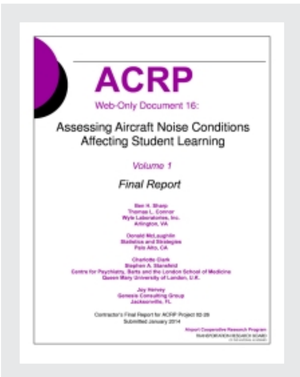
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Volume 1
Final Report

Assessing Aircraft Noise Conditions Affecting Student Learning, Volume 1: Final Report

DETAILS

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AUTHORS

Sharp, Ben H.; Connor, Thomas L.; McLaughlin, Donald; Clark, Charlotte; Stansfeld, Stephen A.; and Hervey, Joy

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EXECUTIVE SUMMARY

Aviation noise effects on schools and school children have been well-researched and documented. Recent studies indicate a potential link between aviation noise and both reading comprehension and learning motivation, particularly for those children who are already scholastically challenged. However, there has been little work done on establishing a dose-response relationship between aviation noise and classroom effects. This lack of a reliable dose-response relationship makes the evaluation of aircraft noise on schools and setting policy very difficult. With this background, the objectives of this project were to:

1. Identify and evaluate conditions under which aircraft noise affects student learning,
2. Identify and evaluate one or more alternative noise metrics that best define those conditions.

The project consisted of seven tasks conducted in two phases. In Phase I, a literature search was conducted, leading to the identification of gaps in knowledge relevant to the project objectives. Alternative research plans were designed to fill these gaps and presented to the ACRP Panel for final selection. In Phase II, the research plan was implemented. This final report fully documents the Phase I and Phase II research activities and presents the results of the research analyses.

The research plan selected by the Panel was to conduct a nationwide macro-analysis to identify the relationship between aircraft noise exposure and student performance, taking into account the effect of school sound insulation and other confounding factors. The study examined this relationship for schools exposed to aircraft noise in the years 2000/01 to 2008/09 at the top 46 US airports, prioritized by the number of schools exposed to DNL 55 dB and higher. Student performance measures were based on the standardized reading and mathematics test scores in Grades 3 through 5 at each school.

The study found statistically significant associations between airport noise and student mathematics and reading test scores, after taking demographic and school factors into account. Associations were also observed for ambient noise and total noise on student mathematics and reading test scores, suggesting that noise levels per se, as well as from aircraft, might play a role in student achievement.

This study further contributes to the increasing evidence base which suggests that children exposed to chronic aircraft noise at school have poorer reading ability and school performance on achievement tests, than children who are not exposed to aircraft noise. Overall, evidence for the effects of noise on children's cognition is strengthening and there is increasing synthesis between epidemiological studies, with over twenty studies having shown detrimental effects of aircraft and road noise on children's reading

The study is one of the first studies to quantify the potential impact of sound insulation on children's learning achievement for aircraft noise exposure. From a sample of 119 elementary schools it was shown that insulated schools have better test scores than those with no insulation, which may be an indication that insulation could contribute to improved scores by returning test scores to what they would have been with no aircraft noise.

Finally, the study showed that the effect of noise was greater for non-disadvantaged students than for disadvantaged students, although the analysis process does not make it possible to provide a rationale for this result. This issue may be addressed in the upcoming ACRP Project 02-47 Assessing Aircraft Noise Conditions Affecting Student Learning - Case Studies

CHAPTER 1. INTRODUCTION

Airports continue to face serious environmental challenges that impede their capacity to meet forecast growth in air travel, aircraft noise being the principal impediment to system and airport expansion. Over the years, much has changed in the understanding of this complex issue. Increased air travel, new and quieter aircraft, increased awareness of land use planning and aviation noise, and mitigation of previously incompatible land uses are just a few of these changes. Knowledge of the effects of aviation noise has also changed. The greatest increases in knowledge have come in the areas of health effects, annoyance, sleep disturbance, and the potential effects on learning abilities in schools, which is the subject of this research project.

In 2008, TRB published *ACRP Synthesis 9: Effects of Aircraft Noise: Research Update on Selected Topics* which was designed to inform airport operators, stakeholders, and policy makers of updated information about aviation noise effects. The Synthesis 9 findings, based on research conducted by others, most pertinent to this project are that:

- Annoyance remains the single most significant effect associated with aviation noise.
- Despite decades of research, including review of old data and new research efforts, it is as yet impossible to determine causal relations between health disorders and noise exposure.
- Speech interference (SI) is an important component in annoyance response. However, most SI studies and guidelines deal with steady-state noises. Aircraft noise is an intermittent noise, and therefore the SI literature is inadequate with respect to aircraft noise.
- Aviation noise effects on schools and school children have been well-researched and documented. Recent studies indicate a potential link between aviation noise and both reading comprehension and learning motivation, particularly for those children who are already scholastically challenged.

While Synthesis 9 summarized work conducted by others that concluded a potential link between aircraft noise and learning, it also reported that there has been little work done on establishing a dose-response relationship between aviation noise and classroom effects. The Synthesis goes on to say that lack of a reliable dose-response relationship between aircraft noise and classroom effects makes the evaluation of aircraft noise on schools and setting policy very difficult. With this in mind, the objectives of this project are to:

1. Identify and evaluate conditions under which aircraft noise affects student learning,
2. Identify and evaluate one or more alternative noise metrics that best define those conditions.

The mechanisms available to airports to reduce the impact of noise on surrounding communities include modifying structures, including schools, to reduce noise. FAA supports these efforts through noise set-aside funds from the Airport Improvement Program (AIP) which can be used to sound insulate schools in areas exposed to significant aircraft noise. FAA also provides guidance to airports on criteria and technology for such sound insulation programs. As befits an ACRP study, this current project is to provide practical findings that airports can apply for the purpose of noise mitigation. Accordingly, an additional objective of the project is to:

3. Identify the most effective of the current criteria for school sound insulation projects.

The project consists of seven tasks conducted in two phases. In Phase I, a literature search was conducted, leading to the identification of gaps in knowledge relevant to the project objectives. A research plan was designed to fill these gaps. In Phase II, the research plan was implemented. This Final Report fully documents the Phase I and Phase II research activities and presents the results of the research analyses.

CHAPTER 2. LITERATURE REVIEW

This literature review critically evaluates the field of noise effects on children's cognitive performance and learning outcomes describing the evidence for effects from research conducted over the past few decades. In addition, the review evaluates the characterization of noise exposure in these studies; considers studies of classroom acoustics; describes current guidelines for the acoustical design of children's classrooms; and identifies current gaps in knowledge and future research priorities.

This review examines non-auditory effects of noise exposure: that is effects on human health which are not the direct result of sound energy. Non-auditory effects are less well established and accepted than the auditory effects of noise which are the direct result of sound energy, such as hearing loss. The review focuses on the non-auditory effect of noise on children's cognition and learning, as well as briefly summarizing other non-auditory effects on children's health.

As part of the literature review a total of 106 key documents were identified. These have been reviewed and an annotated bibliography prepared with abstracts. The annotated bibliography is presented in Appendix A to this report. In addition, a document catalog has been developed in tabular form identifying key elements of each document, namely:

> *Title, Date, Country, Location, Noise source, #Schools, #Classrooms, #Classes, #Students, School grades, Student performance measure, Noise measure, Research method, Data collection method, Analytical method, Citation, Finding, Suggested criteria, Notes.*

This document is presented in Appendix B.

2.1. Scope of the Review

This literature review summarizes the field of noise effects on children's cognitive performance and learning, describing the evidence for effects of noise on children's learning from research conducted over the past few decades, as well as recent developments in the field.

This is a narrative review, focusing on key studies in the field. The literature has been identified from searches of electronic databases including PubMed, IngentaConnect, Science Direct, Educational Resource Information Centre, Google Scholar, and the Acoustical Society of America Digital Library, as well as through searches of reference lists of papers, and searches of specific journals including 'Noise and Health' and the 'Journal of the Acoustical Society of America'. This strategy has been supplemented by the research teams' knowledge of existing reports and publications. The literature is predominantly drawn from Europe and the USA, with a focus on USA-relevant publications, where possible. The review also focuses on studies of aircraft noise exposure, where possible, but does draw on findings of other noise sources such as road traffic noise, where the evidence may be relevant for this project. For convenience, documents referred to in the review are listed at the end of this section.

This review considers the characterization of noise exposure in these studies; examines the findings of epidemiological studies which focus on chronic rather than acute noise exposure; considers studies of classroom acoustics; reviews current guidelines for the acoustical design of children's classrooms; and concludes by identifying current gaps in knowledge and future research priorities.

Article I. 2.2. Background to the Research Field

The direct effect of sound energy on human hearing is well established and accepted (Babisch, 2005; Kryter, 1985). Auditory impairments are typically seen in certain industrial occupations, hence protective legislation requiring hearing protectors to be worn. In contrast, non-auditory effects of noise on human health are not the direct result of sound energy. Instead these effects are the result of noise as a general stressor: thus the use of the term noise not sound: noise is unwanted sound. The non-auditory effects of noise are less well established and accepted than auditory effects. This review focuses on the non-auditory effect of noise on children's cognition and learning.

The effect of environmental noise exposure on children's cognitive performance and learning has been researched since the early 1970s. Typically, in more recent years, the effect of chronic noise exposure on children's cognition has been examined by methodologically robust epidemiological studies, while the effect of acute noise exposure has been examined in experimental, laboratory studies. It has been suggested that children may be especially vulnerable to effects of environmental noise as they may have less cognitive capacity to understand and anticipate environmental stressors, as well as a lack of developed coping repertoires (Stansfeld, Haines and Brown, 2000). Exposure during critical periods of learning at school could potentially impair development and have a lifelong effect on educational attainment.

Overall, evidence for the effects of noise on children's cognition has strengthened in recent years. There is increasing synthesis between epidemiological studies, with over twenty studies having shown detrimental effects of noise on children's memory and reading (Evans and Hygge, 2007). Most research has been carried out in primary school children aged 5 to 12 years. This is seen as a critical learning acquisition period for children in which future learning patterns are established. Studies have established that children exposed to noise at school experience some cognitive impairments, compared with children not exposed to noise: however, these effects are not uniform across all cognitive tasks (Cohen, Evans, Stokols, *et al*, 1986; Evans and Lepore, 1993; Evans, Kielwer and Martin, 1991). Tasks which involve central processing and language comprehension, such as reading, problem solving and memory appear to be most affected by exposure to noise (Cohen, Evans, Stokols, *et al*, 1986; Evans and Lepore, 1993; Evans, Hygge and Bullinger, 1995; Hygge, 1994). These are all tasks with high processing demands and the effect of environmental stressors on cognitive tasks with high processing demands is widely accepted in the environmental stress literature (Cohen, Evans, Stokols, *et al*, 1986; Smith, 1989).

Recent years have seen several methodological advancements in the field including the use of larger epidemiological community samples and better characterization of noise measurement. Evidence from longitudinal studies is beginning to emerge, and studies have started to examine exposure-effect relationships, to identify thresholds for noise effects on health and cognition which can be used to inform guidelines for noise exposure. There has also been a better assessment of confounding factors: noise exposure and cognition are often confounded by socioeconomic position; individuals living in poorer social circumstances are more likely to have poorer cognitive abilities, as well as be exposed to noise. Therefore, measures of socioeconomic position need to be taken into account when examining associations between noise exposure and health.

Article II. 2.3. The Assessment of Noise Exposure

Studies of noise effects on children's cognition typically use established metrics of external noise exposure, which indicate the average sound pressure for a specified period using dBA as the measurement unit (dBA is the unit of A-weighted sound pressure level where A-weighted means that the sound pressure levels in various frequency bands across the audible range have been weighted in accordance with differences in hearing sensitivity at different frequencies). Metrics typically employed are L_{eq16} and L_{day} which indicate noise exposure over a 16 hour daytime period usually 7am-11pm; L_{night} which indicates noise exposure at night (11pm-7am); and L_{dn} which combines the day and night measures to indicate average noise exposure over the 24 hour period, with a 10dB penalty added to the nighttime noise measure. In contemporary studies these metrics are usually modeled using standard airport noise modeling systems, using Geographical Information Systems to present the data, while older studies as well as some contemporary studies measure noise exposure in the community, which can be less reliable if measurements cover short time-periods. A few recent studies have also examined exposure to maximum noise levels (e.g. L_{max}), as in pathophysiological terms it is not known whether the overall 'dose' of noise exposure is important in determining effects on children's cognition or whether peak sound pressure events or the number of noise events might be important. This issue is of increasing importance given that the number of noise events for aircraft and road traffic noise are increasing, while noise emission levels per event are falling.

In the community, people are often exposed to sounds from more than one source. However, to date, studies tend to focus upon only one type of exposure such as road traffic or aircraft noise exposure. Studies that have examined exposure to more than one source (Lercher, Evans and Meis, 2003) have not been able to attribute cognitive effects to specific noise sources within the environment, limiting their relevance for policy formation or noise abatement.

Studies of the non-auditory effects of noise exposure typically use the term 'noise' to refer to the individual's exposure to sound. The term noise is used, regardless of whether the exposure is high or low: lower levels in particular may strictly be better described using the term sound, and the term noise implies that the sound exposure is unwanted and that it is an environmental stressor. This tradition is maintained throughout this literature review.

Article III. 2.4. The Effects of Noise Exposure on Children's Learning

2.4.1. Background

There is increasing synthesis between epidemiological studies, with many studies having shown detrimental effects of noise on children's memory and reading (Evans and Hygge, 2007). While a recent study suggests that children may not be more susceptible to environmental noise effects on cognitive performance than adults (Boman, Enmarker and Hygge, 2005), studies have established that children exposed to noise at school experience some cognitive impairments, compared with children not exposed to noise.

Overall, children exposed to chronic environmental noise have been found to have poorer auditory discrimination and speech perception (Cohen, Evans, Krantz, *et al*, 1980; Cohen, Evans, Stokols, *et al*, 1986; Cohen, Glass and Singer, 1973; Evans and Maxwell, 1997; Moch-Sibony, 1984): as well as poorer memory (Evans and Lepore, 1993; Hygge, 1994; Hygge, Evans and Bullinger, 2002; Stansfeld, Berglund, Clark, *et al*, 2005): deficits in sustained attention and visual attention (Hambrick-Dixon, 1986; Hambrick-Dixon, 1988; Moch-Sibony, 1984; Muller, Pfeiffer, Jilg, *et al*, 1998; Sanz, Garcia and Garcia, 1993): and poorer reading ability and school performance on national standardized tests (Bronzaft, 1981; Bronzaft and McCarthy, 1975; Clark, Martin, van Kempen, *et al*, 2006; Cohen, Glass and Singer, 1973; Eagan, Anderson, Nicholas, *et al*, 2004; Evans, Hygge and Bullinger, 1995; Evans and Maxwell, 1997; Green, Pasternack and Shore, 1982; Haines, Stansfeld, Brentnall, *et al*, 2001; Haines, Stansfeld, Head, *et al*, 2002; Haines, Stansfeld, Job, *et al*, 2001a; Lukas, DuPree and Swing, 1981). The following section discusses the historical development of the research field, highlighting seminal studies in the field and synthesizing the knowledge base.

2.4.2. Epidemiological Studies

(a) **2.4.2.1. The Early Studies.** This field of research in children was first investigated by Cohen and colleagues who carried out a naturalistic field study of elementary school children living in four 32-floor apartment buildings located near an expressway (Cohen, Glass and Singer, 1973). The sample of 73 children were tested for auditory discrimination and reading achievement. Children living on lower floors of the 32-storey buildings (i.e. exposed to higher road traffic noise levels) showed greater impairment of auditory discrimination and reading achievement than children living in higher-floor apartments.

Using a similar naturalistic paradigm Bronzaft and McCarthy (Bronzaft and McCarthy, 1975) compared reading scores of elementary school children who were taught in classrooms on the noisy side of a school near a railway line with the scores of the school children in classrooms on the quiet side of the same school. Children on the noisy side of the school building had poorer performance on the school achievement tests than those taught in classrooms on the quiet side of the school. The mean reading age of children in the classrooms on the noisy side of the school was 3 to 4 months behind the children in the low noise-exposed classrooms. The strength of this study is that the results cannot be attributed to self-selection of children into one school rather than another, a methodological problem found in many field studies. Neither could the results be explained by the selection of more able children into quieter classrooms, as children were not assigned in any systematic manner to classrooms on the noisy or quiet side of the school.

The first study to combine both cross-sectional and longitudinal analysis was a naturalistic study around Los Angeles Airport (Cohen, Evans, Krantz, *et al*, 1980; Cohen, Evans, Krantz, *et al*, 1981). This study found impaired performance on difficult cognitive tasks in primary school children aged 8-9 years. There was also an effect on motivation: after experiencing success or failure on a task, children exposed to chronic aircraft noise were less likely to solve a difficult puzzle and were more likely to give up. At follow-up one year later (Cohen, Evans, Krantz, *et al*, 1981) the finding that noise-exposed children were less likely to solve a difficult puzzle was replicated but the finding that the same children were more likely to give up on a difficult puzzle was not.

The first exposure-effect study was carried out by Green, *et al*. (Green, Pasternack and Shore, 1982) in New York, relating noise exposure scores based on noise exposure forecast contours for New York City Airports and relating that to the percentage of students reading below grade level between 1972 and 1976. The demonstration of exposure-effect relationships is an important element in confirming causal associations between noise and cognitive and health outcomes. The percent of students reading below grade level in each grade was regressed on noise exposure for each of the years 1972-76 and for all 5 years combined. Social disadvantage was adjusted for in terms of the percent eligible for free lunch programmes, along with adjustment for ethnic group, absentee admissions and departure rates, pupil-teacher ratio and teacher experience. The partial regression coefficients for the noise scale variables were all positive and were statistically significant at the 0.05 probability level in 15 of 18 regressions. A summary coefficient, with appropriate weighting, of 0.62 (95% Confidence Interval, CI, in 0.51-0.74) was estimated, suggesting that a one unit increase in noise score would be accompanied by an increase of 0.62% in the number of students reading one or more years below grade level in an average school. The authors described the data as largely compatible with a linear dose-response relationship between noise exposure and percent reading below grade level. The mean difference in the percent reading one or more years below grade level in the noisy schools, compared to the quietest schools, was 3.6% (95% CI 1.5-5.8).

