Aeq} and L_{Amax} levels in the borough.

Table 1. Means and standard deviations of external levels

	$L_{Aeq,5min}$	$L_{A10,5min}$	$L_{A90,5min}$	$L_{A99,5min}$	$L_{Amax,5min}$	$L_{Amin,5min}$
Mean	57.4	59.4	49.2	47.0	70.5	46.0
St. dev	8.8	9.0	7.7	7.4	10.5	7.5

It can be seen that the greatest variation in levels occurs for L_{Amax}; the L_{Amax} measured during a 5 minute period will reflect the occurrence of individual events with noise levels higher than the ambient noise. This parameter would therefore be expected to demonstrate the widest variation of all parameters.

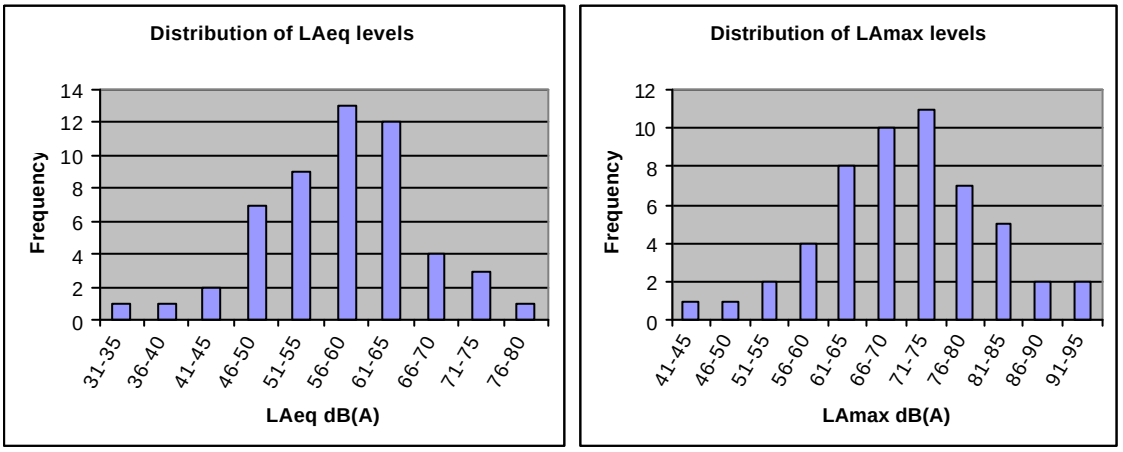

Figure 1. Distributions of L_{Aeq} and L_{Amax} levels outside schools

3.3 Noise sources

During the survey the sources which could be heard outside each school were noted. The most commonly occurring sources were road traffic (cars: 85% of schools; buses: 34%; lorries 34%) and aircraft (heard at 47% of schools).

4 STANDARD ASSESSMENT TESTS (SATS)

Children at primary school take standardised assessment tests (SATs) in Year 2, when they are 7 years old (Key Stage 1 tests) and in Year 6, when they are 11 (Key Stage 2 tests). At Key Stage 1 (KS1) they are tested in reading, writing, spelling and mathematics and at Key Stage 2 (KS2) in English, Mathematics and Science. The Department for Education and Skills publishes results for all schools as the percentages of pupils entered by a school who achieve a certain standard in each subject. Average KS1 and KS2 scores for each school are also published.

The measured noise levels outside the 53 schools were compared with the SATs results for the schools for the year 1999-2000, as this was the academic year in which the majority of the noise levels were measured.

5 SCHOOL CHARACTERISTIC DATA

It is known that social deprivation has a negative effect upon children's performance at school[23]. 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. The following socio-economic data was obtained in relation to the schools: percentage of children receiving free school meals (FSM), percentage of children with English as an additional language (EAL) and percentage of children with special educational needs (SEN). The percentage of children receiving free school meals has been shown to be a reliable indicator of social disadvantage in an area[24,25]. Partial correlation was carried out to eliminate the effects of these three factors on the data.

Preliminary analysis suggested that there might be some relationships between the socio-economic data for each school and noise levels. This was examined further by comparing measured noise levels with the FSM, EAL and SEN percentages.

6 COMPARISON OF EXTERNAL NOISE AND SATS RESULTS

In order to give a preliminary indication of whether or not there was any relationship between external noise levels and SATs results, the measured external noise parameters were first correlated with the average Key Stage 1 and Key Stage 2 scores. Then, in order to establish more precisely the possible existence of relationships between academic performance and noise the SATs scores for individual subjects were correlated with noise levels. Finally, partial correlations were carried out to eliminate the effects of the socio-economic school characteristics. This is because it is possible that any relationships found between noise and SATs scores could be due to social or other factors rather than representing a direct effect of noise on academic performance.

