Environmental Research and Consultancy Department

ERCD REPORT 0908

Aircraft Noise and Children's Learning

K Jones

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Civil Aviation Authority

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Summary

This report is a literature review of the research into the effects of aircraft noise on children's learning and cognition. The primary cognitive processes that are examined in relation to aircraft noise are episodic memory, semantic memory, sustained attention and reading comprehension. The review includes early work in this area from the 1970s, to the most recent studies. Key studies are described, along with suggestions for future research.

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Glossary of Terms

A-weighting A frequency weighting that is applied to the electrical signal within a noise-measuring instrument as a way of simulating the way the human ear responds to a range of acoustic frequencies.

Adrenaline Also referred to as Epinephrine. A hormone and neurotransmitter and member of the catecholamine family, which, when released increases the response of the sympathetic division of the Autonomic Nervous System.

Cortisol Hormone produced by the adrenal gland that is associated with stress responses, increasing blood pressure and blood sugar and reducing immune responses.

dB Decibel units describing sound level or changes of sound level.

dBA Levels on a decibel scale of noise measured using a frequency dependent weighting, which approximates the characteristics of human hearing. These are referred to as A-weighted sound levels.

L_{eq} Equivalent sound level of aircraft noise, often called equivalent continuous sound level. L_{eq} is most often measured on the A-weighted scale, giving the abbreviation L_{Aeq}.

Noradrenaline

Also known as Norepinephrine. Part of the catecholamine family, with dual roes a hormone and neurotransmitter. A stress hormone, along with adrenaline, noradrenaline also underlies the fight-or-flight response, directly increasing heart rate, triggering the release of glucose from energy stores, and increasing blood flow to skeletal muscle.

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1. Introduction

1.1 The effects of aircraft noise have been shown to have implications for sleep disturbance (Basner, 2004; Griefahn, 2000) and cardiovascular effects during sleep (Spreng, 2002; Di Nisi, 1990), and although the effects of transportation noise have been studied during waking hours in adult populations, there are also important implications for the impact of aircraft noise on children's learning and cognitive performance. This review aims to describe the documented effects of aircraft noise on children's development and learning abilities, and suggests potential areas for future work in this area.

1.2 The primary cognitive processes that are examined in relation to aircraft noise are episodic memory, semantic memory, sustained attention and reading comprehension. Episodic memory refers to the memory of people, places, times, events and other conception-based knowledge in relation to an experience. It can be thought of as an autobiographical memory, which is personal to the individual. Semantic memory refers to the memory of meanings, understandings and other concept-based knowledge that is unrelated to experiences. It is the conscious recollection of factual information and general knowledge about the world that is thought to be independent of context and personal experience. Sustained attention refers to a vigilance state that requires attention to be maintained on a focus over a period of time, without lapsing.

1.3 Although there is a wealth of literature on noise and children, the aim of this review is to describe the results of work conducted specifically on aircraft noise and children's cognition.

2 Early Work on Aircraft Noise and Children's Learning

2.1 The early work into this area began in 1975, when Ando *et al* examined the effects of aircraft noise on a simple search and addition task on 1144 elementary school pupils living around an airport, and in a quite area in Kobe, Japan. The conditions of no stimulus sound were compared to that of jet stimulus of 90 ± 5dBA. In terms of performance, those children from relatively noisy areas showed occasional short periods of substantially slower than their average rate of work. When working in continual noisy rather than quiet conditions, these differences did not exist, and the results were independent of gender and attitudes of the children towards aircraft noise.

2.2 There is always a conflict between the pros and cons of laboratory studies versus field study settings. Although laboratory studies allow for detailed and careful manipulation of specific parameters, and a higher degree of control over extraneous confounding variables, field settings offer the opportunity to explore the effects of noise within people's homes, following their usual schedule and with possible habituation to aircraft noise.

The Los Angeles Study

2.3 Cohen *et al* (1980) argued that there needed to be interplay between the two study types, and that maximum understanding of the impact of environmental variables could be achieved by combining both designs. The authors presented the results from an individual testing procedure in a field setting. A matched-group design was used to allow the study of children attending the four noisiest elementary schools around Los Angeles International Airport.

2.4 The peak sound recordings in the schools reached 95dbA, with over 300 over-flights each day (approximately one every 2.5 minutes during school hours). Three schools (in quiet areas) were matched with the experimental schools for a range of variables such as grade levels, ethnic and racial distribution of children, percentage receiving state aid, and occupation and education levels of parents.