There are several limitations to this study, the crudeness of the noise exposure scale, the possibility that pupils transfer from schools across noise zones and therefore, have a varied history of noise exposure, the crudeness of the variables used to assess confounding and the aggregate nature of the percentage reading below grade level outcome which fails to take into account individual differences in reading ability. Nevertheless, these results are striking and it could be argued that were the methodological errors soluble, the size of the effect would be likely to be larger, rather than smaller. This study was very much ahead of its time and another exposure-effect study was not conducted until the RANCH study in the early 2000’s (Stansfeld, Berglund, Clark, *et al*, 2005).

(b) **2.4.2.2. The Heathrow Studies.** A repeated measures field study carried out around Heathrow airport in London, partially confirmed the findings of Cohen et al’s (1980; 1981) study of Los Angeles airport. This study compared the cognitive performance of children aged 9-10 years, attending four schools exposed to high levels of aircraft noise (exterior levels >66 dB $L_{Aeq\ 16hr}$) with children attending four matched control schools exposed to lower levels of aircraft noise (<57 dB L_{Aeq16}) (Haines, Stansfeld, Job, *et al*, 2001a). Children tested at baseline were re-tested a year later at follow-up (Haines, Stansfeld, Job, *et al*, 2001b). The results indicated that chronic exposure to aircraft noise was associated with impaired reading comprehension and sustained attention after adjustment for age, main language spoken at home and household deprivation (Haines, Stansfeld, Job, *et al*, 2001a). The within subjects analysis at follow-up indicated that children’s development in reading comprehension may be adversely affected by chronic aircraft noise exposure (Haines, Stansfeld, Job, *et al*, 2001b). This study was followed by a larger study - The West London Schools Study (Haines, Stansfeld, Brentnall, *et al*, 2001) which compared the cognitive performance and stress responses of children in ten high-noise schools with that of children in ten matched control schools. The results indicated that children in the noise-exposed schools experienced greater annoyance and had poorer reading performance on the difficult items of a national standardized reading test.

A further multi-level modeling study of national standardized test scores (SATs) carried out around Heathrow airport (Haines, Stansfeld, Head, *et al*, 2002), examined test scores for 11,000 11-year-old children in relation to aircraft noise exposure contours for their school. The results showed that there was an exposure-effect relationship between noise exposure and performance on reading and math tests, but that this was influenced by socioeconomic factors. Overall, the evidence from the Heathrow studies is supportive of an effect of aircraft noise exposure on children's reading comprehension, suggesting that effects may not habituate over time and may be influenced by socioeconomic factors. While some previous studies have examined the role of socioeconomic factors and demonstrated an effect of noise on cognition over and above the influence of socioeconomic factors (Haines, Stansfeld, Job, *et al*, 2001a), other studies have not (Haines, Stansfeld, Brentnall, *et al*, 2001; Haines, Stansfeld, Job, *et al*, 2001b). Many studies have either failed to measure socioeconomic status adequately or have neglected to measure it at all, despite its potentially important role in the relationship between noise exposure and cognitive performance.

(c) **2.4.2.3. The Tyrol Mountain Study.** A recent cross-sectional study also found an effect of noise exposure on cognitive performance (Lercher, Evans and Meis, 2003). This study examined the effect of modest levels of ambient community noise (mainly train and road traffic noise) on the cognitive performance of 9-10-year-old children from rural Alpine areas. Half of the sample were from areas where ambient noise levels were below 50 dBA and half from areas where ambient noise levels were above 60 dBA; all children were tested in a sound-attenuated laboratory. Lercher and his colleagues found a significant effect of ambient noise exposure on memory, but no effect for attention; it is possible that the attention test was affected by a ceiling effect. The authors concluded that even relatively modest levels of exposure to community noise may be sufficient to have a detrimental effect on children's cognitive functioning.

(d) **2.4.2.4. The Munich Study.** Stronger evidence to suggest the existence of noise effects on cognitive performance comes from intervention studies and natural experiments where changes in noise exposure have been accompanied by changes in cognition. One of the most interesting and compelling studies in this field is the naturally occurring longitudinal quasi-experiment reported by Evans and colleagues, examining the effect of the relocation of Munich airport on children's health and cognition (Evans, Bullinger and Hygge, 1998; Evans, Hygge and Bullinger, 1995; Hygge, Evans and Bullinger, 2002). In 1992 the old Munich airport closed and was relocated. Prior to relocation, high noise exposure was associated with deficits in long-term memory and reading comprehension in children with a mean age of 10.8 years. Two years after the closure of the airport, these deficits disappeared, indicating that noise effects on cognition may be reversible if exposure to the noise ceases. Most convincing, was the finding that deficits in memory and reading comprehension developed over the 2 year follow-up for children who became newly noise exposed near the new airport: deficits were also observed in speech perception for the newly noise-exposed children. The Munich study is one of the few longitudinal studies in the field, providing important evidence for a cause-effect relationship between noise exposure and cognitive deficits.

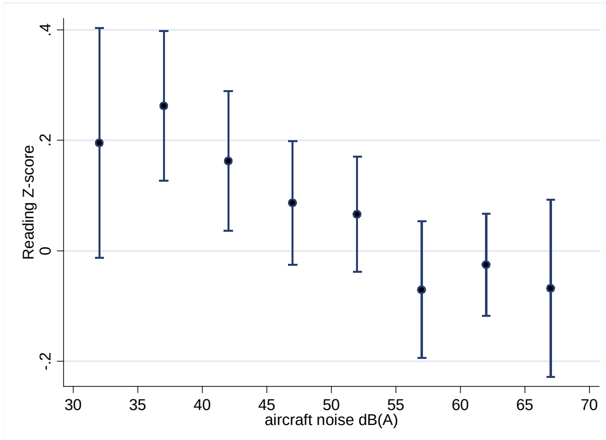
(e) **2.4.2.5. The RANCH Study.** While by the end of the 1990s, studies had demonstrated effects of noise exposure on children's cognition and learning, there were several significant limitations to the knowledge base. Firstly, little knowledge about exposure-effect relationships between noise and children's cognition was available, as studies had tended to compare the performance of children in high noise exposure with children in low noise exposure: thus limiting the range of noise exposures examined. Secondly, it had not been possible to compare the effect size across countries, due to the differing methodologies employed in each country and also the different noise metrics examined.

The RANCH study (Road traffic and Aircraft Noise exposure and children's Cognition and Health) (Clark, Martin, van Kempen, *et al*, 2006; Stansfeld, Berglund, Clark, *et al*, 2005), compared the effect of aircraft noise and road traffic noise on the cognition over 2000 9-10-year-old children attending 89 schools around three major airports in the Netherlands, Spain and the UK. This was the largest cross-sectional study of its type to date; was the first study to derive exposure-effect associations for a range of cognitive and health outcomes; and was the first to compare effect sizes across countries. Cognition (reading comprehension, recognition memory, conceptual recall, information recall, working memory and sustained attention) was measured using the same paper and pencil tests of cognition across the countries, administered in the classroom. Parents and children also completed questionnaires to obtain information about socioeconomic and demographic factors, and noise annoyance. The data were pooled and analyzed using multi-level modeling to take school-level variance into account.

The study found a linear exposure-effect relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account including mother's education, long-standing illness, the extent of classroom insulation against noise, and acute noise during testing (Stansfeld, Berglund, Clark, *et al*, 2005). No associations were observed between chronic road traffic noise exposure and cognition, with the exception of conceptual recall and information recall, which surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory: this is the largest study to date to examine attention and this finding contrasts with older studies which had shown effects (Cohen, Glass and Singer, 1973; Moch-Sibony, 1984). In terms of the magnitude of the effect of aircraft noise on reading comprehension, a 5 dB L_{eq16} increase in aircraft noise exposure was associated with a 2 month delay in reading age in the UK and a 1 month delay in the Netherlands (Clark, Martin, van Kempen, *et al*, 2006): this association remained after adjustment for aircraft noise annoyance and cognitive abilities including episodic memory, working memory and attention.

One further contribution of the RANCH study was that the exposure-effect associations identified between aircraft noise and reading comprehension and recognition memory, made it possible to start to quantify the magnitudes of noise induced impairments on children's cognition. Figure 2-1 shows the exposure-effect association between aircraft noise exposure and reading comprehension in the RANCH study (Stansfeld, Berglund, Clark, *et al*, 2005), which can be used to guide decision making by stakeholders and policy makers, as well as to estimate the benefits of noise reduction. This figure indicates that reading falls below average (a z score of 0) at exposures greater than 55 dBA: however, as the relationship between aircraft noise and reading comprehension was linear, reducing exposure at any level should lead to improvements in reading comprehension.

Another conclusion of the RANCH study was that while aircraft noise has only a small effect on reading comprehension, it was possible that children may be exposed to aircraft noise for many of their childhood years and the consequences of long-term noise exposure on reading comprehension and further cognitive development remain unknown. A follow-up of the UK RANCH sample is currently being analyzed, to examine the long-term effects of aircraft noise exposure at primary school on children's reading comprehension (Clark, Stansfeld and Head, 2009). Preliminary analysis indicates a trend for reading comprehension to be poorer at 15-16 years of age for children who attended noise-exposed primary schools. There was also a trend for reading comprehension to be poorer in aircraft noise-exposed secondary schools. However, further analyses adjusting for confounding factors are ongoing and are required to confirm these initial conclusions.



Reprinted from *The Lancet*, Vol. 365, Stansfeld, S. A., Berglund, B., Clark, C., pp. 1942-1949, 2005 with permission from Elsevier.

Figure 2-1. RANCH study adjusted mean reading Z score (95% Confidence Intervals) for 5 dBA bands of annual aircraft noise exposure at school (adjusted for age, sex and country) (Clark, Martin, van Kempen, et al, 2006; Stansfeld, Berglund, Clark, et al, 2005).

[NB: reading comprehension was measured using a z score which has a mean score of 0 and a standard deviation of 1].

(c) **2.4.2.6. The FICAN Pilot Study.** The Federal Interagency Committee on Aviation Noise (FICAN) recently funded a novel pilot study which assessed the relationship between aircraft noise reduction and standardized test scores (Eagan, Anderson, Nicholas, *et al*, 2004; FICAN, 2007). The study evaluated whether abrupt aircraft noise reduction within classrooms, caused either by airport closure or newly implemented sound insulation, was associated with improvements in test scores, in 35 public schools near three US airports in Illinois and Texas. This study is one of the only recent studies to examine the effectiveness of school sound insulation programmes as few intervention studies have been carried out (Bronzaft, 1981; Cohen, Evans, Krantz, *et al*, 1981).

This study is novel as it assesses noise exposure using a number of different metrics to compare the associations between different metrics and learning outcomes. This study examined L_{eq} [the indoor equivalent sound level averaged over the 9-hour school day]; a Speech Intelligibility Index (SII) [the number of events disrupting indoor speech ANEv<0.98SII – disruption of 1% of words]; and Speech Interference Level (SIL), which was assessed by the number of events above 40dBA disrupting indoor speech – ANEv>40SIL, and by the fraction of time speech is disrupted above 40dBA. However, it is important to note for comparison purposes that this study relies on computed noise exposure metrics, which were converted to **indoor values**; this makes comparison with other studies difficult, as most studies in this field use outdoor exposure values or computed metrics to assess effects on children's learning. Children's learning outcomes assessed from standardized tests scores included the percentage of students with the worst test grade; the average numerical score; and the percentage of students with the best test grade. Class averaged scores on these tests after one year of schooling following noise reduction were compared with scores in the years prior to noise reduction.

After adjusting for demographic and school construction factors, the study found a significant association between noise reduction and a decrease in failure rates but only for high school students and not middle or elementary school students: conversely, there were some weaker associations between noise reduction and an increase in failure rates for middle and elementary schools. For high school students, when the time exposed to over 40 dBA was reduced by 5%, the failure rate decreased by 20%. The study also found a significant association between noise reduction and average test scores for high school, middle, and elementary school students: average test scores increased by 7-9% when the average time exposed over 40dBA was decreased by 5%. When the number of events with L_{Amax} greater than 40dB was examined, middle and elementary school students showed modest improvements in average score, between 4-5% when the number of events decreased by 20, while for high school students a reduction in the number of events was associated with poorer average scores, between 17-19%. Overall the study found that the associations observed were similar for children with or without learning difficulties, and between verbal and math/science tests.

Overall, this small scale study does find some evidence for effects of aircraft noise reduction and improved test results, although it must be acknowledged that some associations were null and some associations were not in the direction hypothesized. This was a pilot study and the authors stress that the airports and schools selected for the study may not be representative; that further, larger studies are required; that future studies should utilise airport data for noise exposure assessment; and that outdoor-to-indoor noise measurements at each school should be considered.

2.4.3. Mechanisms

The findings of studies of noise effects on children's cognitive performance suggest that noise may directly affect reading comprehension or that noise effects could be accounted for by other mechanisms including teacher and pupil frustration (Evans and Lepore, 1993), learned helplessness (Evans and Stecker, 2004) and impaired attention (Cohen, Glass and Singer, 1973; Evans and Lepore, 1993).

Noise exposure can cause arousal, which improves performance on simple tasks but impairs performance on complex tasks (Yerkes and Dodson, 1908). Further, noise could restrict attention during complex tasks. Typically, it has been assumed that children may adapt to noise interference during activities by filtering out unwanted noise stimuli (Cohen, Evans, Stokols, *et al*, 1986). This 'tuning out' strategy may over generalize to situations where noise is not present such that children tune out indiscriminately. Thus, they may tune out when they should be listening to important information. The presence of this tuning out response is supported by the finding of some older studies that children exposed to noise have deficits in attention, auditory discrimination and speech perception (Cohen, Glass and Singer, 1973; Evans, Hygge and Bullinger, 1995; Moch-Sibony, 1984). However, there is evidence from more recent studies that sustained attention is not impaired by aircraft noise (Haines, Stansfeld, Job, *et al*, 2001b; Stansfeld, Berglund, Clark, *et al*, 2005) and that noise effects on cognition are not mediated by impairment of attention (Hygge, Boman and Enmarker, 2003).

Another possibility is that noise interferes in the interactions between teachers and pupils. Teacher frustration and interruptions in communication between teachers and children could also be a mechanism for cognitive effects (Evans, Kielwer and Martin, 1991). In the noisiest schools teachers may have to stop teaching while aircraft fly over and if this is frequent it may contribute to interruptions in communication and fatigue in teachers and children and to a reduction of morale and motivation in teachers.

A further mechanism which has been proposed is that of learned helplessness, which is when children do not perceive themselves to be in control of their environment. This could be a mechanism that accounts for deficits in motivation in children exposed to noise (Cohen, Evans, Krantz, *et al*, 1980; Evans, Hygge and Bullinger, 1995). Certainly in both the earlier Los Angeles studies and in the Munich study children exposed to high levels of aircraft noise, did not persist as long as children not exposed to noise, at difficult standard puzzles (Cohen, Evans, Krantz, *et al*, 1980; Evans, Hygge and Bullinger, 1995), which is suggestive of learned helplessness.

Noise also causes annoyance, especially if an individual feels their activities are being disturbed or if it causes difficulties with communication. In some individuals, this annoyance may lead to stress responses. Although the recent FICAN pilot study speculated that impaired learning may result from noise stress (Eagan, Anderson, Nicholas, *et al*, 2004) at present there is little evidence to directly support the annoyance pathway as a mechanism for effects on cognition.

Another pathway for the effect of noise on cognition which has been considered is that of sleep disturbance caused by noise exposure at home. Where catchment areas for schools are fairly small, there is a strong correlation between home and school aircraft noise exposure (Clark, Martin, van Kempen, *et al*, 2006). Sleep disturbance can impact on well-being causing annoyance, irritation, low mood, fatigue, and impaired task performance (HCN, 2004). Overall few studies have examined sleep disturbance as a mediator of noise effects on cognitive performance. A recent analysis of the cross-sectional Munich and RANCH datasets found that self-reported sleep disturbance did not mediate the association of aircraft noise exposure and cognitive impairment in children (Stansfeld, Hygge, Clark, *et al*, In press). Future studies should examine this pathway further and include both subjective and objective assessments of sleep disturbance.

Experimental studies have tried to develop a greater understanding of how cognitive processes are affected by noise. A series of recent papers (Boman, Enmarker and Hygge, 2005; Enmarker, Boman and Hygge, 2006; Hygge, Boman and Enmarker, 2003) all exploit the same experimental data where participants from four age groups (13-14y, 18-20y, 35-45y, and 55-65y) completed 18 memory tests, covering episodic and semantic systems in declarative memory, while exposed to one of three noise conditions: meaningful but irrelevant speech (speech that has meaning but is not relevant to the subject under review), road traffic noise or quiet. In terms of noise effects on performance, both road traffic noise and meaningful irrelevant speech had a similar effect on task performance and noise effects were strongest for memory of texts, followed by episodic and semantic memory tasks (Boman, Enmarker and Hygge, 2005; Hygge, Boman and Enmarker, 2003). These findings suggested that noise may affect memory by impairing the quality with which information is rehearsed or stored in memory (Hygge, Boman and Enmarker, 2003). However, a later paper, (Enmarker, Boman and Hygge, 2006) found that noise exposure did not alter the structure of different aspects of declarative memory, suggesting that noise was not influencing performance via a change in resource allocation or strategy.

Overall, several plausible pathways and mechanisms for the effects of noise on children's cognition have been put forward, but in general evidence for these mechanisms is fairly sparse.

2.4.4. Classroom Acoustics and Children's Performance

(g) **2.4.4.1. Background.** Only 6 years ago, Lubman and Sutherland (Lubman and Sutherland, 2004) suggested that there was an unawareness of the educational impact of poor school acoustics, and the joint assessment of classroom acoustics and children's learning outcomes is a fairly recent development in the field. The past few years have seen the publication of several papers examining the role of classroom acoustics in noise effects on cognition (Astolfi and Pellerey, 2008; Bradley and Sato, 2008; de Oliveira Nunes and Sattler, 2006; Dockrell and Shield, 2004; Dockrell and Shield, 2006; Sato and Bradley, 2008; Shield and Dockrell, 2004; Shield and Dockrell, 2008). These studies typically focus upon noise interference with verbal communication as the mechanism for the effect: some studies simply describe the acoustic characteristics of classrooms, some specifically assess speech intelligibility, and a few relate acoustic conditions to performance outcomes.

