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The effects of environmental and classroom noise on the academic attainments of primary school children

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While at school children are exposed to various types of noise including external, environmental noise and noise generated within the classroom. Previous research has shown that noise has detrimental effects upon children's performance at school, including reduced memory, motivation, and reading ability. In England and Wales, children's academic performance is assessed using standardized tests of literacy, mathematics, and science. A study has been conducted to examine the impact, if any, of chronic exposure to external and internal noise on the test results of children aged 7 and 11 in London (UK) primary schools. External noise was found to have a significant negative impact upon performance, the effect being greater for the older children. The analysis suggested that children are particularly affected by the noise of individual external events. Test scores were also affected by internal classroom noise, background levels being significantly related to test results. Negative relationships between performance and noise levels were maintained when the data were corrected for socio-economic factors relating to social deprivation, language, and special educational needs. Linear regression analysis has been used to estimate the maximum levels of external and internal noise which allow the schools surveyed to achieve required standards of literacy and numeracy. © *2008 Acoustical Society of America.* [DOI: 10.1121/1.2812596]

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I. INTRODUCTION

Children are exposed to many different types of noise while at school. Previous studies have shown that schools may be exposed to high levels of environmental noise, particularly in urban areas.[1,2] Sources include road traffic, trains, aircraft, and construction noise. Inside schools a wide range of noise levels have been measured,[3–7] the levels varying significantly between different types of space and different classroom activities.[1] For much of the day in a primary school classroom, young children are exposed to the noise of other children producing "classroom babble" at levels typically of around 65 dB(A) L_{Aeq},[1] while the typical overall exposure level of a child at primary school has been estimated at around 72 dB(A) L_{Aeq}.[1]

The effects of noise on children and their teachers have been investigated in many studies in the past 40 years. It is generally accepted that noise has a detrimental effect upon the cognitive development of primary school children, and that older children in this age group are more affected than the younger children.[8,9] Two major reviews of previous work in this area, published in the early 1990s, concluded that chronic noise exposure of young children has an adverse effect, particularly upon their reading ability.[10,11]

Most of the previous work has concerned the effects of environmental noise, notably aircraft noise, upon children. Exposure to high levels of aircraft noise has been found to affect memory and reading ability, and to reduce motivation in school children.[11–15] These effects appear to be long term; noise reduction inside a school has been found to have little immediate effect upon children's performance[16] while another study found that when an airport was closed it took several years for the detrimental effects of noise exposure to cease.[13] These results suggest that noise reduces the learning trajectories of the pupils involved so that extended periods of teaching and learning are required for children to reach typical levels of performance.

In addition to aircraft noise other types of environmental noise, including that from railways[17,18] and road traffic,[19] have been found to affect reading. Road traffic noise outside schools, at levels of around 70 dB(A), has also been found to reduce children's attention.[20,21]

While there is a large body of work concerning the effects of external environmental noise upon children at school, there have been far fewer investigations into the effects of typical classroom noise upon children's performance. However in recent years evidence has been found to suggest that noise inside the classroom affects letter, number, and word recognition.[10,22–25]

It is thus now generally accepted that all types of noise exposure at school affect children's learning and academic performance. The majority of the previous studies have com-

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pared 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 which have demonstrated a dose/response relationship between noise and effects on children's performance, thereby making it difficult to determine threshold levels at which adverse effects occur, which in turn makes it difficult to establish specific guideline values to prevent such effects.[26]

In recent years several countries have introduced standards and guidelines relating to the acoustic design of schools and classrooms. For example, in the United States ANSI standard S12.60,[27] published in 2002, sets out guideline values for noise levels, reverberation times, and sound insulation in schools. Since 2003 new school buildings in England and Wales must comply with the Building Regulations. The acoustic requirements are specified in Building Bulletin 93 (BB93),[28] published in 2003. The requirements of S12.60 and BB93 are similar, for example the maximum noise level specified by both for empty classrooms is 35 dB(A) L_{Aeq}. However, in general the noise specifications for classrooms are based upon speech intelligibility requirements, rather than the levels of noise which have direct detrimental effects upon children's performance in the classroom.

In the study described here noise levels measured outside 142 primary schools in central London (UK), and inside a range of spaces inside 16 schools have been compared with assessment scores of the schools in national standardized tests. The approach taken enables the effects on children at school of different levels and types of noise to be investigated. It is also possible to compare the impact of various types of noise upon different aged children across a variety of academic tasks. In addition, this approach allows the most important property of the noise (for example, its background, maximum, or ambient level) in relation to academic performance to be determined, an issue that has not been considered in previous studies.

A simultaneous study by the authors[29] used experimental testing to investigate the effects of environmental and classroom noise on children's performance on a range of tasks in the classroom. It will be seen that the results of the two investigations are complementary and advance the understanding of the different ways in which children's academic performance and development are affected by noise.

II. MATERIALS AND METHODS

A. Procedure

The study investigated the effects of chronic noise exposure upon children's academic attainments by comparing measured noise levels with recognized standardized measures of children's attainments in primary school. The relationships between attainment scores for individual schools and both external (environmental) and internal noise were examined. The effects of acute exposure to environmental and classroom noise were also investigated in the abovementioned complementary experimental study.[29]

B. Measures of children's attainments: Standardized assessment tests (SATs)

In the 1990s a standard national curriculum was introduced for all schools in England and Wales. To complement this curriculum, standardized assessment tests (SATs) in various subjects including English, Mathematics, and Science were introduced across the age range at both primary and secondary school level. The majority of children at state schools take these tests at the ages of 7 ("Key Stage 1"), 11 ("Key Stage 2") and 14 ("Key Stage 3") years. Average results for all schools in all subjects are published by the Department for Education and Skills. The published school data consist of the percentages of children in each school who reach a recognized criterion level in each subject at each stage. Average school scores for each stage are also published. Each year the UK government sets targets for literacy and numeracy in primary schools by specifying Key Stage 2 SAT scores which schools must aim to achieve. At the time of the survey the target scores for schools were 75% for Key Stage 2 Mathematics and 80% for Key Stage 2 English.