6.1 Average SATs scores

All noise parameters were significantly negatively correlated with average KS1 and KS2 scores, except for L_{peak} which was significantly correlated with just the average KS2 score. The significant correlation coefficients are shown in Table 2.

Table 2. Significant correlation coefficients between average SATs results and external noise levels

	External noise parameters						
	L_{Aeq}	L_{Amax}	L_{peak}	L_{Amin}	L_{A99}	L_{A90}	L_{A10}
KS1 Average	-.360*	-.322*		-.391**	-.401**	-.402**	-.357*
KS2 Average	-.409**	-.454**	-.351*	-.431**	-.434**	-.430**	-.369

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

Table 2 shows that the correlation coefficients tend to be higher for the KS2 tests, suggesting that there is a stronger relationship between academic achievement and noise for the older children than for the younger children. This is consistent with the results of previous studies[15,21] which have found that noise has a greater impact upon the performance of older, rather than younger, primary school children. The noise parameter most closely associated with the average KS2 results is L_{Amax}, suggesting that individual noise events may have an effect upon children's performance. The background (L_{A90}) and underlying (L_{A99}) noise parameters are the ones most closely associated with KS1 results. Figure 2 illustrates the relationship between KS2 average scores and L_{Amax} levels.

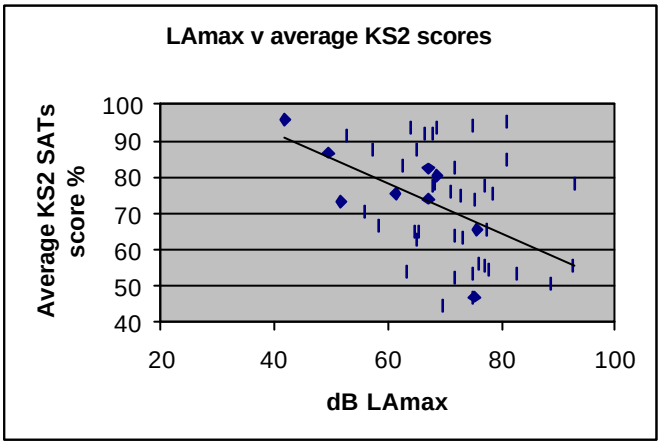

Figure 2. Scatter diagram illustrating relationship between Key Stage 2 average score and L_{Amax}

This preliminary analysis suggests that external environmental noise has a detrimental effect upon a school's overall SATs performance. However, as discussed above, it is possible that this effect is strongly influenced by school socio-economic characteristics; this aspect is dealt with below when the results of partial correlation to eliminate the effects of socio-economic school data are discussed.

6.2 Subject SATs scores

SATs scores for all subjects at both Key Stage 1 and Key Stage 2 were significantly negatively correlated with at least five noise parameters. The significant correlation coefficients are tabulated in Table 3. It can be seen that there are significant correlations between L_{Aeq}, L_{Amin}, L_{A99}, L_{A90} and L_{A10} levels and all Year 2 and Year 6 SATs results. L_{Amax} is significantly correlated with all except the KS1 Mathematics results and L_{peak} is correlated with all KS2 results. As with the average scores the strongest relationships are in general between KS2 results and noise, again implying that test results at Key Stage 2 are more strongly affected by noise than Key Stage 1 tests.

Table 3. Significant correlation coefficients between SATs results and external noise levels

	External noise parameters						
	L_{Aeq}	L_{Amax}	L_{peak}	L_{Amin}	L_{A99}	L_{A90}	L_{A10}
KS1 Reading	-.339*	-.312*		-.359*	-.364*	-.365*	-.325*
KS1 Writing	-.316*	-.293*		-.324*	-.337*	-.343*	-.310*
KS1 Spelling	-.344*	-.311*		-.368*	-.380**	-.378**	-.349*
KS1 Maths	-.339*			-.427**	-.433**	-.429**	-.343*
KS2 English	-.368**	-.391**	-.301*	-.403**	-.411**	-.404**	-.325*
KS2 Maths	-.399**	-.456**	-.381**	-.412**	-.412**	-.400**	-.358*
KS2 Science	-.400**	-.450**	-.321*	-.411**	-.411**	-.419**	-.369**

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

The strongest correlations were between L_{Amax} and KS2 Mathematics ($r = -0.456$, $p<.01$) and KS2 Science ($r = -0.450$, $p<.01$). Scatter diagrams illustrating the relationships between L_{Amax} and KS2 Mathematics and KS2 Science are shown in Figure 3. These results again suggest that the interference effect of loud external noises may be related to the performance of older children in these two subjects. This is consistent with the results of the experimental testing which showed that intermittent environmental noise events affected children's performance in non-verbal tasks[1], and with the results of the questionnaire survey which showed that the older (Year 6) children were more aware of environmental noise than the younger (Year 2) children[3,4].