2.4.4.2. Acoustic Characteristics of Classrooms. Several studies have attempted to identify which acoustical factors may contribute to poor room acoustics in educational facilities (Bradley, 1986; Bradley and Sato, 2008; Houtgast, 1981; Picard and Bradley, 2001; Sato and Bradley, 2008; Yang and Bradley, 2009). Research has typically focused on the effects of noise levels, reverberation times, and the speech-to-noise ratio on speech intelligibility within classrooms. A review of the field, suggests that younger children require quieter conditions for optimum speech intelligibility, leading the authors to suggest that students aged 6-7 years would require maximum ambient sound levels in occupied classrooms of 28.5 dBA, rising to 34.5 dBA for 8-9 year olds, to 39 dBA for 10-11 year olds, and to 40 dBA for students aged 12 years or older (Picard and Bradley, 2001). Picard and Bradley also concluded that reverberation time was less important than sound levels, with $RT_{1\ kHz}$ around 0.5 seconds being optimum in occupied classrooms: along with speech-to-noise ratios of 15dBA. Another important issue to take into account when considering noise effects on children's learning and classroom acoustics is that speech intelligibility may vary with age. A recent study, proposes that the suggested 15 dBA speech-to-noise ratio may not be adequate for younger children (Bradley and Sato, 2008) as children's ability to recognize speech in noise improves with age, leading to the suggestion that 6-year-old children require 7 dBA higher speech-to-noise values to achieve the same speech intelligibility scores as 11 year olds. Younger children are also less likely to have the benefit of increased intelligibility in situations where reverberation times are decreased (Picard and Bradley, 2001; Yang and Bradley, 2009).

However, as argued by Picard and Bradley, noise levels in classrooms are often in excess of these optimum conditions leading to problems with speech perception. A recent US study found that ambient noise levels in unoccupied classrooms ranged between 38 and 55 dBA and that occupied reverberation times ranged between 0.3 to 1.1 seconds (Bowden, Wang and Bradley, 2004). In terms of occupied classrooms, a study of Canadian elementary school classrooms found that on average students experienced sound levels of 49.1 dBA, teacher speech levels of 60.4 dBA, and a mean speech-to-noise ratio of 11 dBA during teaching activities (Sato and Bradley, 2008).

(h) **2.4.4.3. Associations between Classroom Acoustics and Performance.** Following on from their studies of classroom acoustics in the UK (Dockrell and Shield, 2004; Shield and Dockrell, 2004), examined the associations between classroom acoustics and the performance of primary school children on a series of verbal literacy and non-verbal speed tasks (Dockrell and Shield, 2006). Children completed the tasks under one of three experimental conditions; quiet, babble (noise of children at 65dB L_{eq}), or babble and environmental noise (65dB L_{eq}). Noise affected verbal and non-verbal performance in different ways: non-verbal processing tasks were performed significantly more poorly by those exposed to babble and environmental noise, while the verbal literacy tasks were performed most poorly by those exposed to the babble noise. Children with special education needs performed differently in noise compared with the rest of the sample: they had poorer performance on the verbal tasks in the babble condition, but better performance on the non-verbal tasks in babble.

A recent further study has confirmed associations between external and internal noise exposure at school and the results of national tests for children aged 7-11 years attending London primary schools (Shield and Dockrell, 2008). External noise showed a larger effect on the performance of older children and L_{max} showed the strongest association with test scores, suggesting that individual noise events may play an important role on performance effects. The latter finding is also supported by another study which found that pupil's subjective assessments of noise disturbance and noise intensity showed a stronger relationship with L_{max} than with L_{eq} or L_{90} noise measurements (Astolfi and Pellerey, 2008). Astolfi and Pellerey concluded that pupils seem to be disturbed more by intermittent loud noises than by constant noise.

Article IV. 2.5. Current Guidelines for Acoustics in Children's Classrooms

Several guidelines for both internal and external noise exposure at children's schools have been proposed in recent years in the US and across Europe. The majority of these are guidelines which are not statutory and most specify noise limits for ambient environmental noise, rather than specifying limits for specific noise sources such as aircraft or road traffic noise. This section summarizes relevant international, American, and European guidelines.

One of the most influential and foremost guidelines tackling the effects of noise exposure on human health are the World Health Organization (WHO) Community Noise Guidelines (WHO, 2000). These international guidelines specify that for pre-school and school classrooms, internal sound levels should not exceed 35 dB L_{Aeq} during class time and that outdoor levels in school playgrounds should not exceed 55 dB L_{Aeq} during play. These guidelines are often cited, but are felt by many acousticians to be unachievable, given the extremely low level of sound specified for occupied classrooms.

The American National Standards Institute (ANSI) specified a standard for school acoustics in 2002 (ANSI, 2002), which is voluntary not mandatory. The standard specifies a 35 dBA internal background noise limit for unoccupied classrooms: this level was chosen to achieve a minimum 15dB speech-to-noise ratio at the back of the classroom. The standard also specifies a 0.6 s reverberation time for classrooms < $283m^3$, rising to 0.7 s for classrooms > $283m^3$ to $566m^3$ and that intermittent noise should not exceed 40 dBA. The ANSI standard is supported by the Acoustical Society of America and INCE-USA (Lubman and Sutherland, 2004) and it is estimated that two-thirds of American classrooms fail to meet the specified 35 dBA background noise limit (Lubman and Sutherland, 2004). While the WHO and the ANSI guidelines both specify a maximum sound level of 35 dBA, it should be noted that for ANSI guidelines this is for unoccupied classrooms, while for the WHO guidelines this is for occupied classrooms. This difference reflects a more pragmatic approach by the ANSI standard. The 35 dBA ANSI standard is also in agreement with the work of Bradley and colleagues on optimum classroom acoustics (Bradley and Sato, 2008). The ANSI guideline was reviewed in 2010 and the requirement that intermittent noise should not exceed 40 dBA was removed from the revised standard (ANSI 2010).

There are no Europe-wide guidelines for children's noise exposure. However, under the EU Noise Directive (2002/49/EC), European countries can prepare noise action plans or include noise reduction in national environment and health plans (Bistrup, Haines, Hygge, *et al*, 2002). Many European countries, such as Sweden, the UK, Germany, and the Netherlands, have issued guidance on safe levels for noise exposure outside and inside schools but all recommended levels for external noise exposure are guidelines and cannot be mandated. Within Europe, the recommended external environmental noise level for schools ranges from 50 – 60 L_{eq} dB. For example, in the Netherlands the Noise Nuisance Act suggests that dwellings, schools, and hospitals should be exposed to indoor levels no greater than 35 dBA $L_{corrected,\ 24h}$ and outdoor levels no greater than 50 dBA $L_{corrected,\ 24h}$. The Environmental Management Act 1998 also specifies that between 7am and 7pm noise levels outside of schools should not exceed 50 dBA and inside should not exceed 35 dBA. Building regulations further stipulate that the average reverberation time in a classroom should not exceed 1.0 second.

Standards for classroom acoustics are also available in some European countries. For example, in the UK Building Bulletin 93 (BB93) was introduced to govern the acoustical design on newly built schools and school building extensions (DfES, 2004). BB93 stipulates that in unoccupied primary and secondary school classrooms internal ambient noise levels should not exceed 35 dB $L_{eq,\ 30\ min}$. Reverberation times should not exceed 0.6 seconds and 0.8seconds for primary and secondary school classrooms, respectively. These regulations are compulsory for new school buildings.

Article V. 2.6. Non-Auditory Effects on Children's Health

2.6.1. Background

While the focus of this review is on noise effects on children's cognition and learning, other non-auditory effects on children's health have been researched, including noise annoyance, psychological health, physiological function, and sleep disturbance. Noise could indirectly influence health in several ways. Acute noise exposure directly causes a number of predictable short-term physiological responses including increased blood pressure and endocrine outputs and it is proposed that chronic noise exposure may cause a longer-term activation of these responses resulting in subsequent symptoms and illness. Alternatively, if the noise levels are sufficiently high to cause significant annoyance, then it may be annoyance itself that activates these physiological responses. In some individuals noise annoyance may lead to stress responses and subsequent symptoms and illness. This section presents a brief overview of research in this field, summarizing the current strength of the evidence for the effects of aircraft noise on child health outcomes.

2.6.2. Noise Effects on Children's Health

(a) **2.6.2.1. Noise Annoyance.** Noise annoyance is a multifaceted psychological concept including both evaluative and behavioural components used to describe negative reactions to noise (Guski, Schuemer and Felscher-Shur, 1999). Annoyance is an important health effect of noise (WHO, 2000) and is often the primary outcome used to evaluate the effect of noise on communities. Noise annoyance is a widely observed response to noise and this has also been examined with particular reference to children's noise annoyance. Studies have consistently found evidence that exposure to chronic environmental noise causes annoyance in children (Bronzaft and McCarthy, 1975; Evans, Hygge and Bullinger, 1995). In the Munich Airport study noise-exposed children were found to be more annoyed by noise as indexed by a calibrated community measure (Evans, Hygge and Bullinger, 1995). In London, child-adapted standard self-report questions (Fields, de Jong and Brown, 1997) were used to assess annoyance showing higher annoyance levels in noise-exposed children (Haines, Stansfeld, Brentnall, *et al*, 2001). In a follow-up one year later the same result was found suggesting that annoyance effects were not subject to habituation (Haines, Stansfeld, Job, *et al*, 2001b).

Studies have derived exposure-effect associations for the effects of aircraft and road traffic noise for adults (Midema and Oudshoorn, 2001) and the recent RANCH study derived exposure-effect relationships for children examining aircraft noise and road traffic noise (van Kempen, Lopez Barrio, Haines, *et al*, 2009). This study predicted for aircraft noise an increase in the percentage of severely annoyed children of around 5.1% at 50 dB to around 12.1% at 60 dB.

The extent to which noise is found to be annoying appears to depend upon the extent to which the noise interferes with the activity in progress. Thus, activities involving speech communication such as conversation, watching television, or listening to the radio are the activities most disturbed by aircraft noise (Hall, Taylor and Birnie, 1985), thus annoyance could be an important end-point to consider in effects of aircraft noise on children's learning. The RANCH study found that aircraft noise annoyance reduced the effect of aircraft noise exposure on reading comprehension to some extent, suggesting that noise annoyance may play a role in the mechanism for noise effects on reading comprehension (Clark, Martin, van Kempen, *et al*, 2006).

(b) **2.6.2.2. Psychological Health.** Given the effect of chronic noise exposure on annoyance responses, it has been proposed that chronic noise exposure could have an effect on psychological health, as prolonged annoyance could lead to poor psychological health (McLean and Tarnopolsky, 1977).

Several studies have examined associations between noise exposure and children's psychological health. The Tyrol Mountain study compared child and teacher ratings of psychological health for children exposed to ambient noise either <50 dBA L_{dn} or > 60 dBA L_{dn} (Lercher, Evans, Meis, *et al*, 2002). Ambient noise was associated with teacher ratings of psychological health but was only associated with child rated psychological health for children who also had early biological risk which was defined as low birth weight and/or premature birth. The West London School study of children attending schools near Heathrow airport also found that children who were exposed to aircraft noise had higher levels of psychological distress, as well as a higher prevalence of hyperactivity (Haines, Stansfeld, Brentnall, *et al*, 2001). However, the RANCH study only partially replicated the West London School study findings in a larger sample drawn from the United Kingdom, the Netherlands, and Spain. While no associations were observed between either aircraft noise or road traffic noise and psychological distress, the association between aircraft noise exposure and hyperactivity was replicated (Stansfeld, Clark, Cameron, *et al*, 2009).

As with studies of adults, overall the evidence suggests that chronic noise exposure is probably not associated with serious psychological illness and disorder but there may be effects on well-being and quality of life. This conclusion is however limited by the lack of longitudinal research in the field. Also few studies examine psychiatric diagnoses. Other research needs include the further exploration of whether hyperactive children are more susceptible to stimulating environmental stressors such as aircraft noise.

(c) **2.6.2.3. Coronary Risk Factors.** Recent years have seen a strengthening of evidence for effects of chronic noise exposure on adult cardiovascular outcomes such as hypertension and coronary heart disease (Babisch, 2006; Jarup, Babisch, Houthuijs, *et al*, 2008). A meta-analysis of adult studies suggests that a 5 dBA increase in noise is associated with a 25% increase in risk of hypertension compared with those not exposed to noise (Van Kempen, Kruize, Boshuizen, *et al*, 2002).

However, epidemiological evidence for effects of noise on coronary risk factors for children is mixed. There is some evidence that chronic noise exposure may give rise to physiological effects in children in terms of raised blood pressure. In the Los Angeles Airport Study (Cohen, Evans, Krantz, *et al*, 1980), chronic exposure to aircraft noise was found to be associated with raised systolic and diastolic blood pressure. However, these increases although significant were within the normal range and were not indicative of hypertension. At follow-up a year later (Cohen, Evans, Krantz, *et al*, 1981) the findings were the same showing that these effects had not habituated. In the Munich study chronic noise exposure was found to be associated with both baseline systolic blood pressure and lower reactivity of systolic blood pressure to a cognitive task presented under acute noise (Evans, Hygge and Bullinger, 1995; Hygge, Evans and Bullinger, 2002). After the new airport opened a significant increase in systolic blood pressure was observed providing evidence for a causal link between chronic noise exposure and raised blood pressure (Hygge, Evans and Bullinger, 2002). No association was found between noise and diastolic blood pressure or reactivity. The RANCH study of 9-10-year-old children's blood pressure around Schiphol and Heathrow airports found an effect of aircraft noise at home, as well as nighttime aircraft noise exposure on systolic and diastolic blood pressure but no effect for aircraft noise at school (van Kempen, Van Kamp, Fischer, *et al*, 2006). These findings suggest that it may be aircraft noise exposure in the evening and at night that are important for effects on children's blood pressure. Overall, the evidence for noise effects on blood pressure is mixed and further research is required before conclusions can be drawn about noise effects on children's blood pressure.

(d) **2.6.2.4. Stress Hormones.** Studies have examined the effect of chronic noise exposure on adrenaline, noradrenaline, and cortisol, all of which are released by the adrenal glands in situations of stress. Studies of noise effects on stress hormones typically have fairly small sample sizes. A further methodological limitation to these studies is that these stress hormones are notoriously difficult to assess, as urinary and salivary measures of these hormones are easily influenced by other unmeasured factors. For example, cortisol has a diurnal variation and is usually high in the morning and low in the evening, making it difficult to measure effectively.

Several airport noise studies have assessed the effects of noise on children's endocrine disturbance. The Munich Airport study (Evans, Bullinger and Hygge, 1998; Evans, Hygge and Bullinger, 1995) examined overnight, resting levels of urinary adrenaline and noradrenaline. In the cross-sectional study at the old airport endocrine levels were significantly higher in the noise-exposed children, indicating raised stress levels. The longitudinal data also revealed a sharp increase in adrenaline and noradrenaline levels in noise-exposed children following the opening of the new airport. Cortisol levels were also examined but no significant differences were observed in either the cross-sectional or longitudinal data. This latter finding is consistent with the findings of the Heathrow Studies (Haines, Stansfeld, Brentnall, *et al*, 2001; Haines, Stansfeld, Job, *et al*, 2001a) which found no association between aircraft noise exposure above 66 dB L_{Aeq16} and morning salivary cortisol measures (Haines, Stansfeld, Job, *et al*, 2001a), nor between aircraft noise exposure above 62 dB L_{Aeq16} and twelve hour urinary cortisol, adrenaline and noradrenaline measures (Haines, Stansfeld, Brentnall, *et al*, 2001).

Overall further studies of this field are required to clarify where effects may be observed between chronic aircraft noise exposure and stress hormones. The pathway for such effects also needs further clarification: there is a lack of understanding about whether raised endocrine responses represent normal short-term responses to environmental stress or whether they represent longer-term activation of the endocrine system. If they represent the latter, there is also a lack of understanding about how long-term activation of the endocrine system links to health impairment and whether endocrine responses can habituate to noise exposure.

(e) **2.6.2.5. Sleep Disturbance.** Exposure to nighttime noise can potentially interfere with the ability to fall asleep, shorten sleep duration, cause awakenings and reduced the perceived quality of sleep (Michaud, Fidell, Pearsons, *et al*, 2007), which could influence well-being causing annoyance, irritation, fatigue, low mood and impaired task performance (HCN, 2004). Recent reviews of evidence for noise effects on sleep disturbance in adults are available (Michaud, Fidell, Pearsons, *et al*, 2007; Midema and Vos, 2007) yet few studies of the effects of noise on sleep disturbance have included children.

A sub-study of the RANCH study in a Swedish sample used sleep logs and actigraphy to compare the effect of road traffic noise on child and parent sleep, finding an exposure-effect relationship between noise exposure and sleep quality and daytime sleepiness for children and an exposure-effect relationship between noise and sleep quality, awakenings and perceived interference from noise for parents (Ohrstrom, Hadzibajramovic, Holmes, *et al*, 2006). While the findings of this study are suggestive of effects of noise exposure on children's sleep disturbance, it is difficult to generalize from one Swedish study, where road traffic noise may not be as high as that found in other cities. In addition, longitudinal data is needed to confirm causal associations between noise exposure and sleep disturbance, as well as between noise exposure, sleep disturbance, and well-being related outcomes. Specific studies focusing on aircraft noise and children's sleep disturbance are required. While the Munich and RANCH studies found that self-reported sleep disturbance did not mediate the association of aircraft noise exposure and cognitive impairment in children (Stansfeld, Hygge, Clark, *et al*, In press): whether the same results would be found with objective measures of sleep disturbances remains to be answered.

Sleep disturbance could be an important issue to consider further in future studies of the effects of aircraft noise on children's learning.