The study described here concerned children of primary school age. The relevant test data for comparison with noise were therefore Key Stage 1 and Key Stage 2 SAT results. At Key Stage 1 (KS1) the assessment includes both teacher assessments and national standardized tests, which are combined to give a single score for each subject for each child. At Key Stage 2 (KS2) children sit for standard nationwide examinations. Between two and four examinations are taken in each subject, the examination results being averaged to give a single mark for each subject.

The subjects assessed at the two stages at the time of this study were as follows: Key Stage 1 (Year 2 of primary school, 7 years of age on average): Reading; Writing; Spelling; and Mathematics. Key Stage 2 (Year 6 of primary school, 11 years of age on average): English; Mathematics; and Science.

The schools' attainment scores in each subject, plus average scores, at Key Stage 1 and Key Stage 2, were compared with noise levels measured inside and outside the schools.

C. Selection of study areas and schools

The areas chosen for the study were based upon the local government boroughs of London, of which there are 33. It was important for the study that the boroughs chosen should be representative of London as a whole in terms of noise exposure, academic achievements, and demographic characteristics in order to reduce the number of potentially confounding variables.

It was decided that boroughs in which aircraft were the dominant environmental noise source should be excluded from the survey, as there was already a considerable body of research on the effects of aircraft noise on children. There was also a concurrent study of the effects of aircraft noise on children in schools to the west of London, around Heathrow airport.[14] Furthermore, there were fewer detailed studies of the impact of general environmental noise than of aircraft

TABLE I. SAT results, demographic factors, and external noise levels for the three boroughs.

Stage	Subject	Borough A Mean	Borough A s.d.	Borough B Mean	Borough B s.d.	Borough C Mean	Borough C s.d.
Key Stage 1 test results	Reading	76.1	14.1	74.7	13.2	78.4	16.9
	Writing	76.8	14.9	74.8	13.9	78.2	16.9
	Spelling	63.8	17.1	59.3	17.2	64.7	18.4
	Maths	86.4	8.9	83.5	12.0	86.4	13.2
Key Stage 2 test results	English	68.5	18.5	69.8	15.7	69.5	16.6
	Maths	66.1	16.2	67.0	15.7	68.2	19.1
	Science	77.9	15.9	81.0	12.6	78.9	17.3
Demographic factors	% FSM	38.8	19.3	41.5	14.2	33.6	10.7
	% EAL	43.9	19.2	35.3	16.8	39.6	17.7
	% SEN	10.3	2.9	28.3	10.0	26.2	7.8
External noise levels	$L_{\text{Aeq,5 min}}$	57.4	8.8	56.2	9.4	58.9	7.4
	$L_{\text{A10,5 min}}$	59.4	9.0	58.4	9.9	61.2	7.7
	$L_{\text{A90,5 min}}$	49.2	7.7	46.5	9.3	50.2	8.2
	$L_{\text{A99,5 min}}$	47.0	7.4	44.3	9.2	47.8	8.2
	$L_{\text{Amax,5 min}}$	70.5	10.5	68.3	17.0	72.0	9.0
	$L_{\text{Amin,5 min}}$	46.0	7.5	41.3	12.4	47.0	8.3

noise. Therefore, in selecting boroughs for the purpose of this study those affected particularly by aircraft noise were excluded.

Remaining boroughs were examined to ensure that their primary school academic attainments and demographic characteristics (see Sec. II D) were typical of London as a whole. The distributions of SAT results in boroughs were studied in order to select boroughs for which (a) test scores displayed an acceptable range, as indicated by the standard deviations of the SAT results in all subjects and (b) the mean scores for reading, writing, and mathematics were not above the mean score of all London boroughs. Of the boroughs selected in this way agreement was obtained from the Directors of Education of three boroughs to participate in the project. Borough A is a suburban London borough, all schools being within approximately 6 miles of central London. Boroughs B and C, on the other hand, are more centrally located, with all schools within a distance of approximately 3 miles from central London. Demographic differences between the boroughs are discussed in Sec. II D.

Means and standard deviations of the subject scores for the three boroughs are shown in Table I. Analysis of variance showed that there was no significant difference between the subject scores for the three boroughs.

It can be seen from Table I that there was in general close agreement between mean subject scores in the three boroughs, while borough C displayed slightly higher standard deviations in most subjects indicating a wider spread of scores in this borough.

D. Demographic characteristics

The socio-economic characteristics of schools in the boroughs were also examined. The data considered were the percentages of children in each school receiving free school meals (FSM); the percentages of children for whom English is an additional language (EAL); and the percentages of children with special educational needs (SEN). The percentage of children receiving free school meals is commonly accepted as a reliable indicator of social disadvantage in an area.[30,31]

The means and standard deviations of these data for the three chosen boroughs are also given in Table I. Analysis of variance showed that there were some differences between the boroughs, particularly in the distributions of children with special educational needs. There were considerably fewer children with special needs in (suburban) borough A while the percentages for the central boroughs were similar and around 2.5 times the percentage in borough A.

A major difference between the boroughs is in the density of population. At the time of the surveys the populations per square kilometer of the three boroughs were approxi-

TABLE II. Internal noise levels.

	School location: Occ teach space	Unocc teach space	Corr/ foyer /stair	Occ hall	Unocc hall	Class (age group): Nurs (3–4)	Rec (4–5)	Yr 1 (5–6)	Yr 2 (6–7)	Yr 3 (7–8)	Yr 4 (8–9)	Yr 5 (9–10)	Yr 6 (10–11)
L_{Aeq}	72.1	47.0	58.1	73.4	53.2	71.9	73.9	74.3	66.3	68.9	69.6	73.2	71.2
L_{A90}	54.1	36.9	44.6	55.1	44.3	57.3	62.3	61.0	51.3	52.5	49.8	53.8	52.9

Exhibit A38-5

mately as follows: borough A 7600; borough B 12 200, and borough C 10 100. Boroughs B and C therefore represent the more densely populated inner city areas, while borough A is more typical of suburban boroughs.

E. Noise surveys

Noise levels were measured outside all the state-funded primary schools in boroughs A ($N=53$) and B ($N=50$) and outside a majority of the 61 schools in borough C ($N=39$). Of these, eight schools in boroughs A and B were also selected for internal surveys. The eight schools were chosen to reflect the full range of external noise levels measured, the external L_{Aeq} levels of the 16 schools ranging from 49 to 75 dB(A). The measurement methods, noise levels, and noise sources present have been described elsewhere.[1] The external and internal levels that have been used in examining the impact of noise upon test results are summarized in the following.