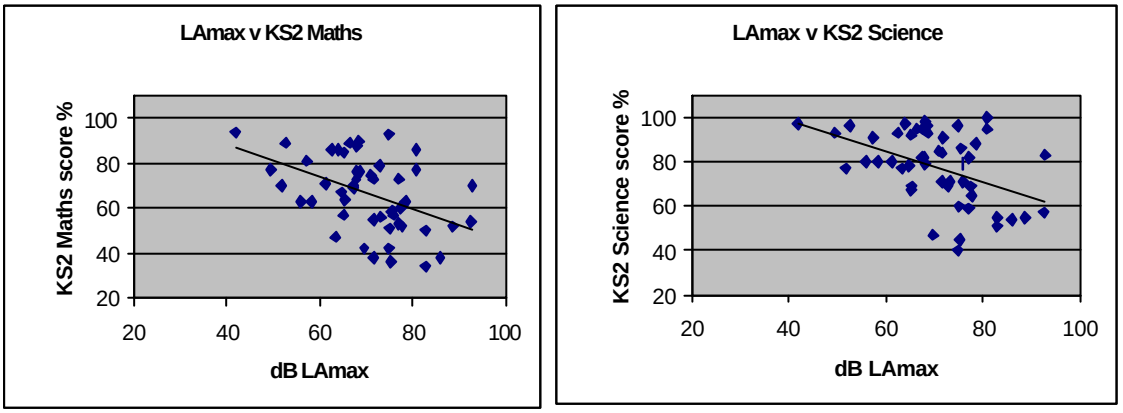

Figure 3. Scatter diagrams illustrating relationships between Key Stage 2 Mathematics and Science scores and L_{Amax}

6.3 Correcting for school socio-economic data

The above analysis was repeated using partial correlation to eliminate the effects of each of the three socio-economic school factors: percentage of children receiving free school meals (FSM); percentage of children with English as an additional language (EAL); and percentage of children with special educational needs (SEN).

6.3.1 Free school meals (FSM)

For the average SATs scores, when eliminating the effects of FSM, significant correlations were found between KS2 average scores and L_{Aeq} ($r = -0.314$, $p<.05$); L_{Amax} ($r = -0.314$, $p<.01$); and

L_{peak} (r = -0.308, p<.05). There were no significant correlations between noise and average KS1 scores.

For individual subjects there were no significant correlations between Key Stage 1 scores and noise but all KS2 subjects were significantly correlated with L_{Aeq}, L_{Amax} or L_{peak} levels. In particular, L_{Amax} was significantly correlated with all subjects at KS2 (English: r = -0.340, p<.05; Maths: r = -0.431, p<.01; Science: r = -0.396, p<.01).

Thus, even when controlled for free school meals data, external noise was still related to SATs results at Key Stage 2. Furthermore it appears to be the ambient, maximum and peak aspects of the noise that affect results rather than the background and underlying noise levels, with L_{Amax} having the strongest correlation of all parameters.

6.3.2 English as an additional language (EAL)

When controlling for EAL data, there were significant correlations between average scores at both Key Stage 1 and Key Stage 2 and several noise parameters, the strongest relationship again being between L_{Amax} and average KS2 results (r = -0.532, p<.01).

There were also significant correlations between all KS1 subjects except writing and all KS2 subjects and some noise parameters. As before, the strongest correlations were with KS2 results although it is interesting to note that KS1 Mathematics and KS2 Science were both significantly correlated with most noise parameters. Furthermore, L_{Amax} was again the noise parameter with the strongest relationship with Key Stage 2 results. (English r = -0.480, p<.01; Maths r = -0.518, p<.01; Science r = -0.476, p<.01).

6.3.3 Special educational needs

With effects of SEN data eliminated there were significant correlations between the average KS1 score and all noise parameters except L_{peak}, and between the average KS2 score and all parameters. The correlations were again stronger with the average KS2 score, L_{Amax} being the most closely correlated (r = -.467, p<.01), although there was similar correlation between average KS1 score and background L_{A90} level (r = -.402, p<.01).

When the individual subjects were considered there were significant correlations between all KS1 and KS2 subjects and most noise parameters, the stronger correlations again being with KS2 subjects. The correlations for both KS1 and KS2 Mathematics were in general higher than for other subjects, KS1 Maths being strongly correlated with the L_{Amin} (r = -.416, p<.01) L_{A99} (r = -.432, p<.01) and L_{A90} (r = -.425, p<.01) levels and KS2 Maths with L_{Aeq} (r = -.405, p<.01) and L_{Amax} (r = -.470, p<.01) levels.