2.7. Summary of the Noise Effects on Children's Cognition and Learning

The effect of environmental noise exposure on children's cognitive performance and learning has been researched since the early 1970s. Studies are predominantly cross-sectional, examining associations between noise exposure at school and children's cognitive performance or learning outcomes. Studies tend to focus on one type of noise exposure such as aircraft noise or road traffic noise. There are only a few longitudinal studies, some of which are before-and-after studies assessing naturalistic changes in noise exposure via insulation programmes or airport closures. To understand the causal pathways between noise exposure and learning, and design preventive interventions, there is a need to study associations longitudinally. Recent advancements in the field include the use of larger-scale epidemiological community samples and better characterization of noise measurement.

Studies of noise effects on children's cognition typically use established metrics of external noise exposure, such as L_{eq16} which indicates average noise exposure in dBA over a 16 hour daytime period. Studies of noise effects on children's learning typically measure noise exposure but some recent studies model exposure using Geographical Information Systems.

Overall, evidence for the effects of noise, and in particular aircraft noise, has strengthened and synthesized in recent years, with many studies demonstrating that children exposed to chronic aircraft noise exposure at school have poorer reading comprehension and memory than children who are not exposed. This evidence is predominantly cross-sectional but has also been confirmed with longitudinal data. Similarly, studies have shown that children who are exposed to chronic aircraft noise at school perform more poorly than their non-noise-exposed counterparts on nationally standardized tests.

Demonstrating exposure-effect relationships between aircraft noise exposure and children's cognition and learning is important for confirming causal associations between noise and cognition as well as for identifying thresholds for the effects. To date, only two studies have examined exposure-effect relationships: both suggest a linear relationship between aircraft noise exposure and children's cognition. The most recent study suggests that reading comprehension begins to fall below average at aircraft noise exposure greater than 55 dB L_{eq16} but as the association is linear, any reduction in aircraft noise exposure should improve reading comprehension.

Few studies have examined the influence of noise abatement, via insulation schemes or airport relocation, on children's learning and cognition. Overall, these studies suggest that a reduction of noise exposure can eliminate previously observed cognitive deficits associated with noise but further studies in this area remain a priority.

2.7.1. Mechanisms

Aircraft noise could directly influence cognitive skills such as reading comprehension, or noise effects could be accounted for by other mechanisms including teacher and pupil frustration and communication difficulties, learned helplessness, impaired attention, impaired memory, and noise annoyance. In general, research evidence for most of these mechanisms is quite limited.

2.7.2. Classroom Acoustics and Guidelines

Recent years have seen research begin to explore the link between classroom acoustics and children's learning outcomes. Research has focused on internal noise levels, reverberation times, and speech-to-noise ratios as important determinants of speech intelligibility within classrooms. Interestingly, younger children may require quieter conditions for optimum speech intelligibility compared with older children. Some recent studies have shown associations between classroom acoustics and performance on individually completed cognitive tests, as well as on nationally standardized tests.

Guidelines for internal and external noise exposure at children's schools exist in the US and in Europe. The majority of these guidelines are not statutory and suggest noise levels that apply to ambient environmental noise, rather than specific noise sources per se. Of particular relevance to the current project, is the ANSI standard for school acoustics (ANSI 2010), a voluntary code which specifies 35 dBA as a background noise limit for unoccupied classrooms and reverberation times between 0.6 seconds to 0.7 seconds depending upon the size of the classroom.

2.7.3. Noise Effects on Children's Health

There is also evidence for non-auditory effects of noise on children's health. Evidence for the effect of aircraft noise on children's annoyance responses is convincing, while evidence for effects on children's psychological symptoms, blood pressure, stress hormones, and sleep disturbance is more moderate and would benefit from further and longitudinal study in child samples.

CHAPTER 3. GAPS IN KNOWLEDGE AND FUTURE RESEARCH

3.1. Summary of Research Findings

The previous section of this report provides a critical review and evaluation of research conducted on the effect of noise on children's cognitive performance and learning, with emphasis on the effects of aircraft noise. From this review, it is now possible to identify the gaps in knowledge on solutions to the child learning problem that can form the basis of a research plan to meet the specific objectives of this project, namely:

1. Identify and evaluate conditions under which aircraft noise affects student learning.
2. Identify suitable noise metrics that best define those conditions.
3. Identify the most effective of the current criteria for school sound insulation projects.

The gaps in knowledge to be identified will be those germane to these objectives and to the type of mitigation actions available to airport authorities.

The most expedient way to identify gaps in knowledge is by setting forth a list of questions that need to be answered, and examining the scientific literature for answers to those questions. Potential gaps in knowledge will then be determined by the extent to which the literature cannot answer the questions. The questions that we will use in this evaluation are as follows:

1. To what extent is student learning affected by aircraft noise?
2. What is the most appropriate noise metric for describing aircraft noise as it affects learning?
3. What is the threshold above which the effect is observable?
4. Has sound insulation meeting existing classroom criteria improved student performance?
5. How does aircraft noise effect learning for students with different characteristics?

The findings related to these questions that are offered by the scientific literature reviewed in Chapter 2 are presented in Table C.1 of Appendix C. The same scientific literature also recommends areas of further research, from which gaps in knowledge can be identified with respect to the above questions and the objectives of this project. These recommendations are listed in Table C.2 of Appendix C.

3.2. Summary of Gaps in Knowledge

The summary of research findings and listing of the gaps in knowledge germane to the research objectives of this project can be summarized as follows:

To what extent is student learning affected by aircraft noise?

Developing further knowledge about exposure-effect relationships will inform decisions concerning the design of physical, educational, and psychological interventions for children exposed to high levels of noise. Such relationships can be assessed using either individually collected cognitive performance data or via school-level test data.

Whereas previous studies have demonstrated effects of chronic aircraft noise exposure on children's reading comprehension and memory, it must be acknowledged that the majority of the evidence comes from cross-sectional studies. The development of cognitive abilities such as reading are important not only in terms of educational achievement but also for subsequent life chances and adult health (Kuh and Ben-Shlomo, 2004). To understand the causal pathways between noise exposure and cognition, and design preventive interventions there is a need to study these associations longitudinally. Few longitudinal studies have examined the effects of persistent exposure throughout the child's education: studies of the long-term consequences of noise exposure during school for later cognitive development and educational outcomes have not yet been conducted and remain of prime policy importance.

What is the most appropriate noise metric for describing aircraft noise as it affects learning?

By far the majority of recent studies have relied on the established metric of average external noise exposure, L_{Aeq}, with the average taken over an 8-hour school day or over 16 daytime hours. While average exposure metrics demonstrate effects on children's learning little is known about the effect of the number of noise events or the importance of peak sound events in noise effects on children's learning. Two recent studies have suggested that peak sound events and the number of noise events could be important (Astolfi and Pellerey, 2008; Shield and Dockrell, 2008). Future studies should incorporate a range of additional noise metrics and examine their associations with children's learning and cognitive performance to explore noise characterization in more detail. Such studies could also be informative for examining mechanisms for effects.

What is the threshold above which the effect is observable?

Recent evidence of exposure-effect relationships between aircraft noise exposure and children's cognition has provided knowledge about thresholds for effects, further informing the design of interventions for children exposed to high levels of aircraft noise. Further examination of exposure-effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics remains a research priority.

Has insulation meeting existing classroom acoustic criteria improved student achievement?

Given the evidence that aircraft noise is related to impairment of school performance, the question of what can be done to reduce noise induced learning impairments becomes salient. One possibility is reduction of external sound in the classroom through sound insulation. However, there has been little research testing whether sound insulation of classrooms might lessen the effects of aircraft noise on children's learning (Bronzaft, 1981). While the recent FICAN study addressed this issue (Eagan, Anderson, Nicholas, *et al*, 2004), it was carried out on a small sample of schools which may not be representative. Future research needs to examine whether learning impairments related to aircraft noise can be reduced by sound insulation of the classroom in large-scale studies. Building on previous research, such studies could employ several types of methodology. Before-and-after studies of schools where insulation has been installed could be carried out at the school level, examining associations between external measures of aircraft noise exposure and standardized exam results for the school, taking school-level assessments of socioeconomic status into account. The FICAN pilot study is an example of this type of study (Eagan, Anderson, Nicholas, *et al,* 2004) but future studies would need to be on a much larger scale. Opportunities to conduct naturally occurring before-and-after experiments, where schools are already being insulated should be taken advantage of.

The literature suggests an increasingly important role of classroom acoustics on performance (Shield and Dockrell, 2008): however, it could be difficult to incorporate internal classroom acoustical factors into a study. In their study of noise exposure and national test scores for elementary school children, Shield and Dockrell (2008) successfully included internal acoustics in a sub-sample of 16 out of 142 schools: this illustrates the difficulties and potential lack of power of including classroom acoustics in such studies.

How does aircraft noise affect learning for students with different characteristics?

While the recent RANCH study has considerably advanced knowledge about exposure-effect relationships between noise and children's cognition and health, further demonstration of exposure-effect relationships in different contexts and for different samples and vulnerable groups remains a research priority.

CHAPTER 4. SELECTION OF RESEARCH DESIGN PLAN

4.1. Introduction

The objectives of this study are twofold, namely to: (1) to identify and evaluate conditions under which aircraft noise affects student learning, and (2) to identify and evaluate one or more alternative noise metrics that best define those conditions. To these, we have added a third requirement (3) to identify the most effective of the current criteria for school sound insulation projects To achieve these objectives, and in response to the identified gaps in knowledge noted in Chapter 3, five research plan candidates were formulated for evaluation by the ACRP panel members using the principles of the Pugh Matrix methodology (see Section 4.4). The candidates were selected in an attempt to provide answers to the following questions:

1. *To what extent is student learning affected by aircraft noise?*
2. *What is the most appropriate noise metric for describing aircraft noise as it affects learning?*
3. *What is the threshold above which the effect is observable?*
4. *Has insulation meeting existing classroom acoustic criteria improved student achievement?*
5. *How does aircraft noise affect learning for students with different characteristics?*

The first of the five candidates represents the initial thinking, and is termed the Datum candidate. It consists of a nationwide macro-analysis at a large sample of US airports to examine the relationship between student performance, as measured by test scores, and noise level as measured by different metrics. The analysis considers schools exposed to aircraft noise, schools that have been sound insulated, and control schools not exposed to noise.

The other four candidates are modifications of the Datum, formed by introducing on-site case studies at the expense of a reduced number of schools to be analyzed in the macro-analysis.

This section of the report summarizes the five candidate plans and describes the process used for selection of the plan that best meets the objectives of the study. Additional details on the candidate plans, together with pros and cons of each approach, can be found in Appendix D to this report.

4.2. Research Plan Candidates

The research plan candidates are summarized as follows:

Datum: *Macro-analysis (60 airports)*

Conduct a nationwide macro-analysis of the relationship between aircraft noise exposure and student performance taking into account the effect of school sound insulation and other confounding factors. The analysis will use the top 60 US airports sorted by the number of schools exposed to DNL 55 dB and higher. The student performance measure is the standardized test scores (reading and mathematics).

Alternative 1: *Macro-analysis (50 airports) with Follow-up Analysis*

This is the same type of macro-analysis as the Datum except that the top 50 US airports will be used instead of the top 60. Resources are shifted in order to follow-up the macro-analysis with a more detailed examination at a small sample of schools that the analysis identifies as atypical.

Alternative 2: *Macro-analysis (40 airports) with Observation Case Study*

This is the same type of macro-analysis as the Datum and Alternative 1 except that the top 40 airports will be used instead of the top 60 or 50, respectively. Resources are shifted in order to conduct a single school case study to observe changes in classrooms when exposed to aircraft noise and to measure the individual noise events.

Alternative 3: *Macro-analysis (30 airports) with Follow-up Analysis and Case Study*

This is the same type of macro-analysis as the Datum and Alternatives 1 and 2 except that the top 30 airports will be used. Resources are shifted in order to conduct both a follow-up study and a single school case study. The follow-up analysis is like Alternative 1. The case study is the same as Alternative 2.

Alternative 4: *Macro-analysis (15 airports) with Follow-up Analysis and Expanded Case Study*

This is the same type of macro-analysis as the Datum and Alternatives 1, 2, and 3 except that the top 15 airports will be used. Resources are shifted in order to conduct both a follow-up analysis and expanded case study. The follow-up analysis is like Alternatives 1 and 3. The case study involves classroom observations as proposed in Alternatives 2 and 3, but includes two schools with the addition of student and teacher questionnaires given through focus groups.

Table 4-1 presents a preliminary estimate of the data sample sizes for each candidate. The differences in sample sizes among the candidates reflect the different distribution of resources in order to accommodate the various analyses and studies within the study budget.

TABLE 4-1 Data Gathering for the Research Candidates

Data/Candidate	Datum	Alt 1	Alt 2	Alt 3	Alt 4
Macro-analysis					
# Airports	60	50	40	30	15
# Target Schools					
DNL 55-60	694	662	624	576	437
DNL 60-65	240	234	219	199	154
> DNL 65	76	76	74	70	59
Follow-up Schools	NA	< 20	NA	< 20	< 20
Case Study					
# Airports	NA	NA	1	1	1
# Schools			1	1	2

A power analysis was conducted to determine if the target school sample sizes are sufficient to provide statistically significant results. With assumptions on the expected effect size taken from the recent RANCH study (Stansfeld 2005), the corresponding minimum sample sizes would be approximately 210 at DNL 60-65, 120 at DNL 65-70, and 80 at DNL 70-75 to answer these same research questions. A detailed description of the power analysis conducted can be found in Appendix D.6.

It was concluded that the research plan candidates fall short of meeting sample size minimums to varying degrees However, the power analysis was based on previous research involving only L_{eq}-based aircraft noise metric. The current study is planned to explore metrics that are distinctly different from L_{eq} in hopes of finding one that has a better relationship with learning. Thus, the preliminary estimates of sample size requirements could be viewed as a worst case scenario.

4.3. Evaluation of Research Plan Candidates

A two-step procedure was used to evaluate the five candidate research plans, select the best overall alternative, and modify the individual components to achieve the study objectives. First, a formal quantitative evaluation of the five candidates was performed using the Pugh Matrix method. This was followed by a qualitative analysis performed by the ACRP 02-26 Project Panel and the research team to take into account comments received from the formal evaluation. The final decision on selection of a research design was then made by the Project Panel. The evaluation process is described in the following sections.

4.3.1. Pugh Matrix

The Pugh Matrix is a method for concept selection using a scoring matrix in which alternatives are scored relative to weighted criteria. It is widely used in the Six Sigma Method as it provides a straightforward means to choose the best alternative with limited information. It uses simple scoring of the relative merits of the alternatives based upon criteria that attempt to take into consideration the needs of the user. The Pugh Matrix compares a concept to a reference concept, usually referred to as the Datum, using a matrix of the form in Table 4-2.

TABLE 4-2 Example of the Pugh Matrix

Evaluation Criteria		**Concepts**				
	Weight	**Datum**	**A_1**	**A_2**	**A_3**	**A_4**
R_1	**W_1**		S_{11}	S_{12}	S_{13}	S_{14}
R_2	**W_2**		S_{21}	S_{22}	S_{23}	S_{24}
R_3	**W_3**		S_{31}	S_{32}	S_{33}	S_{34}
R_4	**W_4**		S_{41}	S_{42}	S_{43}	S_{44}
R_5	**W_5**		S_{51}	S_{52}	S_{53}	S_{54}
Score			T_1	T_2	T_3	T_4

First, a set of criterion (R) is established. The weight applied to each evaluation criterion (W) is derived from the relative importance of that factor. The sum of the weights (W_i) must equal 1. The rating scheme assigns a criteria score (S) for each alternative (A). Each score is based on a comparative judgment against the datum or reference concept. The total score (T) for each alternative is simply the summation of the individual rating multiplied by the criterion weight as shown in the following equation:.

$$T_{kj} = \sum_{i=1}^{6} \left(W_i \cdot S_{ij}\right)$$

Where k = individual evaluator. The most preferred concept is the one that achieves the highest overall score (T). An example of rating scheme (S) to evaluate concepts against the datum is given in Table 4-3.

TABLE 4-3 Pugh Matrix Rating Scheme

Relative Performance	Rating
Much worse than reference concept (Datum)	1
Worse than reference concept (Datum)	2
Same as reference concept (Datum)	3
Better than reference concept (Datum)	4
Much better than reference concept (Datum)	5

The evaluation criteria for comparing alternatives is based on rigorous, defensible experimental design, successful plan execution within the funding and time constraints (i.e. risk), and implementable findings that meet the project objectives. To these three prime elements, is added the desire that whatever is learned from this study can be of value to future research. The evaluation criteria (R) and weighting (W) for the assessment of alternative research plans are presented in Table 4-4.

TABLE 4-4 Research Plan Evaluation Criteria

Criteria	Description	Weighting
Experiment Design:		
• Internal validity	*Degree to which observed changes (student performance) can be attributed to the intervention (aircraft noise) and not to other possible causes.*	10%
• Content validity	*Degree to which a test measures an intended content area.*	10%
• External validity	*Degree to which the conclusions would hold for other persons in other places and at other times.*	10%
Risk	*Potential for relative success or failure, such as running out of time or money before completion.*	30%
Reward	*Degree to which the plan answers the project research questions and the potential for immediate application of findings to airport practices*	30%
Knowledge	*Value of the knowledge gained for future research or application.*	10%
	Total	100%

The scores are used to fill the Pugh Matrix to find the alternative with the highest weighted total score. Table 4-5 presents an example of the Pugh Matrix that was used.

TABLE 4-5 Pugh Matrix for ACRP 02-26 Research Plan Evaluation

Performance Evaluation Criteria		Concepts				
	Weight	Datum	A_1	A_2	A_3	A_4
Design: Internal Validity	0.10	3				
Design: Content Validity	0.10	3				
Design: External Validity	0.10	3				
Risk	0.30	3				
Reward	0.30	3				
Knowledge	0.10	3				
Total Score (T)		3				

Note that the Datum scores are all equal to 3. The Datum is the yardstick by which all alternative designs are evaluated and a score of 3 means "Same as the reference concept (Datum)."

4.3.2. Results of the Formal Evaluation Process

Seventeen members of ACRP 02-26 Panel and the project team evaluated the five research study candidates based on the Pugh Matrix. Nonparametric statistics were used instead of typical (parametric) statistics, like mean and standard deviation, because there is not enough information to determine whether the evaluators' ratings conform to a normal distribution - a necessary requirement for use of parametric statistics.