1. External levels

Table I also shows the means and standard deviations of various environmental noise parameters measured in the three boroughs. These levels were measured at, or have been normalized to, a distance of 4 m from the school façade during the school day.[1]

It can be seen that the levels were reasonably consistent across the three boroughs, with borough C having slightly higher levels than the other two boroughs. This was to be expected as this borough is the one nearest central London. The mean levels in borough B were slightly lower than might be expected given that this is also an inner city borough. However many of the schools in this area are situated in the middle of housing estates or on side streets, and are thus sheltered to some extent from the noise of road traffic, the main noise source in the areas surveyed.[1] This is illustrated by the larger standard deviations of noise levels in borough B.

2. Internal levels

In the internal school noise survey levels were measured in classrooms and other areas around a school. Most spaces were measured in both occupied and unoccupied conditions. The averaged ambient (L_{Aeq}) and background (L_{A90}) levels for the types of spaces considered in each school are shown in Table II.

Internal levels were also categorized according to the age of the class; the average L_{Aeq} and L_{A90} levels for different age groups in each school are also shown in Table II. For the purposes of analyzing the effects, if any, of noise on SAT results noise levels for Year 2 and Year 6 are the only ones considered in the subsequent discussion.

F. Analyses

In order to study the impact, if any, of noise on children's attainment the noise levels measured inside and outside the schools were correlated with the SAT scores for the academic year in which the noise survey was carried out.

TABLE III. Borough A: Correlation coefficients between test scores and external noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	-0.34^{b}	-0.31^{b}	-0.37^{a}	-0.33^{b}
KS1 Maths	-0.34^{b}	-0.27	-0.43^{a}	-0.34^{b}
KS2 English	-0.37^{a}	-0.39^{b}	-0.40^{a}	-0.33^{b}
KS2 Maths	-0.40^{a}	-0.46^{b}	-0.40^{a}	-0.36^{a}
KS2 Science	-0.40^{a}	-0.45^{b}	-0.42^{a}	-0.37^{a}
KS1 average	-0.36^{b}	-0.32^{b}	-0.40^{a}	-0.36^{b}
KS2 average	-0.41^{a}	-0.45^{a}	-0.43^{a}	-0.37^{a}

[a]Significant at 1% level.
[b]Significant at 5% level.

For external noise it was found that results for L_{A90}, L_{A99}, and L_{Amin} were very similar, as would be expected and was confirmed by factor analysis. Therefore in the following sections, relationships between SAT results and L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} only are considered. These are the most commonly cited measures of environmental noise and are generally considered to capture the key features of the noise environment.

Similarly, factor and correlation analysis showed a close relationship among results for KS1 literacy-related tests Reading, Writing, and Spelling, as would be expected. Therefore, in the subsequent analysis and discussion, of these tests, results are presented for KS1 Reading only as being a reliable indicator of the younger children's attainments in literacy.

Correlation and regression analysis were carried out for the noise and test data. The noise levels were correlated with subject and average school SAT scores. Obviously any relationships found between noise and SAT scores in this way could be due to social or other factors rather than representing a direct effect of noise on academic performance. In order to eliminate the effects of socio-economic factors, partial correlations were carried out, in which the schools' data on children with FSM, EAL, and SEN were controlled for.

Current guidance on choosing a site for new school buildings in England and Wales recommends an upper limit of 60 dB $L_{Aeq,30\ min}$ at the boundary of school premises.[28] For this reason, in addition to considering all schools mea-

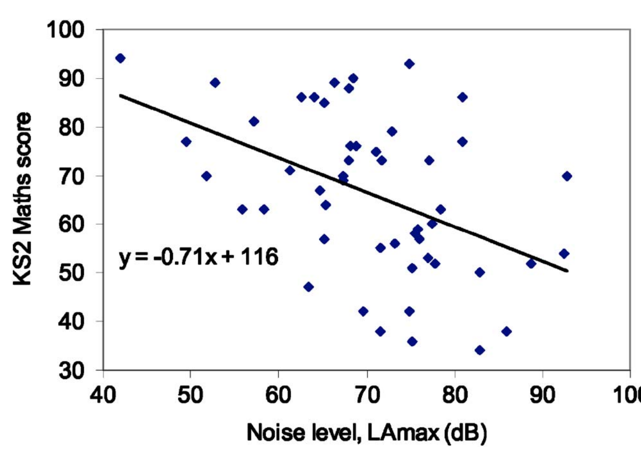

FIG. 1. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and Key Stage 2 Mathematics scores in borough A.

Page 000005

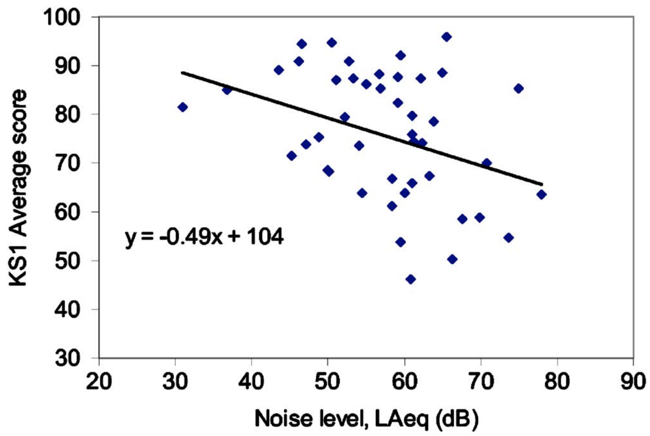

FIG. 2. (Color online) Scatter diagram illustrating relationship between external L_{Aeq} and average Key Stage 1 scores in borough A.