The correlation coefficients obtained when correcting for SEN were very similar to those obtained with the uncorrected data.

6.4 Comparison of external levels and socio-economic data

Preliminary inspection and anecdotal evidence suggested that there might be significant relationships between noise and socio-economic factors. Therefore the data on incidence of free school meals, English as an additional language and special educational needs for schools in the borough were correlated with external noise levels. There were significant positive correlations between FSM data and all noise parameters, while EAL data was significantly correlated with L_{Amin}, L_{A99} and L_{A90} levels. In both cases the strongest correlations were with L_{Amin} (FSM: r = .428, p<.01; EAL: r = .367, p<.01) and L_{A99} (FSM: r = .435, p<.01; EAL: r = .366,

p<.01) levels. There were no significant correlations between SEN data and noise. As stated above, data on FSM provides a good indication of general social disadvantage in an area. Therefore a possible interpretation of these results is that children from more disadvantaged families attend schools, and can therefore be assumed to live, in the areas of the borough with higher background noise levels. This can be understood if it is assumed that the 'noisier' areas are those with higher densities of housing, greater exposure to road traffic, less outdoor space and so on.

7 DISCUSSION OF RESULTS

Analysis of external noise levels and SATs results in an outer London borough shows significant relationships between noise and SATs scores. These relationships still exist when socio-economic factors relating to social disadvantage are accounted for.

Overall the results suggest that external noise has more effect upon SATs results at Key Stage 2 than at Key Stage 1. This is in agreement with the results of previous studies which have shown older primary school children to be more affected by noise than younger children[5,6]. It is also supported by the questionnaire surveys of children in Years 2 and 6 which found that the older children were more aware of external noise sources than the younger children[3,4].

At Key Stage 2 the noise parameter with the strongest correlations with results is L_{Amax}. Thus it appears that at this level it is the intrusive nature of individual sound events outside a school which may be affecting performance. The subjects with the strongest associations with noise were Mathematics and Science; this is consistent with the research carried out in parallel with the present study which showed environmental noise combined with classroom noise to have a detrimental effect upon performance of non-verbal tasks[1].

Although the relationships between noise and academic performance are still valid when school data relating to social disadvantage are accounted for, the correlations between noise levels and socio-economic data suggest a complex relationship between noise, social disadvantage and academic performance.

8 INNER LONDON BOROUGH

Although the comparison of SATs data and noise levels in the outer London borough showed strong correlations, suggesting that environmental noise has a detrimental effect upon children's academic achievements, the results were not repeated for the inner London borough examined. A possible explanation for this discrepancy is that the boroughs differed in the distributions of both noise levels and socio-economic data for primary schools.

Although mean noise levels for the two boroughs were very similar, the standard deviations of levels in the inner London borough were greater for all parameters, particularly L_{Amax}, than in the outer borough. A probable reason for the higher standard deviations of the inner borough is that many schools are set back from the road in large grounds and are thus in much quieter surroundings that might typically be expected of schools in inner London. Thus the distribution of noise levels outside schools in this borough may not be typical of London as a whole. Examination of the distributions of the school characteristic indicators showed the distributions of free school meal and English as an additional language data to be similar for the two boroughs. However, there was a large difference in the distributions of children with special educational needs, with many more children with SEN in the inner London borough than in the outer borough. This in turn could distort the SATs data for the inner London borough.

Another possible interpretation of the discrepancy between the two boroughs is as follows. The subjective impression formed when carrying out the external noise survey was that noise levels

outside several schools in the inner borough were unrepresentative of (normally lower than) the general environmental noise climate in the area. In contrast, in the outer borough the external school levels were probably more typical of general environmental noise levels. The fact that the results for this borough suggest a relationship between noise and SATs results whereas those for the inner borough do not could therefore indicate that there is a relationship between SATs scores and environmental noise in the *general neighbourhood* of a school, that is the area in which the children are likely to live, rather than noise measured *immediately outside* a school.

9 CONCLUSIONS

The consistent negative correlations between noise levels and SATs results for primary schools in one London borough suggest that external environmental noise is related to children's academic performance, having a detrimental effect upon children's attainments as reflected by schools' SATs scores. However, it is likely that there are many other factors, including social and economic factors, which influence children's results and which may interrelate with the effects, if any, of noise on academic performance. A similar analysis of noise and test results in a second borough did not show the same relationships between external noise and SATs scores; this may be due to inconsistencies in the noise and/or school data. In order to more fully examine the effect of environmental noise on performance of primary school children in London it is necessary to repeat the noise and SATs surveys on a London wide basis.

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