Table 4-6 presents the median ratings and scores for the Datum and each alternative. The median is the middle value of an ordered set of values; in this case the ratings and scores given by the 17 evaluators. The solid green cells identify the maximum value for a given criteria or total score. The diagonal red line cells identify the minimum values.

TABLE 4-6 Median Values of the Ratings and Scores

		Research Plan Candidates				
			Alternative			
Performance Evaluation Criteria	Weight	Datum	#1	#2	#3	#4
Experimental Design: Internal Validity	0.10	3.00	3.00	3.00	3.00	2.00
Experimental Design: Content Validity	0.10	3.00	3.00	3.00	2.90	2.00
Experimental Design: External Validity	0.10	3.00	3.00	2.90	3.00	2.50
Risk	0.30	3.00	3.00	2.00	2.00	2.00
Reward	0.30	3.00	3.00	4.00	4.00	2.00
Knowledge	0.10	3.00	4.00	4.00	4.50	4.00
Total Score		3.00	3.08	3.10	3.23	2.58

Alternative #3, Macro-Analysis with Follow-up Analysis and Case Study, received the highest total score and the highest ratings for 4 of the 6 evaluation criteria. It also tied for the lowest rating for the Risk criteria.

4.3.3. Qualitative Evaluation of Candidate Plans

Following the formal quantitative evaluation of the candidate research plans the ACRP 02-26 Panel convened with the research team to discuss the comments received from the Pugh Matrix process and make a final selection of the plan to be performed. The major comments and responses are listed below (in some cases the actual comments are paraphrased without change in meaning).

Comment: There is another aspect of this problem of variation in outdoor-to-indoor noise reduction which does not appear to be explicitly identified - the variation in outdoor-to-indoor noise reduction for schools located in different cities with very different climates

Response: We agree that variation of indoor to outdoor levels at classroom and school level is a factor that we cannot control within the study design, but believe that the potential confounding effect is mitigated by the large sample sizes involved and the approach that we plan to take. The analysis to find whether aircraft noise has an effect is done by assessing achievement differences between target schools and comparable control schools at the state level and then to aggregate across states; the assumption being that target and control schools at the state level are similar enough that any difference in achievement is due to the aircraft noise exposure.

Comment: If highway is feeder to airport, then it should be viewed as airport-related.

Response: The overall objective of the study is to determine the effect of aircraft noise on student learning. Some of the schools (target and control) will be exposed to highway noise. It is not possible within the scope of the study to calculate the actual highway noise levels at each school, but, as stated in our research plan, we will be conducting a spatial analysis to determine the distance from each school to a major highway, and including this distance as a confounding variable in the analysis.

Comment: I am concerned about the overall data analysis plan. I agree that normalization is appropriate to compare schools across states, but it's unclear to me why the state effect was not explicitly modeled using a random or fixed effect approach. It also seems to me that there will be other group effects that need to be controlled for that are not accounted for in the current plan, including differences by school district, and by school when subgroups or grades are analyzed. Also, the analytical plan describes the dependent variable as 'school-level' test scores, but then also describes a longitudinal analysis that will follow students by grade. So is the analysis by grade level or school level? If it is by grade level, there need to be additional controls to capture unobserved differences across schools. Also, some of the independent variables appear to be constructed at the 'grade level', such as the 'percentage of different racial/ethnic backgrounds by grade', but there is no approach outlined to account for the mismatch among the dependent (school level) and independent (grade level) variables.

Response:

The dependent variable data available for this study are aggregate mathematics and reading/language arts achievement indicators for students in each tested grade in each public school, in some cases also disaggregated by gender, race/ethnicity, poverty, or disability status.

The comment concerns three potential group effects in the study: states, school districts, and grades.

States. Because individual states administer different achievement tests, with different properties, while within each state all schools administer the same test battery, it is necessary to eliminate state effects from the analysis. For this reason, all analyses to be carried out in this study compare achievement measures in schools exposed to airport noise with other schools in the same state. State effects are eliminated from the analysis by setting the means of variables included in the analysis to zero within each state. Because the number of schools exposed to significant airport noise in a single state is small, it is necessary to aggregate the results of the within-state comparisons across states to achieve acceptable power for statistical tests. Nevertheless, results for individual states will be compared to explore potential explanations of outliers if they should occur.

School districts. School district effects on achievement are primarily due to demographic and resource factors (e.g., race/ethnic distributions, percentages of students eligible for free lunch, urbanicity, enrollment size, pupil-teacher ratios), which will already be statistically controlled as predictors of school-level achievement variation in the analysis. A test will be made for significant district-level variation not accounted for by school-level predictors, and where it is found, it will be included in the analysis.

Grades. Although airport noise levels are at the school level, the available achievement level data are for individual grades at each public school. For example, for analysis of the relationship between airport noise and third-grade achievement, we can use third-grade achievement scores. However, for various states in various years, achievement data are only available for a subset of grades, because those states only required testing in some grades. For the analysis, the achievement data for each grade in each school in a state exposed to airport noise are compared to all other students in the same grade in the same state. In order to maximize the power of the study, data must be aggregated across states and years in which testing was in different grades. In addition, because average achievement for one grade is only moderately reliable as a measure of average achievement in an entire school, we plan to aggregate achievement across grades in each school for the main analysis. If separate grade level effects are significant, the average grade level of tested students in each school will be included as a control.

General Comments:

- Although Alternative 3 may offer more rewards, it may sacrifice statistical validity and ability to analyze alternative metrics. It also carries more risk. I would be hesitant to recommend this alternative.
- The expanded case study approach would add value in concept but remains too limited to justify the significant decrease in the number of airports included in the basic analysis.
- Even though the Panel member was a huge proponent of case studies, he felt that by only selecting one school, the results would not be scientific.
- The purpose of the project was first and foremost the identification of the dose-response relationship, and advocated either all case studies or maximizing the number of schools to analyze.
- The gain to the industry of one case study could be minimal, and would depend on, among other factors, luck.
- A Panel member stated that he initially had negative feelings about the case studies, but has since had additional issues with decreasing the number of schools.
- A general discussion of Alternative 3 noted that it has the risk of not including enough airports, thus affecting the ability to distinguish impacts because of the decreased number of airports included in the survey.
- Alternative 3 does not include getting verbal response from students or teachers. A case study may improve the ability of identifying effect of intermittent significant noise events.

4.4 Conclusion

In summary, the Panel recognized the potential advantage of including a case study, but that since only one or two schools would be studied, the results might not be representative. The Panel was of the opinion that including a case study would reduce the number of schools in the macro-analysis, but that the most important objective of the study was to develop a relationship between noise and test scores. The number of schools should be maximized to reduce risk. As a result, the Panel agreed that Alternative 1 was the first choice, with suitable documentation being provided for the tradeoffs, variables, and potential for future research.

CHAPTER 5. IMPLEMENTATION OF THE RESEARCH PLAN

5.1. Introduction

The research plan selected by the Panel was to conduct a nationwide macro-analysis to identify the relationship between aircraft noise exposure and student performance, taking into account the effect of school sound insulation and other confounding factors. The study was designed to examine this relationship for schools exposed to aircraft noise in the years 2000/01 to 2008/09 at the top 50 US airports, selected by the number of schools exposed to DNL 55 dB and higher. Student performance measures are based on the standardized reading and mathematics test scores in Grades 3 through 5 at each school.

Schools were classified into three categories: target, control, and insulated. Target schools are those exposed to aircraft noise, defined as Day-Night Level (DNL) 55 dB or greater in the year 2000. Control schools are those located outside the DNL 55 contours in the year 2000 and are considered not exposed to aircraft noise. Insulated schools are those that have received modifications to increase the structural noise reduction.

5.2 School Database

School location information was obtained from the US Department of Education (ED) Common Core Database (CCD) at http://nces.ed.gov/ccd, which provides names and street addresses for public elementary and secondary schools in the US. Latitude and longitude information were extracted from CCD to determine school locations. For cases where such data were missing in CCD, address information from CCD was used to identify the latitude and longitude of the school.

The schools existing within the years of interest and in the states included in the study were extracted from the CCD database, and the following spatial data were added for subsequent analysis.

- Population density around each school using Block Group data from the 2010 census;
- Distance to major road from each school;
- Identification of schools that are within the Year 2000 DNL 55 noise contour (target schools);
- Elevation of target schools;
- The airports near each school and their distance from each school.

The scope of this macro statistical study did not allow for consideration of school type or age, nor windows open or closed.

The master school database which contains all the school information (identified by unique number, lat/long, whether open or closed, by year, and name) contains a total of 59,722 entries for elementary schools serving Grades 3, 4, and/or 5. This does not mean that there are that many elementary schools in the US - there are many redundancies as schools open and close, change their name or addresses, or move. For example, the number in the year 2000 database is 41,035. Of these, 972 were within the Year 2000 DNL 55 contours of the selected 50 airports. A number of these target schools were insulated either before 2000 or in the period from 2000 to 2009.

5.3 School Noise Data

The exterior noise levels at target (noise-exposed) schools were estimated using the Integrated Noise Model (INM) together with input files developed for US airports as part of FAA's Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA). The FAA uses the MAGENTA model to perform an annual assessment of total US airport noise exposure. INM studies appropriate for each year in the period 2000 to 2009 were obtained from the airports. The data source for airport traffic for the period 2000 to 2009 was the Enhanced Traffic Management System (ETMS) database provided by the FAA. The ETMS database includes scheduled and unscheduled air traffic, which allows for more accurate modeling of freight, general aviation, and military operations. The ETMS also provides details on aircraft type for an accurate distribution of aircraft fleet mix.

Using the Year 2000 ETMS data, noise contours were calculated for the top 96 US airports and superimposed over school locations obtained from the US Department of Education Common Core Database (CCD) to determine the number of target schools within the DNL 55 noise contour. A total of 50 airports were then selected with the highest number of target schools.

Of the selected 50 airports, three were excluded for lack of suitable INM studies in the years of interest 2000 to 2009 (Indianapolis, Milwaukee, and Sioux Falls). Omaha was excluded as the test scores in Nebraska were not reported in forms comparable from district to district. As a result, the analyses were based on 9 years of airport noise data at 46 of the nation's largest airports in 26 states. The airports and states are listed in Table 5-1.

TABLE 5-1 Airports and Schools in Corresponding States Included in the Study.

Airport	State	Airport	State	Airport	State
Albuquerque (ABQ)	NM	Newark (EWR)	NJ	Chicago O'Hare (ORD)	IL
Anchorage (ANC)	AK	Fresno (FAT)	CA	Philadelphia (PHL)	NJ
Atlanta (ATL)	GA	Fort Lauderdale (FLL)	FL	Phoenix (PHX)	AZ
Boeing Field (BFI)	WA	Honolulu (HNL)	HI	Providence (PVD)	RI
Birmingham (BHM)	AL	Houston (HOU)	TX	Reno (RNO)	NV
Boston (BOS)	MA	New York (JFK)	NY	Rochester (ROC)	NY
Buffalo (BUF)	NY	Las Vegas (LAS)	NV	San Diego (SAN)	CA
Baltimore (BWI)	MD	Los Angeles (LAX)	CA	San Antonio (SAT)	TX
Cleveland (CLE)	OH	New York (LGA)	NY	Louisville (SDF)	KY
Charlotte (CLT)	NC	Orlando (MCO)	FL	Seattle (SEA)	WA
Columbus (CMH)	OH	Chicago (MDW)	IL	San Francisco (SFO)	CA
Cincinnati (CVG)	KY	Memphis (MEM)	TN	San Jose (SJC)	CA
Dallas Love Field (DAL)	TX	Miami (MIA)	FL	St. Louis (STL)	MO
Dallas Ft Worth (DFW)	TX	Minneapolis (SP)	MN	Tulsa (TUL)	OK
Detroit (DTW)	MI	Ontario (ONT)	CA	Tucson (TUS)	AZ
El Paso (ELP)	TX				

Full-year ETMS operations data were collected for calendar years 2000 through 2009. The dataset was processed to yield operations corresponding to school days and school hours, and included operations occurring Monday through Friday, between the hours of 7am and 3pm. The data were filtered on a per-year basis, and split into two parts for each calendar year: January through May in any given year, and September through December. Then the data for January through May were appended to the previous year's data for September through December, and combined into a file representing one school year. The naming convention selected is such that the year corresponding to the September through December portion is the year to which the school year designation refers. So for example, the September through December data for 2004, plus the January through May data for 2005, added together, corresponds to the full 2004 school year file.

Following the assignment of INM studies to specific school years, and the assignment of ETMS data to those INM studies, the US MAGENTA model was exercised to estimate exterior noise levels at each target school. The following noise metrics were calculated (all levels are A-Weighted):

- Arithmetic Average L_{Amax} for school hours, including all aircraft events greater than 65 dB (L_{max}65) and greater than 70 dB (L_{Amax}70);
- Energy Average SEL for school hours, including all aircraft events greater than 70 dB (SEL70) and greater than 80 dB (SEL80);
- Average noise level, L_{eq}, for school hours;
- Time Above a threshold noise level L, TA(L), - TA(55), TA(60), TA(65), TA(70), TA(75), and TA(80) for school hours;
- Numbers of Events Above a threshold level L, NA(L), - NA(55), NA(60), NA(65), NA(70), NA(75), and NA(80) for school hours.

Following the execution of the US MAGENTA model to generate noise data at all 46 airports, the results were collected into a single master database which was then joined with the modified CCD database to allow for the subsequent school-level and system-wide analyses.

The basic statistics of the aircraft noise file are shown in Table 5-2. The sample size (N) reflects the number of years each target school was open, and not insulated, multiplied by the number of open schools.

TABLE 5-2. Statistics for Airport Noise Measures in Schools Exposed to Aircraft Noise.

Measure	Units	Min	Max	Mean	StdDev*	N	N_{miss}
L_{Amax}65db	decibels	65	98.5	70.1	2.5	7152	0
L_{Amax}75db	decibels	75	100.8	78.4	1.8	7121	31
SEL70db	decibels	70	102.2	78.7	5.1	6976	176
SEL80db	decibels	80	103.1	84.4	3.5	5765	1387
L_{eq}	decibels	30.9	86.3	54.2	5.2	7152	0
NA55	Count/8hrs	0.7	628.2	106.6	84.0	7152	0
NA60	Count/8hrs	0.2	435.5	72.1	62.9	7152	0
NA65	Count/8hrs	0	380.5	43.1	47.6	7152	0
NA70	Count/8hrs	0	314.9	20.4	32.8	7152	0
NA75	Count/8hrs	0	314.7	8.5	21.4	7152	0
NA80	Count/8hrs	0	291.8	2.9	13.3	7152	0
TA55	Minutes/8hrs	0.2	427.8	49.8	45.1	7152	0
TA60	Minutes/8hrs	0	288.9	23.8	25.4	7152	0
TA65	Minutes/8hrs	0	202.2	9.9	14.1	7152	0
TA70	Minutes/8hrs	0	142.7	3.4	7.5	7152	0
TA75	Minutes/8hrs	0	99.1	1.1	4.0	7152	0
TA80	Minutes/8hrs	0	64.9	0.4	2.1	7152	0

Note: Entries under N are number of school years, up to 9 each, for schools open and exposed to airport noise. N_{miss} is the number of records for which the noise variable was not recorded.

* Standard Deviation

The distribution of the exterior equivalent noise levels, L_{eq}, at the target schools averaged over the years 2000 to 2009 is as shown in Figure 5-1, with a mean of 54.2 dB and standard deviation of 5.2 dB. It must be remembered that these are average levels for the school day from 7 am to 3 pm, and not day-night average levels, DNL, with a nighttime weighting factor applied.

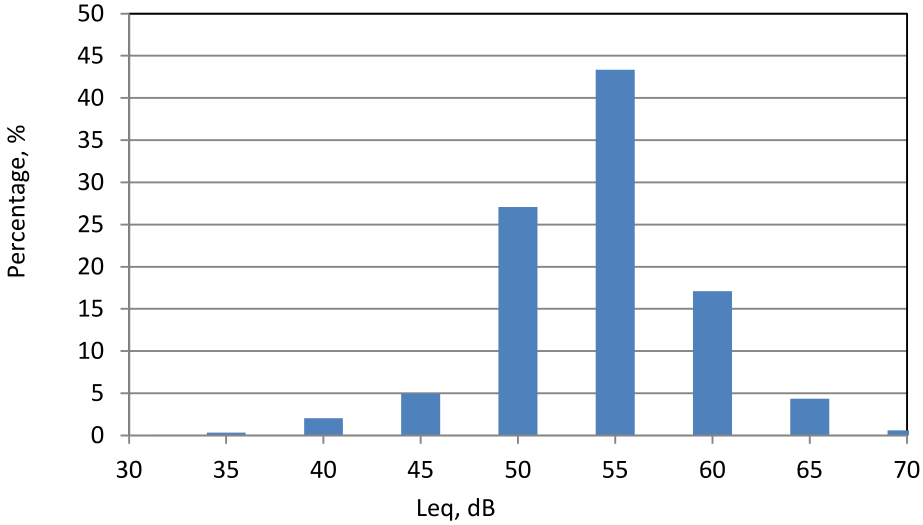


Figure 5-1. Distribution of Aircraft Noise Levels at Target Schools

The increased operations occurring in the morning hours are included, but not those of the late afternoon. In fact, for most of the school day, from 10am to 3pm, aircraft operations at all but the largest airports are at a fairly low level.

Although the aircraft L_{eq} values at target schools range from about 30 dB to over 80 dB (the low values being at airports with mostly nighttime operations), Figure 5-1 indicates the limited range of noise levels for most target schools – 81 percent are exposed to exterior L_{eq} levels in the 15 dB range between 45 dB and 60 dB, 13 percent are exposed to levels greater than 60 dB, and only 3 percent to levels greater than 65 dB.