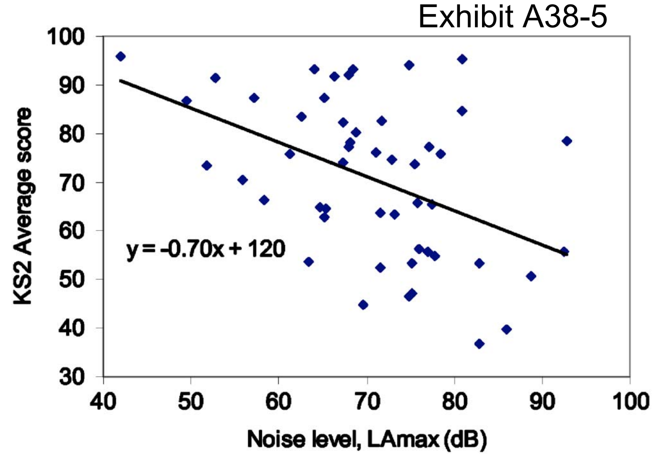

FIG. 3. (Color online) Scatter diagram illustrating relationship between external L_{Amax} and average Key Stage 2 scores in borough A.

sured in each borough, those schools where the measured external L_{Aeq} levels are greater than or equal to 60 dB(A) have been considered separately.

III. RESULTS: RELATIONSHIPS BETWEEN EXTERNAL NOISE AND TEST RESULTS

The values of the noise parameters L_{Aeq}, L_{Amax}, L_{A90}, and L_{A10} measured outside each school were compared with average and subject SAT scores for the younger (aged 7 years) and older (aged 11 years) children.

The Pearson correlation coefficients between average and subject scores and external noise levels were calculated for all schools in boroughs A, B, and C. Table III shows the coefficients for borough A. It can be seen that there were negative relationships between external noise and SATs for all scores, that is, the greater the noise level the lower the school test performance score. Furthermore, all except one of the relationships were significant at the 1% or 5% level. However, for both boroughs B and C the correlation coefficients were very small, varying from −0.15 to 0.28. There were no significant relationships and the coefficients were very similar for the two boroughs. This may be due to the differences between the central and suburban boroughs reflected in the SEN data shown in Table I, and also to the different characteristics of the boroughs as represented by their population densities, discussed in Sec. II D. For this reason the two central boroughs (B and C) are considered together and separately from the suburban borough (A) in the following discussion.

A. Borough A

1. All schools

Table III shows that when all schools in borough A are considered there were significant negative relationships between all SAT scores and all external noise parameters, except for KS1 Mathematics and L_{Amax}. The relationships were stronger for Key Stage 2 subjects, suggesting that noise has more of an impact upon the performance of the older children. A possible explanation for this is that the older children have been exposed to the noise for a longer period of time. This is consistent with the results of previous research demonstrating the effects of long-term noise exposure.[13–16] However, it is also possible that the nature and demands of the tasks for older children differ from those of the younger children and are more vulnerable to the effects of noise.

At Key Stage 1 and for KS2 English the external noise level with the strongest correlation with test scores was the background level, as measured by L_{A90}. For other subjects at Key Stage 2, L_{Amax} was the parameter which had the strongest association with test scores. This suggests that the younger children were affected by general external background noise, while the older children were more affected by individual external noise events such as motorbikes or lorries

TABLE IV. Borough A: Correlation coefficients between test scores and external noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.17	−0.26	−0.32[b]	−0.15	−0.26	−0.29[b]	−0.11	−0.24	−0.35[b]	−0.16	−0.25	−0.31[b]
KS1 Maths	−0.23	−0.28	−0.32[b]	−0.15	−0.22	−0.24	−0.29	−0.35[b]	−0.41[a]	−0.24	−0.28	−0.33[b]
KS2 English	−0.17	−0.27[b]	−0.34[b]	−0.25	−0.38[a]	−0.37[a]	−0.08	−0.23	−0.39[a]	−0.12	−0.22	−0.31[b]
KS2 Maths	−0.23	−0.32[b]	−0.38[a]	−0.36[a]	−0.44[a]	−0.44[a]	−0.10	−0.25	−0.38[a]	−0.19	−0.27	−0.35[a]
KS2 Science	−0.25	−0.32[b]	−0.39[a]	−0.34[b]	−0.42[a]	−0.44[a]	−0.19	−0.30[b]	−0.41[a]	−0.23	−0.29[b]	−0.36[a]
KS1 average	−0.20	−0.29	−0.34[b]	−0.17	−0.27	−0.30[b]	−0.18	−0.29	−0.39[a]	−0.21	−0.28	−0.35[b]
KS2 average	−0.25	−0.33[b]	−0.39[a]	−0.36[a]	−0.45[a]	−0.44[a]	−0.14	−0.28[b]	−0.41[a]	−0.20	−0.28[b]	−0.36[a]

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE V. Schools in boroughs B and C with external $L_{Aeq} \geqslant 60$ dB(A): Correlation coefficients between test scores and noise levels.

	L_{Aeq}	L_{Amax}	L_{A90}	L_{A10}
KS1 Reading	−0.40[b]	−0.40[b]	−0.22	−0.36[b]
KS1 Maths	−0.10	−0.09	−0.03	−0.20
KS2 English	−0.39[b]	−0.43[a]	−0.37[b]	−0.38[b]
KS2 Maths	−0.21	−0.31	−0.15	−0.27
KS2 Science	−0.25	−0.36[b]	−0.15	−0.24
KS1 average	−0.31	−0.31	−0.12	−0.28
KS2 average	−0.30	−0.39[b]	−0.24	−0.32

[a]Significant at 1% level.
[b]Significant at 5% level.

passing the school. This is consistent with the findings of previous research,[12–18] which has found that reading is affected by noise caused by individual external sources such as trains or planes. It is also consistent with a questionnaire survey of children carried out by the authors which found that older, Key Stage 2 age, children were more aware of external noise than the younger children at Key Stage 1. The subject showing the strongest negative effect of noise (with background levels at Key Stage 1 and with maximum levels at Key Stage 2) was Mathematics. The mathematics assessment at Key Stage 2 is complex, involving orally presented mental arithmetic, written arithmetic, and word problems. Thus performance at these tasks is vulnerable to the effects of noise on both reading and speeded responses, two areas which have been found to be affected by noise in previous studies.[10–18,29]

Figures 1–3 give examples of scatter diagrams relating external noise levels and SAT scores. Figure 1 shows the relationship between L_{Amax} and Key Stage 2 Mathematics scores; Fig. 2 shows the scatter diagram of L_{Aeq} and average Key Stage 1 score; and Fig. 3 average Key Stage 2 score and L_{Amax}. Regression lines relating external noise levels and SAT scores are also shown in Figs. 1–3. The implications of these relationships are discussed in Sec. V.

Table IV shows the partial correlation coefficients obtained when the data for borough A were controlled for the FSM, EAL, and SEN data. It can be seen that when social deprivation (as measured by FSM data) was taken into account there was still a negative relationship between external noise and test scores, but there were fewer significant relationships than with the uncorrected data. However, L_{Amax} was still significantly correlated with two subject scores (Mathematics and Science) and the average score at Key Stage 2. The strongest relationship was again with the Mathematics scores. When potential language demands (as indicated by EAL data) were accounted for there were still strong associations between L_{Amax} and all subjects at Key Stage 2, with Mathematics again being the subject most strongly related to noise. As with the uncorrected data, KS1 Mathematics scores were most strongly, and significantly, related to the external background noise level. When controlling for SEN, it can be seen that the pattern was very similar to that for the uncorrected data, with KS2 Mathematics and Science again being the subjects most affected by external noise, and L_{Amax} having the strongest negative relationship with test scores at Key Stage 2.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

When considering only those schools with external L_{Aeq} levels of 60 dB(A) or more in borough A ($N=22$), KS1 Mathematics was the only subject significantly related to noise, being significantly related at the 5% level to L_{A90}. This significant relationship was maintained when the data were corrected for socio-economic factors, becoming significant at the 1% level when correcting for SEN.

B. Boroughs B and C

1. All schools

As mentioned previously, there were no significant relationships between test scores and external noise for the central London boroughs when all schools in the two boroughs were considered. The reason for the difference between these schools and those in borough A is unclear, but may be related to the discrepancies in the percentages of children with special needs in the central and suburban boroughs, or to the differing population characteristics between the boroughs.

2. Schools with external L_{Aeq} levels of 60 dB(A) or greater

If only those schools where the external level exceeds 60 dB L_{Aeq} in the two boroughs were considered ($N=35$) then there were stronger negative relationships between SAT

TABLE VI. Schools in boroughs B and C with external $L_{Aeq} \geqslant 60$ dB(A): Correlation coefficients between test scores and noise levels corrected for data on FSM, EAL, and SEN.

	L_{Aeq}			L_{Amax}			L_{A90}			L_{A10}		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.35[b]	−0.40[b]	−0.35[b]	−0.40[b]	−0.41[b]	−0.43[a]	−0.13	−0.22	−0.16	−0.23	−0.36[b]	−0.29
KS1 Maths	−0.00	−0.08	−0.02	−0.04	−0.10	−0.10	0.09	0.05	0.07	−0.04	−0.15	−0.10
KS2 English	−0.34[b]	−0.37[b]	−0.32	−0.46[a]	−0.46[a]	−0.48[a]	−0.30	−0.28	−0.29	−0.23	−0.32	−0.29
KS2 Maths	−0.09	−0.18	−0.11	−0.30	−0.32[b]	−0.34[b]	−0.01	−0.06	−0.05	−0.06	−0.21	−0.16
KS2 Science	−0.16	−0.23	−0.20	−0.35[b]	−0.37[b]	−0.37[b]	−0.03	−0.08	−0.09	−0.06	−0.19	−0.17
KS1 average	−0.25	−0.31	−0.25	−0.29	−0.31	−0.33	−0.02	−0.11	−0.04	−0.14	−0.28	−0.21
KS2 average	−0.22	−0.28	−0.23	−0.41[b]	−0.41[b]	−0.43[a]	−0.13	−0.16	−0.16	−0.13	−0.26	−0.22

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE VII. Internal noise: Correlation coefficients between test scores and Year 2 and Year 6 noise levels.

	Year 2 $N=11$		Year 6 $N=13$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	0.01	−0.12		
KS1 Maths	−0.17	−0.33		
KS2 English			−0.45	−0.48
KS2 Maths			−0.04	−0.00
KS2 Science			−0.36	−0.11
KS1 average	−0.15	−0.29		
KS2 average			−0.33	−0.25

scores and noise, as shown in Table V. For most external noise parameters, as with borough A schools, the relationships were stronger for Key Stage 2 results, and in general L_{Amax} was the parameter most closely related to test results. In these boroughs, however, English was the subject showing the greatest effect of noise. Both KS1 Reading and KS2 English scores were significantly related to external L_{Aeq}, L_{Amax}, and L_{A10} levels, while KS2 English was also significantly related to the background L_{A90} level. Unlike the suburban borough, Mathematics scores were not significantly related to any external noise parameter.

Table VI shows the correlations when the data were corrected for socio-economic factors. In all cases the results were very similar to those for the uncorrected data. KS1 Reading and KS2 English were the subjects most affected by external noise, KS2 English being significantly correlated with L_{Amax} at the 1% level and L_{Amax} again being the noise parameter with the strongest correlations with test scores. When correcting for EAL and SEN, all subjects at KS2 were significantly related to L_{Amax}. Relationships between KS2 English and L_{Amax} were significant at the 1% level, and stronger than for the uncorrected data.

IV. RESULTS: RELATIONSHIPS BETWEEN INTERNAL NOISE AND TEST RESULTS

In investigating relationships between internal noise and SATs, average and subject Key Stage 1 and Key Stage 2 SAT scores were correlated with relevant internal noise data. For this analysis, correlations were carried out for the complete set of 16 schools (eight in borough A and eight in borough B) for which internal noise data were available. The internal noise data that were used consisted of the L_{Aeq} and L_{A90} levels for Year 2 and Year 6 (as these are the years in which children sit for SATs); and in the various school locations which were measured.

A. Correlation with year group levels

Table VII shows the correlations between KS1 test scores and Year 2 noise levels, and between KS2 scores and Year 6 levels. It can be seen that there were negative relationships between all scores and noise levels, except for Key Stage 1 Reading; however, none of the correlations were significant, possibly because of the small sample size. The subject showing the strongest effect of internal noise was KS2 English, which was related to both L_{Aeq} and L_{A90} levels. This is consistent with the results of the parallel experimental testing,[29] which showed that classroom babble affected all tasks both verbal and nonverbal.

When the data were corrected for socio-economic factors KS2 English was still the subject most strongly affected by internal noise; when correcting for FSM there was a significant negative relationship ($r=-0.59$, $p<0.05$) between background noise (L_{A90}) in Year 6 classrooms and test scores for this subject.