The noise levels presented above are averaged values taken over a school year of aircraft operations; in other words, they are based on the total number of operations occurring within school day hours for the school year divided by the number of school days in the school year. At airports where the runway usage is fairly constant (Los Angeles International is a good example), the noise exposure is constant day to day and is well represented by the number of annual average operations. However, at airports where changes in wind direction require changes in runway usage the actual aircraft noise exposure levels may vary considerably day to day. On some days the aircraft noise levels will be higher than the calculated average, on other days they will be close to zero. The effect (if any) on test scores of such respites from aircraft noise cannot be determined as both test scores and aircraft noise levels used in this analysis are annual averages.

In using the annual average noise levels we are making the assumption that aircraft noise has a negative effect on learning that results in lower test scores, and not that the aircraft noise interferes with the tests themselves, although this may also be true.

5.4 Ambient Noise

The potential effects of aircraft noise on student learning may also be influenced by the level of external ambient noise at a school site from non-aircraft sources. An aircraft noise level of 65 dB might be more disturbing in a quiet suburban area than in a noisy urban environment. An estimate of the ambient noise at each school was obtained from information on the population density surrounding the school. Schomer (2010) has shown from empirical data that the ambient noise level in an area removed from major sources of noise (such as airports and major highways) can be expressed in terms of the Day-Night Average Level (DNL) by the expression:

$$\text{Ambient DNL} = 10\log(\rho) + 19\text{, dB}$$

where ρ is the population density in people per square mile. This formula is based on measurements at locations selected to obtain diversity in nearness to a major road or arterial street with a balance of near to arterials, near to lightly travelled roads, and in between. Measurement locations were more than 300 meters from a freeway, and not near an airport.

The DNL noise metric is an average value of the equivalent noise level, L_{eq}, taken over 24 hours, with a 10 dB weighting applied to noise during the nighttime hours (10pm to 7am). For application to schools, which operate only in the daytime hours, it was necessary to develop a relationship between DNL ambient and daytime noise ambient. This was achieved by using community noise data presented in EPA’s seminal report on community noise (EPA 1974) that shows daytime ambient levels are about 1.5 dB less than the day-night average ambient level, DNL. With this adjustment, we have

$$\text{Daytime Ambient } L_{eq} \approx 10\log(\rho) + 17.5\text{, dB}$$

The ambient noise levels presented in Schomer 2010 were measured in a wide range of areas with population densities as low as 118 and as high as 40,000 people per square mile. At the lower values, the number of data points is small, and hence the ambient DNL is less certain. For this study, a lower limit of 100 people per square mile was established, representing a minimum ambient L_{eq} of 37.5 dB.

The average ambient noise estimate for target schools included in this study is 56.5 dB, with a standard deviation of 5.4 dB. The average ambient level for all other schools is 48.8 dB, a difference of 8.1 dB. The average ambient level for other schools *in the same school districts as the target schools* is 55.3 dB, 1.2 dB less than that for the target schools themselves. Note that these differences do not represent the influence of aircraft noise, as this is specifically excluded from the empirical data of Schomer 2010. Target schools, and other schools in the same school districts, which are near airports, tend to be in more urban-like areas, whereas schools away from airports are in more suburban and rural areas with lower ambient noise levels.

The distribution of noise level differences, i.e. the difference between L_{eq} from the aircraft and the ambient L_{eq}, at target schools is shown in Figure 5-2. It is noteworthy that the ambient L_{eq} level exceeds the aircraft noise level at more than half of the schools. It must be

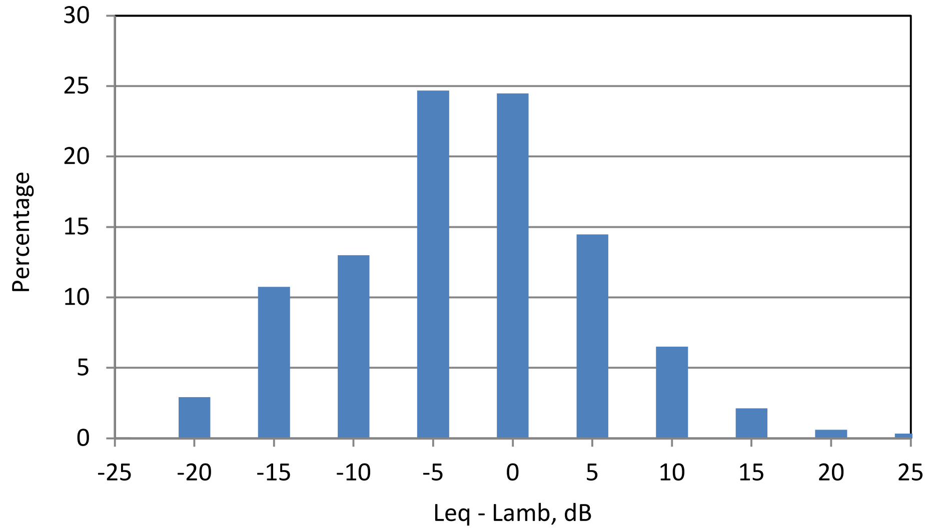


Figure 5-2. Distribution of L_{eq} - L_{amb} at Target Schools.

remembered, however, that the time histories for the two noise sources are quite different. Ambient noise, by definition, is a steady noise throughout the time period with only minor fluctuations. Aircraft noise, on the other hand, is characterized by discrete noise peaks corresponding to aircraft events, separated by periods of low noise. Individual jet aircraft noise levels are almost always greater than ambient levels even in the highest ambient conditions experienced in urban areas. Nevertheless, it is clear that target schools are not located in pristine areas, but are exposed to considerable noise from sources other than aircraft. One of those other sources is heavy vehicle traffic on nearby roads and highways, which is not included in the definition of ambient noise, and is excluded from the measured values of ambient noise as presented by Schomer (2010). Particularly in urban/suburban areas, the noise from individual trucks on local roads can approach the levels from aircraft flyovers. The influence of truck noise, if any, is not included in this analysis.

5.5. School Sound Insulation Database

An important objective of the study was to determine whether test scores have been influenced by the implementation of sound insulation modifications. The information on whether or not schools had been sound insulated, and the year that the insulation was completed, was added to the master school database.

The database on the total number of schools that have been sound insulated through the year 2010 has been developed from all of the inputs provided by the airports and/or consultants. The total number at the 46 selected airports is 388. Of these, 187 are either middle or high schools (for which test scores are unreliable, and are not being included in this study), or are parochial schools, many of which do not provide test score information. A further six were not in the CCD database, and 17 were outside the year 2000 DNL 55 noise contour, leaving a total of 173 target elementary schools. Of these, 145 were insulated before or during the year 2000 and thus were not available for analysis of before-and-after test score comparisons, although they were available for the insulated/non-insulated analysis. Thus, 51 elementary schools were insulated in the years between 2001 and 2009 as shown in Table 5-3 Of these, 29 were open for at least 2 years before and after being insulated, and had test scores available.

TABLE 5-3 Numbers of Sound Insulated Elementary Schools at US Airports

Airport	Total ES Ins.	Ins. After 2000	Airport	Total ES Ins.	Ins. After 2000
BOS	13	0	MDW	18	12
BUF	1	1	MHT	1	1
BWI	2	0	MSP	10	3
CLE	2	0	ONT	3	0
CLT	1	0	ORD	50	10
CVG	3	3	PVD	1	0
DAL	3	0	RNO	2	0
DTW	2	0	SAN	3	0
EWR	9	2	SAT	4	0
HNL	2	2	SEA	2	2
JFK	16	8	SFO	2	0
LGA	14	3	SJC	3	1
MCO	1	1	STL	5	2
			Total	**173**	**51**

5.6. School Test Score Databases

The experimental design called for collecting test score data for the schools near the 46 largest commercial airports, which were located in 26 states. Most of the test scores for school years 1997-98 through 2004-05 and 2006-07 and 2008-09 were available from the National Longitudinal School-Level Test Score Database (NLSLSASD). Scores for school years 2005-06 and 2007-08 were extracted and transformed from four additional sources[1].

Longitude and latitude information is not available on CCD prior to the year 2000, and so test scores for years before 2000 were dropped from the database for the study. Also, test scores were not available for 2010, so the year identified as 2009 (the 2009-2010 school year) was not included in the study.

As most standardized testing results in elementary schools during the decade of the study were in Grade 3, 4, and 5, the study focused on those three grades. Scores for Grade 6 were not included in the study because a large number of sixth grades are in middle schools or junior-high schools, which are not comparable to elementary schools. Grades at which tests were administered and results were available for this study are shown in Table 5-4. In a small number of states and years, there were no grade-by-grade test score data but there were aggregate cross-grade scores. These are indicated by an entry of “0” in Table 5-4. Because these are rare, they were not included in the analysis.

[1] National Longitudinal School-Level State Assessment Score Database; GS: Great Schools; State standards mapping study, funded by USDE; Study of magnet schools, funded by USDE; Ohio Department of Education website.

TABLE 5-4 Grades at Which Test Scores were Included for Each State in Each Year

State	Grades with Quantitative Tests								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
AK	34..	345.	.4..	3...	345.	345.	345.	345.	.4..
AL	345.	34..	345.	.4..	.4..	345.	345.	345.	.4..
AZ	345.	345.	345.	3.5.	3.5.	....	345.	345.	.4..
CA	345.	345.	345.	345.	345.	345.	345.	345.	.4..
FL	345.	345.	345.	345.	345.	345.	345.	345.	.4..
GA	345.	345.	.4..	345.	345.	....	345.	345.	.4..
HI	....	3.5.	3.5.	3.5.	345.	....	345.	345.	.4..
IL	3.5.	3.5.	3.5.	3.5.	3.5.	345.	345.	345.	.4..
KY	..5.	..5.	..5.	..5.	..5.	....	345.	....	.4..
MA	.4..	.4..	.4..	.4..	.4..	345.	345.	345.	.4..
MD	3.5.	3.5.	3.5.	345.	345.	345.	345.	345.	.4..
MI	.4..	.4..	.4..	.4..	.4..	....	345.	....	.4..
MN	3.5.	3.5.	3.5.	3.5.	3.5.	345.	345.	345.	.4..
MO	.4..	.4..	.4..	.4..	.4..	345.	345.	....	.4..
NC	345.	345.	345.	345.	345.	345.	345.	345.	.4..
NJ	....	.4..	.4..	34..	34..	345.	345.	....	.4..
NM	....	....	345.	.4..	345.	345.	345.	345.	.4..
NV	.4..	3.5.	345.	345.	345.	345.	345.	345.	.4..
NY	.4..	.4..	.4..	.4..	.4..	345.	345.	345.	.4..
OH	.4..	.4..	.4..	.4..	34..	...0	345.	...0	.4..
OK	..5.	....	..5.	....	345.	....	.4..	345.	.4..
PA	..5.	..5.	..5.	..5.	3.5.	345.	345.	345.	.4..
RI	.4..	.4..	.4..	.4..	....	345.	345.	345.	.4..
TN	....	345.	....	....	345.	....	345.	...0	.4..
TX	345.	345.	345.	345.	345.	....	345.	345.	.4..
WA	34..	34..	34..	34..	34..	345.	345.	345.	.4..

State	Grades with Verbal Tests								
	2000	2001	2002	2003	2004	2005	2006	2007	2008
AK	34..	345.	.4..	3...	345.	345.	345.	345.	.4..
AL	345.	345.	345.	.4..	.4..	345.	345.	345.	.4..
AZ	345.	345.	345.	3.5.	3.5.	....	345.	345.	.4..
CA	345.	345.	345.	345.	345.	345.	345.	345.	.4..
FL	345.	345.	345.	345.	345.	345.	345.	345.	.4..
GA	345.	345.	.4..	345.	345.	345.	345.	345.	.4..
HI	....	3.5.	3.5.	3.5.	345.	....	345.	345.	.4..
IL	3.5.	3.5.	3.5.	3.5.	3.5.	345.	345.	345.	.4..
KY	.4..	.4..	.4..	.4..	.4..	....	345.	....	.4..
MA	34..	34..	34..	34..	34..	345.	345.	345.	.4..
MD	3.5.	3.5.	3.5.	345.	345.	345.	345.	345.	.4..
MI	.45.	.45.	.4..	.4..	.4..	....	345.	....	.4..
MN	3.5.	3.5.	3.5.	3.5.	3.5.	345.	345.	345.	.4..
MO	3...	3...	3...	3...	3...	....	....	....	.4..
NC	345.	345.	345.	345.	345.	345.	345.	345.	.4..
NJ	....	.4..	.4..	34..	34..	345.	345.	....	.4..
NM	....	....	345.	.4..	345.	345.	345.	345.	.4..
NV	.4..	345.	345.	345.	345.	345.	345.	345.	.4..
NY	.4..	.4..	.4..	.4..	.4..	345.	....	345.	.4..
OH	.4..	.4..	.4..	.4..	345.	...0	345.	...0	.4..
OK	..5.	....	..5.	....	345.	....	.4..	345.	.4..
PA	..5.	..5.	..5.	..5.	3.5.	345.	345.	345.	.4..
RI	.4..	.4..	.4..	.4..	....	345.	345.	345.	.4..
TN	....	345.	....	....	345.	....	....	...0	.4..
TX	345.	345.	345.	345.	345.	....	345.	345.	.4..
WA	34..	34..	34..	34..	34..	345.	345.	345.	.4..

To increase the potential analysis sample size of schools exposed to aircraft noise, schools serving only a subset of Grades 3, 4, or 5 were later added to the database. Anticipating the unavailability or unreliability of scores from very small schools, schools with fewer than 5 students in at least one of the Grades 3, 4, or 5 were omitted. Finally, to avoid clearly non-comparable schools in the analysis, only regular schools, schools not focused primarily on vocational, special, or alternative education, (type=1 on CCD) were included in the analyses.

5.7. Preparation of Test Score Data

The first step in preparing test score data was to extract the school average test scores from different sources, identify test scores that could be considered as indicators of verbal (i.e., reading, language arts, or in a few cases, writing) and quantitative (i.e., mathematics) achievement, and remove duplicate records and other extraneous data. The tests themselves and the methods of scoring varied both between states and, in many states, across years.

The second step was to create indexes from the standards-based scores. In most states, following the passage of *No Child Left Behind* in 2002, school-level scores have been reported as the percentages of students meeting each of several standards. For this study, the multiple measures for each test were combined to a single index, multiplying the percentage meeting the lowest standard by 1, the percentage meeting the next higher standard by 2, and so on. While these test scores cannot be compared across states, which set quite different achievement standards (McLaughlin et al. 2007; Bandeira de Mello, Blankenship, and McLaughlin, 2009), they can be compared across schools in the same state and year. The types of school-level test scores included in the study in addition to these indexes are scale scores, raw scores, median percentile scores, and normal curve equivalent scores.

As the tests are different in different states, and may vary with years, the only valid comparisons of test scores are between schools in the same state in the same year. Scores in a school in one state cannot be compared directly with scores of another school in another state, and the scores in a school in one year cannot be compared directly with scores in that school in another year, except in terms of a change in its rank among schools in its state. Because no comparisons of raw test scores are made across states or across years within states, no information is lost by rescaling (normalizing) the test scores in each year across all the schools in each state to have a common mean and standard deviation. The advantage of that rescaling is to give equal weight to test scores in all states in computing summary statistics. Therefore, the means of the test scores in each year in each state were rescaled to 50, and the standard deviations were rescaled to 10.

Thus, a school with test scores at the average of schools in its state with the same demographics would have an adjusted score of 50, and a school with test scores one standard deviation above (or below) schools with the same demographics would have an adjusted score of 60 (or 40). This standard procedure (also employed in the RANCH study) provided a valid basis for combining the within-state comparisons across 26 states.

The third step was to check to ensure the test scores have construct validity by correlating them with demographic and resource measures. (See Appendix E for additional details)

Many states reported more than one verbal achievement measure for each grade in each year, such as reading comprehension, language arts, and writing. The fourth step was to select either a single best measure, or an average of measures, for each state and year to use as the primary reading score and for the primary mathematics score. The selection was based on the construct validity of the scores measured in the preceding step.

5.8. Accounting for Demographic Factors[2]

In assessing the possible relationship between aircraft noise exposure and student test scores, it is necessary to consider other contributing (or confounding) factors. Families that live near schools exposed to substantial airport noise are generally less affluent than families living near other schools in the same area, and such demographic factors have been shown to account for variation in school achievement, even without taking the noise levels into account. Therefore, demographic effects must be controlled to isolate direct effects of airport noise on achievement,

To reduce the extent to which differences in test scores between target schools and control schools might be related to demographics and resources associated with those schools, the scores in each state and for each school year were adjusted to account for four measures of demographic and resource characteristics, namely:

1. The fraction of students eligible for the free and reduced price lunch program;
2. The fraction of the school's enrollment of children who are members of minority groups (African American, Hispanic American, and Native American);
3. The pupil-teacher ratio, a measure of school resources; and
4. The average enrollment per grade in the school.

[2] See Appendix F.1 for additional details.

Demographic data were available from the government's Common Core of Data (CCD) for the large majority of the schools with test scores. As a pre-analysis step, occasional missing values for these factors were filled in using statistical methods documented in McLaughlin (2003) CCD Data File:Thirteen-Year Longitudinal Common Core of Data Non-Fiscal Survey Database.

The demographic adjustment was based on empirical data on the relationships between demographic measures and achievement among schools not near major airports in each state, and hence not exposed to aircraft noise. The predicted test scores for grade 3, 4, and 5 reading and mathematics, based on demographics, were computed for each school and subtracted from the actual scores to produce the demographic adjustment. A separate demographic adjustment to school-level scores was implemented in each year in each state.

There are, of course, a number of other factors why scores might differ between schools close to airports and other schools. For example, it is possible that more effective teachers tend to choose not to teach in schools near airports. It is also possible that other aspects of the neighborhood in which the school is located make it less supportive of student achievement than other schools in the district. However, measures of teacher effectiveness and other factors affecting the learning environment are not systematically available on a large sample of schools. The fact that the measures used in the study accounted for half of the variance in school-level scores suggests that a large portion, if not all, of the demographic and resource differences between schools close to airports and other schools in the same district are eliminated by the adjustment.

5.9. Selection of Data Analysis Procedure

The data to be analyzed were adjusted school-level achievement scores related to the subjects of mathematics and reading in grades 3, 4, and 5. Individual student scores were not available, so the analyses made use of average scores of students in each grade and subject in each school for each year. Target and control schools were included for each of 26 states, and scores for any particular school were included for one or more of the 9 years of the study.