B. Correlation with location levels

Table VIII shows the correlation coefficients between L_{Aeq} and L_{A90} levels for different school locations and subject test scores. There were negative correlations between all subject scores and all noise levels measured in occupied classrooms, unoccupied classrooms, and corridors and foyers. In general the relationships were strongest for occupied classrooms, with the background (L_{A90}) level being significantly related to test scores for most subjects. The subject most strongly affected by internal noise was again KS2 English, which was significantly correlated at the 1% level with occupied classroom L_{A90}. KS1 Mathematics was significantly related to L_{A90} in both occupied and unoccupied classrooms.

Figures 3–6 show scatter diagrams relating internal noise and KS2 English scores, KS1 average scores, and KS2

TABLE VIII. Internal noise: Correlation coefficients between test scores and school location noise levels.

	Occ class $N=16$		Unocc class $N=14$		Corridor/foyer $N=14$		Occ hall $N=8$		Unocc hall $N=7$	
	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}	L_{Aeq}	L_{A90}
KS1 Reading	−0.11	−0.60[b]	−0.33	−0.46	−0.38	−0.39	0.32	0.06	0.14	0.18
KS1 Maths	−0.12	−0.57[b]	−0.52	−0.55[b]	−0.38	−0.40	0.36	0.21	0.43	0.34
KS2 English	−0.55[b]	−0.77[a]	−0.08	−0.20	−0.53[b]	−0.62[b]	−0.12	−0.28	0.47	0.49
KS2 Maths	−0.22	−0.46	−0.06	−0.21	−0.47	−0.49	0.18	0.03	0.28	0.36
KS2 Science	−0.41	−0.50[b]	−0.14	−0.32	−0.38	−0.39	−0.09	−0.31	−0.19	−0.04
KS1 average	−0.16	−0.58[b]	−0.41	−0.51	−0.41	−0.39	0.24	0.06	0.15	0.18
KS2 average	−0.43	−0.64[a]	−0.10	−0.46	−0.49	−0.35	−0.00	0.03	0.15	0.35

[a]Significant at 1% level.
[b]Significant at 5% level.

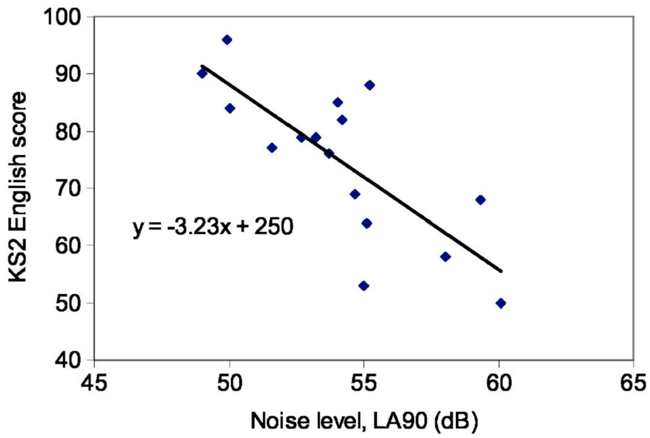

FIG. 4. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and Key Stage 2 English scores.

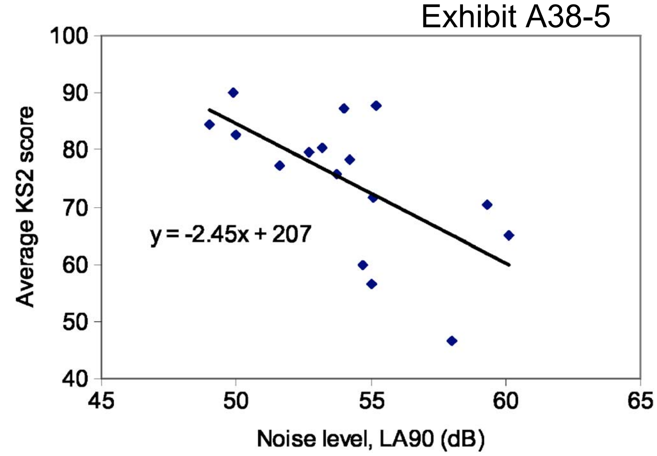

FIG. 6. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 2 scores.

average scores, respectively. Regression lines relating internal noise levels and SAT scores are also shown in Figs. 3–6 and are discussed in more detail in Sec. V.

It is interesting to note that there were consistently negative correlations between test scores and all noise levels in corridors and foyers, being significant again for KS2 English. While carrying out internal noise surveys it was subjectively apparent that the noise in such spaces gave a good indication of the general "noise climate" in a school.

It can be seen that there was no relationship between noise levels in school halls, occupied or unoccupied, and test scores. This is as would be expected and validates the fact that there are strong negative relationships between noise in classrooms and test results.

Tables IX and X show the correlation coefficients between test scores and L_{Aeq} and L_{A90} levels, respectively, in classrooms and circulation areas when the data were corrected for socio-economic factors. In general, relationships were slightly less strong when correcting for FSM and EAL but when correcting for SEN correlations coefficients were similar to those for the uncorrected data. KS2 English was still significantly correlated with L_{Aeq} in occupied classrooms and in corridors/foyers. When correcting for all factors there were significant correlations between KS2 English and L_{A90} in occupied classrooms and corridors/foyers.

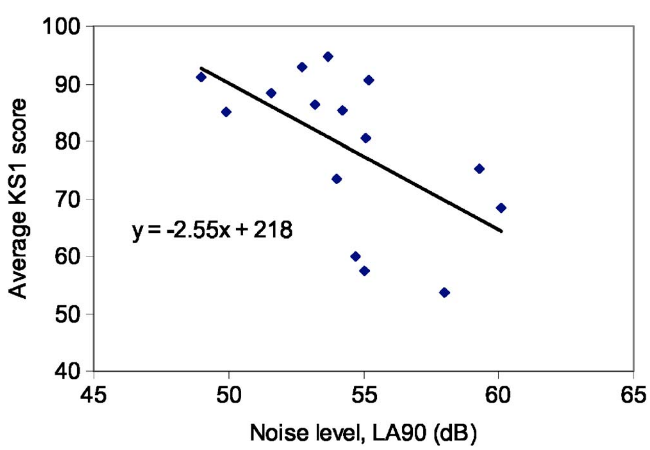

FIG. 5. (Color online) Scatter diagram illustrating relationship between occupied classroom L_{A90} and average Key Stage 1 scores.

V. QUANTIFYING THE EFFECTS OF NOISE

The regression lines relating noise levels and SAT scores for the most significant results have been calculated. In borough A these relationships have been used to investigate the implications of increases in external L_{Aeq}, L_{Amax}, and L_{A90} levels, and to establish the noise levels in this borough which correspond to the UK government targets in numeracy and literacy at the time of the survey (80% of children achieving required level in KS2 English and 75% in KS2 Mathematics). Similar analysis has been carried out for internal background (L_{A90}) levels in occupied classrooms.

A. External noise

The equations of the regression lines relating external noise (L_{Aeq}, L_{Amax}, and L_{A90} levels) and Key Stage 2 English and Mathematics scores in borough A are shown in Table XI. For completeness the relationships between noise and average Key Stage 1 and 2 scores are also shown. These linear relationships have been used to estimate the percentage decreases in the numbers of children achieving the required level for each 10 dB increase in external noise; these are also shown in Table XI. Table XI also shows the external noise levels, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

It can be seen that an increase of 10 dB(A) in external L_{Aeq}, L_{Amax}, and L_{A90} levels in borough A causes 5%, 4%, and 6% drops, respectively, in the number of children achieving the required levels at Key Stage 1, and drops of 7%, 9% and 9%, at Key Stage 2. This further illustrates the greater detrimental effect of noise on the older children in the primary school age range. The external L_{Aeq}, L_{Amax}, and L_{A90} levels corresponding to the UK government target for literacy are 42 dB(A), 54 dB(A), and 37 dB(A), respectively; for numeracy the corresponding levels are 44, 58, and 38 dB(A). It should be noted that these refer to external levels at a point 4 m from the school façade, and should be interpreted with caution as discussed in Sec. VI.

TABLE IX. Internal noise: Correlation coefficients between test scores and school location L_{Aeq} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corridor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	0.11	0.13	−0.09	−0.05	−0.19	−0.34	−0.25	−0.33	−0.49
KS1 Maths	0.15	0.18	−0.14	−0.28	−0.42	−0.52	−0.23	−0.33	−0.42
KS2 English	−0.45	−0.44	−0.53[b]	0.32	0.11	−0.10	−0.43	−0.50	−0.71[a]
KS2 Maths	−0.07	−0.09	−0.24	0.23	0.07	−0.05	−0.38	−0.43	−0.51
KS2 Science	−0.33	−0.32	−0.38	0.04	−0.03	−0.15	−0.31	−0.34	−0.53
KS1 average	0.09	0.08	−0.15	−0.12	−0.29	−0.41	−0.27	−0.36	−0.49
KS2 average	−0.32	−0.31	−0.42	0.21	0.05	−0.12	−0.39	−0.45	−0.62[b]

[a]Significant at 1% level.
[b]Significant at 5% level.

B. Internal noise

The regression lines relating internal background L_{A90} levels in occupied classrooms and Key Stage 2 English and Mathematics scores are shown in Table XII. The linear relationships between noise and average Key Stage 1 and 2 scores are also shown. Table XII also shows the percentage decreases in the numbers of children achieving the required level in SATs for each 5 dB increase in internal background noise, plus the internal background noise levels in occupied classrooms, derived from the regression lines, which correspond to the UK government targets in English and Mathematics.

Table XII shows that there is a 13% reduction in the number of children achieving the required level at Key Stage 1 and a 12% reduction at Key Stage 2, for each 5 dB(A) increase in the background noise level in occupied classrooms. The background noise level corresponding to the government target for literacy is 53 dB(A) L_{A90}, while for numeracy it is 50 dB(A) L_{A90}. As with external levels, care is needed in interpreting these figures as discussed in Sec. VI.

VI. DISCUSSION

The study described here has shown that chronic exposure to noise at school has a detrimental effect upon children's academic performance, as measured by standard assessment testing in schools in England and Wales. These are consistent with the findings of previous studies and with the results of experimental testing of children carried out by the authors, as will be discussed in the following. Both external environmental noise heard inside a school and noise generated within a school have an impact upon children's test scores, but affect children in different ways. In addition to different subjects being affected by external and by school noise, the particular characteristics of the noise which impact upon children's performance differ between the two types of noise.

A. External noise

It was seen that different results were obtained for the suburban (A) and central (B and C) boroughs. For borough A there were strong relationships between all noise parameters and all test scores when all schools were considered, but for the other boroughs significant relationships were found when only the schools on the noisier sites were considered. The reasons for the discrepancies are not fully understood but may relate to differences in demographic, population, and/or noise characteristics between the boroughs. There may be "floor" effects for the inner city boroughs in that, however low the noise levels, the overall school test scores would not improve above a certain level. As was noted earlier the two central boroughs considered had high levels of children with SEN. The parallel experimental study carried out by the authors[29] showed that children with SEN were particularly vulnerable to the effects of noise so it is possible that this factor limits the overall achievements of these schools.

TABLE X. Internal noise: Correlation coefficients between test scores and school location L_{A90} levels corrected for FSM, EAL, and SEN.

	Occupied classroom $N=16$			Unoccupied classroom $N=14$			Corrifor/foyer $N=14$		
	FSM	EAL	SEN	FSM	EAL	SEN	FSM	EAL	SEN
KS1 Reading	−0.44	−0.47	−0.60[b]	−0.21	−0.30	−0.45	−0.26	−0.30	−0.40
KS1 Maths	−0.36	−0.40	−0.60[b]	−0.30	−0.40	−0.57[b]	−0.25	−0.29	−0.40
KS2 English	−0.66[a]	−0.69[a]	−0.76[a]	0.19	0.03	−0.17	−0.55[b]	−0.58[b]	−0.64[b]
KS2 Maths	−0.30	−0.36	−0.49	0.06	−0.07	−0.22	−0.40	−0.43	−0.48
KS2 Science	−0.42	−0.42	−0.48	−0.18	−0.21	−0.29	−0.31	−0.33	−0.40
KS1 average	−0.38	−0.44	−0.59[b]	−0.24	−0.36	−0.51	−0.26	−0.31	−0.41
KS2 average	−0.51[b]	−0.54[b]	−0.63[a]	0.01	−0.10	−0.26	−0.44	−0.47	−0.54

[a]Significant at 1% level.
[b]Significant at 5% level.