The factors in the design are states, school districts, schools, years, subjects, and grades. In design terms, schools are "nested" within school districts, and school districts are "nested" within states. Years, subjects, and grades are "crossed" with schools within districts within states. Schools were either exposed to airport noise from a major airport (target schools) or not exposed to airport noise (control schools). The important properties of these data that determined the approach to the analyses are as follows.

5.9.1. Missing data

The testing policies in the 26 states included different grades in different years, sometimes including only reading or only mathematics. As a result, large amounts of data were systematically, as well as randomly, missing. (Table 5-4 records the changing patterns of testing in different states.) Furthermore, some schools were open for only a subset of the years of the study. Procedures that either require a complete dataset or omit observations (schools in this case) where data is missing are unacceptable, as they introduce potentially serious bias in conclusions to be drawn from the analysis.

Because more than half of the schools would be excluded if only schools with all six scores (reading and mathematics in 3 grades) were included, separate analysis was carried out and presented for each of the six scores. The pattern of missing test scores precludes multivariate analyses of systematic relations among the six scores.

5.9.2. Non-Comparable Dependent Variables

The student testing in different states and, in many cases, in different years in the same state, often employed different measures of mathematics and reading, of different types and on different scales. As a result, it is not possible to compare test results between states. An analysis procedure that attempts to compare results in different states is not appropriate for this study, due to this non-comparability of test scores. This means that it is not possible to develop a simple relationship between raw test scores and noise level that is representative across states.

5.9.3. Non-Constant Data Variances (Heteroscedasticity)[3]

The school test database contains widely varying numbers of students tested in different schools in different years. As a result, the random variation in the school-level achievement measures was very large for small schools and much smaller for large schools. Because the data were school-level scores, they did not satisfy the assumptions of many analytical methods, namely, that scores have roughly the same standard error. The only way to address this issue is to weight each score by the number of students included in the score. A school with ten times as many students tested would then count ten times as much in computing overall averages.

Failing to employ such weights would substantially reduce the power of the study to identify significant effects. The selected analysis procedure must not require homoscedasticity (equal standard errors) and must allow for appropriately employing case weights.

5.9.4. School District Effects[4]

All public schools are located in school districts (“local education agencies”). Even removing demographic factors, achievement scores may be affected by factors associated with a school district and its local administration. Thus it was necessary to take into consideration the variation between school districts in a state. After verifying that achievement in school districts with schools near major airports differed significantly from other school districts in the same state, a decision was made to limit the sample of comparison, or control, schools to schools in the same district as a target school exposed to airport noise.

With this limitation imposed to reduce district effects, the overall database for the analyses consisted of adjusted test scores in 6,198 schools in 104 school districts, and of these schools 917 (= 905 + 12) were classified as exposed to significant airport noise, i.e. target schools, as shown in Table 5-5. A few schools were included as target schools some years and comparison schools in other years, due to changes in either school location or airport operations.

[3] See Appendix F.2 for additional details
[4] See Appendix F.3 for additional details

TABLE 5-5 Total Number of Schools and Districts Included in the Test Score Database

Schools in District	Districts	Exposed Schools	Comparison Schools	Both*
At least 2 exposed and 2 comparison schools	104	905	5281	12
1 exposed and at least 2 comparison schools	44	46	641	1
Fewer than 2 comparison schools	129	214	69	15
Total	277	1165	5991	28

*Schools exposed to airport noise some years and not in others.

Test scores were, on average, available for 5 or 6 of the 9 school years. The numbers of schools included in the main analysis for each grade and subject are shown in Table 5-6.

TABLE 5-6 Number of Schools and Districts Included in the Main Analyses for Each Grade and Subject

Test Score	Districts	Exposed Schools	Comparison Schools	Both*
Reading Grade 3	92	695	4473	8
Reading Grade 4	97	851	4904	9
Reading Grade 5	89	670	4445	9
Math Grade 3	89	683	4451	8
Math Grade 4	99	857	4934	10
Math Grade 5	89	682	4466	8

These schools were in districts with at least two exposed and two comparison schools with the specified test scores. For Grade 3 Reading, for example, the comparisons were based on 703 (= 695 + 8) airport noise-exposed schools and 4481 (= 4473 + 8) comparison schools in 92 school districts.

5.9.5. Correlations Across Years[5].

In each grade, a school has different students each year, but other aspects remain constant from year to year. Thus, average test scores in a school, compared to other schools in the state, after taking demographic factors into account, might be correlated from year to year. i.e. knowing that a school's scores were higher than average one year would tell you whether it was

[5] See Appendix F.4 for additional details.

likely to be above average another year. If they are correlated, then the results obtained from any analysis method would underestimate the standard errors of the quantities in the model.

Analyses verified that the scores were substantially correlated across years (See Appendix F.4). Therefore a standard procedure was employed to adjust the standard errors by computing a "design effect," the ratio of the reported standard errors to the true values of those standard errors.

5.9.6. Analysis Procedure

In summary, the details of the test score data available for the study were carefully considered, and steps were taken to ensure that the results were valid and replicable. It was necessary to accurately reflect the multi-level structure of the data, measures in different grades, subjects, and years at schools in different school districts, in the analysis. Specifically:

- Due to patterns of missing test scores stemming from state testing policies, separate analyses were performed for the six combinations of grade and subject.
- School average test scores were weighted to reflect the number of students tested, in lieu of availability of individual student data, to maximize the power of the analyses.
- To deal with the non-comparability of state tests, between-state variance components were removed from the analysis by standardizing each state's scores to the same mean and standard deviation.
- Because the size of the comparison sample within the same districts as schools exposed to airport noise was more than adequate, there was no advantage to introducing school district as a separate variance component. All test score comparisons were between schools in the same school district.

The analysis method selected, the SAS general linear model procedure (GLM), was dictated by the unusual properties of the dataset. Alternative procedures within the SAS system (CALIS, MIXED, NESTED. ANOVA) were explored to determine whether they were appropriate for this dataset, but none were capable of matching the properties of the dataset. The multi-level modeling approach employed in the RANCH study (Stansfeld 2005) is not appropriate for analyzing this dataset with its many missing observations, and, if used, could have introduced a potentially serious bias in the results. The GLM procedure in SAS handles missing data appropriately.

5.9.7. Analysis Design

The basic analysis design was to compare average adjusted test scores in schools exposed to various levels of aircraft noise (target schools) to average adjusted test scores in control schools in the same district that were not exposed to aircraft noise. The analysis procedure was essentially a linear regression that combines mean adjusted test scores as the dependent variable, and aircraft noise values and an ambient noise estimate as the predictors, for each school and year, from 2000-01 to 2008-09, for which data were available.

Separate comparisons were conducted for mathematics and reading in Grades 3, 4, and 5. Although the results were generally similar across the two subject areas and three grades, there were variations because different states conducted testing in different grades in different years.

Analyses were implemented using the GLM procedure (PROC GLM) in the Statistical Analysis System (SAS (r)), version 9.1.3. This procedure is a generalization of linear regression that combines quantitative and categorical predictors and computes parameter estimates that best fit a dataset to a model. The best fit is defined as the fit that minimizes the variance of deviations between predicted and observed values of a dependent variable. The model used was:

$$\begin{aligned}\langle \textit{adjusted target school test score} \rangle_{ijy} = {} & \langle \textit{mean school district adjusted test score} \rangle_{iy} \\ & + A \times \langle \textit{aircraft noise measure} \rangle_{ijy} \\ & + B \times \langle \textit{ambient noise measure} \rangle_{ijy} + \langle \textit{error} \rangle_{ijy}\end{aligned}$$

for school j in district i in year y, where control schools are in the same district as the target schools.

The deviation of a target school test score from the district average is thus:

$$\begin{aligned}\textit{Deviation}_{ijy} & = \langle \textit{adjusted target school test score} \rangle_{ijy} - \langle \textit{mean adjusted district test score} \rangle_{iy} \\ & = A \times \langle \textit{aircraft noise measure} \rangle_{ijy} + B \times \langle \textit{ambient noise measure} \rangle_{ijy} + \langle \textit{error} \rangle_{ijy}\end{aligned}$$

A mean score was estimated for each school district in each year, and the deviation of a target school's adjusted test score from the district mean in each year was fit to a linear combination of an aircraft noise measure and an ambient noise estimate. Estimates for the quantities A and B were then obtained for best fit of the 26-state database to the model. Aircraft noise measures were set to zero for control schools.

Each observation in the dataset was weighted by the reported or estimated number of students tested. The sample was limited to school districts with at least two schools exposed to aircraft noise and two schools not exposed to aircraft noise, a total of 917 aircraft noise-exposed schools and 5,293 comparison schools in 104 school districts in 26 states. Analogous results obtained by also including districts with a single aircraft noise-exposed school and multiple comparison schools were very similar.

Parameter estimates for the quantities A and B were scaled as percentages of a test score standard deviation per a 10dB change in noise level. The standard deviation was computed for school mean test scores in each state and year, prior to demographic adjustment. The statistical significance of the aircraft noise and ambient noise effects (i.e., the likelihood that the effect is different from zero) were estimated by the ratio of the parameter estimates to their estimated standard errors.

5.9.8. Data Presentation

Because test procedures are different from state to state, and can vary within states for different years, it I not possible to simply present test scores as a function of noise level on a national scale. The test scores for each state have to be normalized before being combined for a national estimate. Having done that, the effect of noise is described by how much the combined, normalized test scores differ from the average.

Effects in this study are reported in terms of differences in average test scores of schools with different levels of exposure to aircraft noise[6]. These differences, or effect sizes, are reported in fractions of standard deviations of the distributions of school test scores across the schools in the various included states and years. Unless otherwise noted, all effect sizes displayed in the report are statistically significantly different from zero ($p<0.05$).

As a reasonable approximation, the distribution of test scores in a state roughly follow the normal bell curve. That means that a school with a score of 60, or one standard deviation above the average, would rank at the 84th percentile of schools in its state, or higher than five out of six schools in the state, while a school with a score of 40 would rank at the 16th percentile, or lower than five out of six schools in the state. Table 5-7 shows the relationship between percentile ranks and standard deviation units.

TABLE 5-7 Relationship Between Percentile Ranks and Standard Deviation Units

Percentile rank	10th	20th	30th	40th	50th	60th	70th	80th	90th
Standard deviation from mean	-1.282	-0.842	-0.524	-0.253	0	0.253	0.524	0.842	1.282
Rescaled test score	37.18	41.58	44.76	47.47	50.0	52.53	55.24	58.42	62.82

Thus, if the effect of exposure to a given level of airport noise is associated with a rescaled test score deficit of 0.524 standard deviations, it would be as if it changed a 70th percentile school into a 50th percentile school or a 50th percentile school into a 30th percentile school, a change of 20 percentile points. Note that the relationship shown in Table 6 is reasonably linear over the range from the 30th to 70th percentile, but deviates from linear at more extreme percentile levels.

To provide context to understand the size of the airport noise effect, consider the analogous association between poverty and test scores. A 10 percent greater number of students at a school who are eligible for the federal free and reduced price lunch program (e.g., 30 percent instead of 20 percent) is, on average, associated with a 0.170 standard deviation deficit in achievement relative to other schools in the state, other things being equal. This 0.170 standard deviation deficit in achievement corresponds to about a 7 percentile change in state ranking, say from the 50th to 43rd percentile.

5.10. Results

The study considered a total of 6198 schools at 46 airports, 917 of which were identified as being within the Year 2000 DNL 55 dB noise contour (target schools), and in school districts containing at least two comparison schools that were not exposed to aircraft noise**.**

The detailed results of the analyses are presented in the tables of Appendix G in terms of fractional changes of a standard deviation for given differences in the value of the selected noise metrics. This is the standard way in which results are presented in educational research studies. To gain a better understanding of the size of the aircraft noise effect the results are summarized in Table 5-8 in terms of the percentile change in state ranking resulting from the effect of aircraft noise based on the relationship in Table 5-7.

[6] The use of the term “effects” is in accord with the use of linear regression models. However, these “effects” are not necessarily causal. They merely indicate that there is a relation between variation on the predictor measures and variation on the dependent variable

TABLE 5-8 Summary of Estimated Noise Effects for Various Aircraft Noise Metrics

Noise Metric	Noise Measure		Percentile Decrease in State Ranking	No. of Target Schools Affected[1]
Airport Noise, L_{eq}	10 dB increase		<1	All
Ambient Noise, L_{amb}	10 dB increase		3	All
Total Noise, L_{tot}	10 dB increase		3-4	All
Average Maximum Level, L_{Amax}	10 dB increase		~1	All
Average SEL	10 dB increase		~1[2]	All
Number of Daily Events Above a Noise Threshold	50 events greater than 70 dB (6/hour)		4	80
	100 events greater than 70 dB (12/hour)		8	25
Daily Time Above a Noise Threshold	20 minutes above 70 dB (2.5 min/hour)		5	22
	25 minutes above 65 dB (3 min/hour)		5	71
Incremental Noise, $\Delta L = L_{tot} - L_{amb}$	All Students	10 dB increase	6	103
		15 dB increase	9	30
(All Target Schools)		20 dB increase	12	10
Incremental Noise, $\Delta L = L_{tot} - L_{amb}$	Non-Disadvantaged Students	10 dB increase	9	103
		15 dB increase	14	30
		20 dB increase	18	10
(Same Target Schools)	Disadvantaged Students	10 dB increase[2]	5	103
		15 dB increase[2]	8	30
		20 dB increase[2]	10	10

[1] Number of affected target schools exposed to the stated condition (noise measure) in 2008.
[2] Effect size not statistically significantly different from zero.

The percentile decrease in state ranking is listed for all the selected noise metrics. In addition, the final column in the table includes the number of target schools (included in this study) that would meet the conditions listed under the 'Noise Measure' column heading for aircraft operations existing in the year 2008. The conclusions that can be made from these results are as follows.

The association between the effects of aircraft noise and student test scores is statistically significant[7] but small when aircraft noise levels are described by the simple decibel noise metrics, such as exterior L_{eq}, L_{Amax}, and SEL, by themselves. In fact, the influence of ambient noise and total noise L_{tot} (aircraft plus ambient noise) has more effect on test scores than aircraft noise described by these metrics. The lack of a correlation with L_{eq} alone is maybe not surprising as the ambient level exceeds the aircraft noise level at more than half of the target schools. The correlation is improved somewhat by considering total noise L_{tot} (airport plus ambient). The single-event metrics, L_{Amax} and SEL, perform poorly perhaps because, even though they describe the individual aircraft noise levels, they contain no information on the frequency of aircraft events.

[7] The magnitude of the effect is small, but the result would be expected to arise simply by chance only in rare circumstances. Hence the result provides enough evidence to reject the hypothesis of "no effect".

Test scores show a much higher correlation with non-decibel airport noise metrics, such as Number of Events above a threshold, NA(L), and Time Above a threshold, TA(L). Most target schools are exposed to less than four events per hour greater than 70 dB during the school day, and only about 5 percent experience more than ten aircraft events per hour greater than 70 dB. The NA metric fails to provide information on the levels of the individual events, but TA does provide information on the length of time that a disturbance may occur.

The influence of airport noise on test scores becomes more apparent when the levels are related to ambient noise levels, such as with the incremental noise level $L_{tot} - L_{amb}$, and the effects are relatively insensitive to ambient levels greater than 50 dB (at least as far as this statistical analysis allows). This result may not be surprising since, even though the individual maximum aircraft levels exceed the ambient, a certain amount of masking does occur. Schools exposed to airport noise are near airports, and many airports are in metropolitan areas with high ambient noise levels. It should be noted that since control schools are in the same school districts as the target schools, their ambient levels will be similar.

Rather than define an absolute level above which aircraft noise can affect test scores, it may be more appropriate to base the onset of effects on the level of ambient noise. If the aircraft L_{eq} is 5 dB greater than the ambient L_{amb}, then the incremental level $L_{tot} - L_{amb}$ is 6 dB, and the percentile decrease in state ranking is about 3 percent and statistically significant. In Appendix G.3 it is estimated that this relationship is valid for ambient levels greater than 50 dB. As a result, a first cut at defining a threshold for the effect of aircraft noise on test scores would be when the aircraft noise is 5 dB greater than the ambient noise for ambient levels greater than 50 dB.

When the analysis is repeated to evaluate the test scores as the aggregate statistic for subgroups of students in the same school (under exactly the same ambient noise and school conditions), it was found that the estimated effect of aircraft noise increment for non-disadvantaged students is almost twice as great as for disadvantaged students. A 10 decibel increment over ambient noise was associated with a 9 percentile change in state ranking for non-disadvantaged students, but for disadvantaged students the estimated association was much smaller and not statistically significantly different from zero. The mean adjusted scores of disadvantaged and non-disadvantaged students in schools exposed and not exposed to airport noise are shown in Table 5-9 from the same schools comparison analysis. Note that the scores for all grades and subjects drop with exposure to noise, and that the mean differences are all larger for non-disadvantaged students than for disadvantaged students.

Although the statistical analysis process may identify that a relationship exists, it does not necessarily provide a rationale for that relationship. At this time, any hypotheses we might offer to explain the differences would be conjecture.

TABLE 5-9 Mean Adjusted Test Scores for Subgroups of Students

	Disadvantaged Students			Non-Disadvantaged Students		
	Not Exposed	Exposed	Delta	Not Exposed	Exposed	Delta
Reading Grade 3	50.53	50.47	-0.06	50.08	49.39	-1.36
Reading Grade 4	50.44	49.83	-0.61	50.10	48.74	-0.68
Reading Grade 5	50.59	50.09	-0.50	50.16	49.48	-0.65
Math Grade 3	50.52	50.05	-0.47	50.04	49.39	-1.70
Math Grade 4	50.39	49.29	-1.10	50.02	48.32	-1.28
Math Grade 5	50.70	50.20	-0.50	50.24	48.96	-1.36

Finally, estimates were made of the effect of sound insulation on student test scores. The obvious method of comparing scores immediately before and after sound insulation was introduced was hampered by the naturally occurring variation in scores from year to year, and a sample size limited to 29 elementary schools that were insulated within the study years for which test scores were available. However, a comparison of the airport noise increment effects in 119 schools that were insulated (many before the period of the study) versus those that were not insulated indicated that the apparent effects of airport noise increments found for non-insulated schools disappeared when measured for insulated schools. In other words, the effect of insulation was essentially to cancel out the effect of the aircraft noise exposure.

The mean adjusted scores, by school category, are shown in Table 5-10 showing that the scores in exposed schools after sound insulation is introduced approach and sometimes exceed those in non-exposed schools. The numbers in this table are averages over all levels of aircraft noise exposure. Schools with higher exposure may show larger improvement than those with lower exposure.

TABLE 5-10 The Effect of Sound Insulation on Reading and Math Scores (119 Schools)

School Category	Reading			Math		
	Grade 3	Grade 4	Grade 5	Grade 3	Grade 4	Grade 5
Not exposed	50.0	50.0	50.1	50.0	50.0	50.1
Exposed and not insulated	49.6	49.0	49.7	49.6	49.0	49.7
Exposed and insulated	49.9	49.8	50.5	50.6	50.3	51.3

5.11. Grade Equivalent Scores

In Europe, researchers have used the concept of grade equivalent scores and “months delay in reading skills” to describe the effects of noise on test scores. For example, when the national data relating to the reading comprehension tests were used, an 8 percent decrease in ranking (equivalent to a decrement of one-fifth of a standard deviation) was equivalent to an 8-month difference in reading age in the United Kingdom, and a 4-month difference in reading age in the Netherlands (Stansfeld et al 2005). The problem in applying this concept to the US is that one-fifth of a standard deviation might be 3 months in one state and 6 months in another, depending on the distribution of test scores in each state. The RANCH study results (Stansfeld et al 2005), for example, shows different relationships in the different countries. Percentile ranks of schools within states mean the same thing in all states.

5.12. Results Related to Study Objectives

The questions to be answered in this study were listed in Section 3,1 of the report. The results outlined above provide the following answers:

6. *To what extent is student learning affected by aircraft noise?*

   Estimated 6 and 12 percentile decrements in state ranking for increases of 10 and 20 dB respectively in incremental aircraft noise level.

7. *What is the most appropriate noise metric for describing aircraft noise as it affects learning?*

The metric that shows the largest effect is the incremental level L_{tot} - L_{amb} for ambient levels greater than 50 dB. The Number of Events Above 70 dB, NA(70), and Time Above 70 dB, TA(70), metrics are also indicators of the effects of aircraft noise.

8. *What is the threshold above which the effect is observable?*

   An approximate threshold is when the aircraft noise L_{eq} exceeds the ambient by 5 dB, based on a criterion of a decrement of 3 percentile points in state ranking.

9. *Has insulation meeting existing classroom acoustic criteria improved student achievement?*

   Insulated schools have better test scores than those with no insulation which may be an indication that insulation could contribute to improved scores by returning test scores to what they would have been with no aircraft noise.

10. *How does aircraft noise affect learning for students with different characteristics?*

    The study showed that the effect of noise was greater for non-disadvantaged students than for disadvantaged students, although the analysis process does not make it possible to provide a rationale for this result. This issue may be addressed in the upcoming ACRP Project 02-47 Assessing Aircraft Noise Conditions Affecting Student Learning - Case Studies

5.13. Cautionary Notes

A note of caution is necessary in interpreting these results. Test scores were available for a large sample of schools (917 target and 5,281 control schools in 104 school districts), and data on airport operations were available for 46 of the largest airports in 26 states, over a period of 9 years, providing some reassurance that the effect of random errors was reduced. However, the results might well be distorted by three types of imperfections in the data.

First, the adjustment for demographic and resource factors was limited to four measures. Schools exposed to airport noise may have differed in other ways from other schools in their districts (besides the noise factor itself) that were not captured by the measures used for demographic adjustments.

Second, the government agency that provided the latitude and longitude information on the location of schools could not provide documentation of quality control on those data, and there was some evidence that some school locations may have been imperfect. Latitude and longitude data were checked for all of the 173 insulated elementary schools and were found to be reasonably true, and certainly not sufficiently inaccurate to account for more than one decibel in noise level.

Third, the estimates of ambient noise were based on a single measure, population density, and although there is empirical data to support the relationship between population density and ambient noise levels, that estimate is subject to error. The noise from local heavy trucks on arterials is included in the definition of ambient noise. Noise from heavy trucks on freeways is not included in the estimate of ambient noise; neither is it included in estimating the effect of noise on test scores at target schools. This may have an effect on the results for schools close to freeways with heavy truck traffic. It should be noted that freeway noise, and specifically individual truck noise, is localized and attenuates rapidly with distance due to shielding from buildings, unlike the noise from elevated aircraft.

5.14. Comparison of Results with Previous Studies

The current study found statistically significant associations between airport noise and student mathematics and reading test scores, after taking demographic and school factors into account. Associations were also observed for ambient noise and total noise on student mathematics and reading test scores, suggesting that noise levels per se, as well as from aircraft, might play a role in student achievement.

This study further adds to the increasing evidence base which suggests that children exposed to chronic aircraft noise at school have poorer reading ability and school performance on achievement tests, than children who are not exposed to aircraft noise (Clark, et al., 2006; Haines, Stansfeld, Brentnall, et al., 2001; Haines, Stansfeld, Job, Berglund, and Head, 2001a, 2001b; Hygge, Evans, and Bullinger, 2002; Stansfeld, et al., 2005). Overall, evidence for the effects of noise on children's cognition is strengthening and there is increasing synthesis between epidemiological studies, with over twenty studies having shown detrimental effects of aircraft and road noise on children's reading (Evans and Hygge, 2007).

The current study has undertaken a series of analyses of separate datasets, together encompassing an extremely large sample of schools (917 target and 5281 comparison schools from 104 school districts), and presents convincing evidence from an extensive set of analyses that both airport noise and ambient noise levels influence children's learning. In comparison, the largest comparable primary study to date, the RANCH study (Clark, et al., 2006; Stansfeld, et al., 2005) examined over 2000 children from a total of 89 schools in the Netherlands, Spain and the United Kingdom. While the current study does not take into account individual differences in reading and mathematical ability and individual level socioeconomic factors, the findings are striking, and if further individual level data were available, larger effects may be observed.

The current study adds specifically to knowledge about aircraft noise effects within the US, which had not been studied in recent years. A strength of the study is that data from 26 states has been examined. A previous study of aircraft noise exposure and school and data from all elementary schools in Brooklyn and Queens, New York from 1972 to 1976 found that an additional 3.6% (95% CI 1.5-5.8%) of the students in the noisiest schools read at least 1 year below grade level. It is hard to compare the findings between these studies, as the current study has had to assess percentile change in state ranking of the school for reading and mathematics. However, both studies indicate a detrimental effect of aircraft noise on learning, despite being conducted over 30 years apart. The findings of the current study are more consistent in their conclusion than those of the FICAN pilot study (Eagan, Anderson, Nicholas, Horonjeff, and Tivnan, 2004; FICAN, 2007), which focused on whether abrupt aircraft noise reduction within classrooms, caused either by airport closure or newly implemented sound insulation was associated with improvements in test scores, in 35 public schools in Illinois and Texas. The pilot study found some evidence for effects of aircraft noise reduction and improved test results, but also, due to its small size, found some associations that were null and some that were in the opposite direction to that hypothesized.

The current study is one of the first studies to quantify the potential impact of sound insulation on children's learning achievement for aircraft noise exposure. The study found evidence from a sample of 119 elementary schools that the effect of aircraft noise on children's learning disappeared once the school had had sound insulation installed. The issue of the effectiveness of sound insulation in reducing learning deficits associated with aircraft noise was identified as a priority in the literature review undertaken for this project. Little prior research has tested whether sound insulation of classrooms lessens the effects of aircraft noise on children's learning. One study by Bronzaft (Bronzaft, 1981) examined the effectiveness of track improvements and the installation of sound absorbing ceilings in 3 classrooms at school. Before insulation, school children in classrooms on the noisier side of the school had poorer reading achievement scores than children on the quieter side of the school. After the intervention, which resulted in a total noise reduction of 6-8 dB in train noise, there were no differences in reading achievement between children on the noisy side and those on the quiet side of the school.

To date, only a few studies have examined associations between noise exposure and mathematical ability (Haines, Stansfeld, Head, and Job, 2002; Ljung, Sorqvist, and Hygge, 2009; Shield and Dockrell, 2008). Only one previous study has examined associations specifically for aircraft noise exposure, finding that the initial association between aircraft noise and mathematics was explained by socioeconomic factors (Haines, et al., 2002). The current study strongly suggests that aircraft noise exposure at school influences mathematical achievement and suggests that mathematics should be examined in further studies.

Effects on achievement tests were found for the following aircraft noise metrics: L_{eq}, L_{tot}, L_{max}, SEL. Test scores also showed associations with non-decibel airport noise metrics such as Number of Events above a threshold NA(L) and time above a threshold TA(L). Associations were observed for ambient noise level at the school (L_{amb}) and total noise (L_{tot}). A few previous studies have examined effects of different noise metrics on children's learning outcomes, but the current study is among the first studies to examine aircraft noise. Shield and Dockrell (Shield and Dockrell, 2008) found associations between external noise (predominantly road traffic noise) and poorer national test scores for children aged 7 and 11 years attending London primary schools, and also found an effect for L_{Amax}. These studies, considered together, suggest increasing evidence that maximum noise levels are important for noise effects on children's learning.

The estimated effect of aircraft noise was found to be twice as great for non-disadvantaged students as for disadvantaged students (disadvantaged students were those whose family, social or economic circumstances hinder their ability to learn at school). The West London School study around Heathrow airport in London did not find any differences in the effect of aircraft noise on children's reading when examining disadvantaged subgroups of children: English and Non-English as the main language spoken at home, children in employed and unemployed households, children in deprived and not deprived households (Haines, Stansfeld, Brentnall, et al., 2001). The findings of the current study need replication in further studies, preferably conducted in different countries, before conclusions about the influence of disadvantage on the association between aircraft noise and children's learning can be drawn.

CHAPTER 6. FUTURE RESEARCH RECOMMENDATIONS

6.1. Longitudinal Studies

While previous studies have demonstrated effects of chronic aircraft noise exposure on children's reading comprehension and memory, it must be acknowledged that the majority of the evidence comes from cross-sectional studies. The development of cognitive abilities such as reading are important not only in terms of educational achievement but also for subsequent life chances and adult health (Kuh and Ben-Shlomo, 2004). To understand the causal pathways between noise exposure and cognition, and design preventive interventions there is a need to study these associations longitudinally. Few longitudinal studies have examined the effects of persistent exposure throughout the child's education: studies of the long-term consequences of noise exposure during school for later cognitive development and educational outcomes have not yet been conducted and remain of prime policy importance.

While there is an ongoing follow-up of the UK RANCH cohort (Clark, Stansfeld and Head, 2009), research needs to address this question with some urgency. There is no longer a need for cross-sectional evidence and research should focus on longitudinal, prospective study designs. Longitudinal studies would also need to address the complexities of exposure assessment where children are placed in different classrooms for differing periods throughout their school life.

6.2. School Case Studies

The effects of aircraft noise conditions on state standardized test scores for elementary school students identified in the current study should be supplemented by case study research aimed at answering the following questions:

- What immediate, observable changes occur when a class is exposed to aircraft noise? How, if at all, do these changes vary based on the 1) nature of the teaching style, 2) lesson content, 3) disability status of the students, and 4) ESL status of the students?
- How do students who are regularly exposed to aircraft noise at school differ from similar students who are not exposed to aircraft noise at school with respect to inhibitory factors including distraction, learned helplessness, memory difficulties, hearing and auditory processing difficulties, stress, health difficulties, noise annoyance, and absenteeism?
- How do teachers who are regularly exposed to aircraft noise at school differ from teachers who are not exposed to aircraft noise at school with respect to inhibitory factors including stress, health difficulties, noise annoyance, absenteeism, and vocal strain?
- To what extent, if any, is the effect of aircraft noise on students and teachers at school influenced by their exposure to noise at home?
- According to students and teachers, how, if at all, does aircraft noise influence teaching and learning?

Such case study research will inform future large-scale and longitudinal research to determine factors that mediate and moderate the effect of aircraft noise on student learning, a research priority that has been identified in previous literature (Boman and Enmarker, 2004; Hygge, 2003; Maxwell and Maxwell, 2000). It would also be useful to conduct future research at schools exposed to varying levels of aircraft noise in order to ascertain the varying influences of different noise levels, rather than using a dichotomous sample composed of noise-exposed and non-noise-exposed schools.

6.3. Classroom Acoustics

Given the mounting evidence that aircraft noise is related to impairment of school performance, the question of what can be done to reduce noise induced learning impairments becomes salient. The literature suggests an increasingly important role of classroom acoustics on performance (Shield and Dockrell, 2008): In their study of noise exposure and national test scores for elementary school children, Shield and Dockrell (2008) successfully included internal acoustics in a sub-sample of 16 out of 142 schools: this illustrates the difficulties and potential lack of power of including classroom acoustics in such studies.

Before-and–after studies could also be carried out at the individual level. Assessing exposure, cognitive performance and socioeconomic status at the individual level could more easily incorporate internal classroom acoustical information but such studies are likely to be on a smaller scale. Opportunities to conduct naturally occurring before-and-after experiments, where schools are already being insulated should be taken advantage of.

Internal classroom noise has been demonstrated to be associated with performance and educational outcomes in recent years: further studies examining classroom acoustical factors such as reverberation and speech-to-noise ratios in relation to performance are required.

6.4. Combined Exposure

To date, studies have yet to examine in detail how noise exposure interacts with other environmental stressors, such as air pollution (Clark and Stansfeld, 2007). Transportation systems (road traffic in particular) generate both noise and air pollution (e.g. particulate matter, nitrogen oxide, hydrocarbons etc) and there is some suggestion that air pollution may also influence children's cognitive performance (Franco Suglia, Gryparis, Wright, *et al*, 2008). Studies have yet to address the effects of joint exposure to noise and air pollution. It is possible that the combined exposure to these transport related stressors could interact and increase their single effects. Air pollution could be a relevant factor for children's learning in schools located near airports, as airport operations are usually associated with high levels of road traffic. Similarly, exposure to more than one noise source, such as aircraft noise and road traffic noise could have a greater effect children's learning than either source alone, although the RANCH study found no effect of this type of combined exposure.

6.5. Thresholds for Effects

Finally, while this study and the recent RANCH study has considerably advanced knowledge about exposure-effect relationships between noise and children's cognition and health, further demonstration of exposure-effect relationships in different contexts and for different samples and vulnerable groups remains a research priority. Developing further knowledge about exposure-effect relationships will inform decisions concerning the design of physical, educational, and psychological interventions for children exposed to high levels of noise. Such relationships can be assessed using either individually collected cognitive performance data or via school-level test data.

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GLOSSARY AND ACRONYMS

ANSI – American National Standards Institute.

Confidence Interval, CI –an indication of the reliability of an estimate. CI is a term used in statistics that measures the probability that a population parameter will fall between two set values. The confidence interval can take any number of probabilities, with the most common being 95%.

CCD – US Department of Education (ED) Common Core Database (CCD) which provides names and street addresses for public elementary and secondary schools in the US..

Cross-sectional Study – A cross-sectional study is one type of observational study that involves data collection from a population, or a representative subset, at one specific point in time. In this school study, for example, comparisons were made between test scores at different schools all in one year.

DNL – The Day/Night Average Noise Level. Also L_{dn}.

ESL – English as a Second Language.

ETMS – Enhanced Traffic Management System.

FICAN – Federal Interagency Committee on Noise.

INCE-USA – Institute of Noise Control Engineering, USA Chapter.

INM – Integrated Noise Model.

L_{amb} – As used in this study, the ambient noise level at a location represents the total A-weighted noise level produced by all unidentifiable sources; that is, excluding major freeways and airports.

L_{day} – The (energy) average A-weighted noise level over the daytime hours, usually 7am to 11pm. Also referred to as L_{eq16}.

L_{night} - The (energy) average A-weighted noise level over the nighttime hours, usually 11 pm to 7am.

L_{eq} – The average (energy average) A-weighted noise level over a given period of time, in this study the 8-hour school day from 7am to 3pm. Also referred to as L_{Aeq}.

L_{dn} – The Day/Night Average Noise Level in dB. Also DNL.

L_{max} - The highest A-weighted sound level measured during a single (aircraft) event in which the sound changes with time.

Longitudinal Study – A longitudinal study is a correlational research study that involves repeated observations of the same variables over long periods of time, for example, monitoring school test scores over time.

MAGENTA – Model for Assessing Global to Noise from Transport Aircraft.

Monte Carlo Simulation – A computational algorithms that rely on repeated random sampling to obtain numerical results; typically one runs simulations many times over in order to obtain the distribution of an unknown probabilistic entity.

NA(L) - Numbers of aircraft events above a threshold noise level L.

NLSLSASD – National Longitudinal School-Level Test Score Database.

Pugh Matrix - A method for concept selection using a scoring matrix in which alternatives are scored relative to weighted criteria.

RANCH – Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health.

SAT – Standardized test scores.

SAS/GLM – SAS is a software suite developed by SAS Institute for advanced statistical analysis/ General Linear Model.

SEL - Sound exposure level is a composite metric that represents both the intensity of a sound and its duration. SEL is a logarithmic measure of the total acoustic energy transmitted to the listener during the event.

SII – Speech Intelligibility Index is a measure, ranging between 0.0 and 1.0 that is highly correlated with the intelligibility of speech.

SIL – Speech Interference Level in dB is the (arithmetic) average of the noise levels in the 500, 1000, and 2000 Hz octave bands, used to characterize a noise signal in the frequency range where the human ear has its highest sensitivity

Student's t – A t-test is used to determine if two sets of data are significantly different from each other.

TA(L) - Time in minutes above a threshold noise level.

WHO – World Health Organization.

Z Score – In statistics, the Z score, or standard score, is the number of standard deviations an observation or datum is above the mean.

APPENDICES

Appendices A through G can be found in *ACRP Web-Only Document 16 Volume 2, Assessing Aircraft Noise Conditions Affecting Student Learning*.