TABLE XI. Borough A: Regression lines relating external noise levels and SAT scores.

	L_{Aeq}			L_{Amax}			L_{A90}		
	Regression equation	% drop ≈10 dB increase	Level≈target	Regression equation	% drop ≈10 dB increase	Level≈target	Regression equation	% drop ≈10 dB increase	Level≈target
KS2 English	$y=-0.76x+112$	8	42	$y=-0.70x+118$	7	54.2	$y=-0.95x+115$	10	36.8
KS2 Maths	$y=-0.72x+107$	7	44.4	$y=-0.71x+116$	7	57.7	$y=-0.82x+106$	8	37.8
KS1 average	$y=-0.49x+104$	5	⋯	$y=-0.37x+102$	4	⋯	$y=-0.63x+107$	6	⋯
KS2 average	$y=-0.73x+113$	7	⋯	$y=-0.70x+120$	7	⋯	$y=-0.87x+114$	9	⋯

In general, for the suburban borough and for the noisier schools in the inner city boroughs correlations between noise and test scores were stronger for Key Stage 2 scores than for those at Key Stage 1 suggesting that external noise has more of an effect on the older children. It has previously been found that the negative effects of environmental noise are long term.[13,16] The greater effect upon the older children may therefore reflect the fact that these children have been exposed to noise at school for a longer period than the younger children. It may also be due to the higher task demands required of the older children in their tests.

In general, over all boroughs, the noise parameter with the highest and most significant correlations with test scores was L_{Amax}, implying that noise of individual events may be the most important in affecting children's performance. However, in the suburban borough external background noise levels, L_{A90}, were also significantly related to test scores.

Significant relationships between tests scores and noise were maintained when the data were corrected for factors relating to social deprivation, non-native speaking, and additional educational needs. In particular in all boroughs (considering just the noisier schools in the inner city boroughs) all KS2 subjects remained significantly related to L_{Amax} while KS1 Reading was also significantly related to some noise parameters.

The dominant external noise source in the schools considered was road traffic.[1] These findings are thus consistent with the findings of other studies which have found that road traffic noise has an impact upon children's performance at school.[19–21] Furthermore, although schools exposed to aircraft noise were not included in the study, the close relationships between L_{Amax} and test scores suggest that the noise of individual events has an impact upon children's performance. This is thus consistent with the results of other studies which have found that both aircraft[12–16] and railway[17] noise affect children's performance.

TABLE XII. Regression lines relating L_{A90} in occupied classrooms and SAT scores.

	Occupied classrooms L_{A90}		
	Regression equation	% drop ≈5 dB increase	Level≈target
KS2 English	$y=-3.23x+250$	16	52.6
KS2 Maths[a]	$y=-1.87x+169$	9	50.3
KS1 average	$y=-2.55x+218$	13	⋯
KS2 average	$y=-2.45x+207$	12	⋯

[a]Correlation ($r=-0.46$) not significant.

The results also complement the findings of a questionnaire survey of children carried out by the authors which found that the older (Year 6) children were more aware of external noise than the younger children.[32] This is consistent with the finding that the test results of these children were more affected by noise than those of the younger children. Furthermore, annoyance caused by external noise among children was significantly related to external maximum noise levels, the levels that are found to have the most effect upon test scores.

Regression analysis has been used to estimate the noise levels corresponding to UK government targets in English and Mathematics in the suburban borough. In this borough those schools where the external L_{Amax} level 4 m from the school façade exceeds 54 dB(A), or L_{Aeq} exceeds 42 dB(A), fail to meet literacy and numeracy targets. These levels are considerably lower than those recommended in current guidelines,[28] and should be interpreted with caution. As can be seen from Figs. 1–3 there is considerable scatter around the regression lines; many schools with levels greater than these do achieve the SAT targets. Furthermore, there are many other factors apart from noise which may affect children's attainments; the regression analysis was carried out for uncorrected data where additional factors which may impact upon learning are not accounted for. These results may therefore not apply to schools in general.

B. Internal noise

There were consistent negative relationships between test scores and L_{Aeq} and L_{A90} levels measured in occupied and unoccupied classrooms and corridors and foyers. The internal noise levels which had the strongest relationships with test scores were the background (L_{A90}) levels in occupied classrooms. All subjects except KS2 Mathematics were significantly correlated with these levels. KS1 Mathematics was also significantly correlated with L_{A90} measured in unoccupied classrooms and KS2 English with L_{Aeq} and L_{A90} measured in corridor and foyer areas. Many of the relationships, particularly those for KS2 English, were maintained when the data were corrected for socio-economic factors.

These results complement the results of the controlled experimental testing of children carried out by the authors in which children performed various tasks in different classroom noise conditions.[29] Classroom babble was found to decrease performance on both verbal and nonverbal tasks, with verbal tasks of reading and spelling being particularly affected. This is consistent with the finding that KS2 English test scores are strongly and significantly related to the ambient and background noise levels in classrooms.

Regression analysis showed that of the schools surveyed, in general those in which background (L_{A90}) levels in occupied classrooms exceed 50 dB(A) failed to meet government targets in literacy and numeracy. Current guidelines specify internal levels in classrooms in terms of ambient L_{Aeq} when both classrooms and the whole school are unoccupied. It is difficult, without further extensive noise surveys in schools both empty and occupied, to compare the occupied classroom background noise level with those in current standards. Furthermore, as with the external levels there is considerable scatter around the regression lines as can be seen in Figs. 4–6; therefore care should be taken when interpreting these results.

VII. CONCLUSION

This study has shown that chronic exposure to both external and internal noise has a detrimental impact upon the academic performance and attainments of primary school children. For external noise it appears to be the noise levels of individual events that have the most impact while background noise in the classroom also has a significant negative effect. Older primary school children, around 11 years of age, appear to be more affected by noise than the younger children.

In order to minimize the impact of noise upon children at school it is therefore necessary to consider two factors. The siting and the internal layout of a school should be such that classrooms are not exposed to high levels of noise from external sources such as road traffic. In addition it is essential to minimize background noise levels in the classroom to ensure that optimum conditions for teaching and learning are achieved.

Further field and experimental studies are required to determine the levels at which different types of external and internal noise affect children's academic performance in different circumstances.

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