2.5 The study centred on the after-effects of noise exposure, therefore all tasks and questionnaires were administered in a quiet area (a noise-insulated trailer parked outside the school). Children for all noise-impacted third and fourth-grade classrooms in each noise school as well as those children from an equal number of classrooms in quiet areas were included.

2.6 The overall mean peak for classrooms in noisy areas were 74dBA and in quiet schools it was 54dBA, with the highest readings at 95dBA and 68dBA, respectively. The results were consistent with laboratory studies, in that children from noisy schools had higher blood pressure than those from quiet schools. Children in noisy schools were more likely to fail on the cognitive task and were more likely to give up before the allocated time to complete the task was allowed. The authors suggested that this might implicate increased helplessness in those children exposed to higher noise levels.

2.7 Cohen (1981) reported data from the Los Angeles Noise Project, a longitudinal study that assessed the impact of aircraft noise on elementary school children. The design was to investigate the course of adaptation and to assess the impact of a noise-abatement intervention on a variety of physiological, cognitive, and motivational measures. The report referred to the results from an extension of the study described above (Cohen, 1980). The matched groups were the same but this report described data collected in the summer following the original data collection. Architectural interventions were installed in 43% of the noisy school classrooms, which resulted in a substantial decrease in noise levels in treated rooms. Following one year after the original testing, children who were still enrolled at the schools were retested on the original measures. The study aimed to assess:

- Whether children retested one year later continue to show effects found during the first session, or do they adapt to the noise over the one-year period?

- The effects of noise abatement interventions in the classroom on various measures of health and behaviour.

2.8 The data established the stability of the original results (Cohen *et al* 1980), in terms of highlighting the effects of motivational and physiological mechanisms that were consistent with the effects found in laboratory settings. The data presented established the stability of these effects over time and reinforced the previous interpretation that children do not adapt to noise over time.

2.9 Noise abatement was found to be partially effective, with the "important school achievement" measure showing some improvement for children in noise-abated classrooms, and had a small improvement effect on cognitive performance, children's ability to hear their teachers, and school achievement.

3. Aircraft Noise and Children's Learning in the 1990s

3.1 Chen and Chen (1993) looked at the effects of aircraft noise on the hearing and auditory pathway function of school-aged children. 228 students attending a school near an airport in Taiwan were compared to 151 students attending a school further away from the airport. Measurements of hearing ability between the two groups were compared, and children from the school under the flight path were found to have significantly worse hearing than those attending school further away. Audiometry and brainstem auditory evoked potentials (BAEP) were compared between the two groups, but there were no significant differences found. The authors suggested the results indicated that central transmission is not affected in children that have been exposed to aircraft noise for several years. The results showed a significant association between aircraft noise and exposure and prevalence of noise-induced hearing loss, and although damage to peripheral cochlear organs was confirmed in school-aged children, involvement of the central auditory pathway could not be demonstrated.

The Munich Study

3.2 Evans *et al* (1995) investigated at the effects of chronic noise and psychological stress on children, using neuroendocrine indices alongside cardiovascular measures. Performance was also measured in terms of speech perception, attention, choice reaction time and visual search (an attention-orientated task). 135 third and fourth graders, with a mean age of 10.78 years who were living in either a high noise-impact urban neighbourhood (24-hr L_{eq}= 68.1dBA; peak=79.8dBA) surrounding Munich International Airport, or in a quiet neighbourhood (24-hr L_{eq}=59.2dBA; peak=69.0dBA) in Munich. The groups were matched for socioeconomic status, occupation within the households, parental education, and family size. Blood pressure, twelve-hour overnight urinary adrenaline and noradrenaline and cortisol levels were assessed. A battery of tests to include measures of attention, memory and reading ability measured cognitive performance. In addition, motivation, annoyance and quality of life were assessed.

3.3 Testing was conducted in a sound-attenuated trailer at the children's school. The results showed that there was a difference in psychophysiological variables between groups. Overnight levels of adrenaline and noradrenaline were significantly different between those children chronically exposed to aircraft noise and those unexposed. Cortisol levels were not significantly different between groups. A significant difference was also observed in the systolic blood pressure among children chronically exposed to aircraft noise, compared to those in a quieter environment, although no difference was reported in diastolic blood pressure.

3.4 The two noise groups did not differ in terms of performance on an attention task, or with regard to reaction times. However, in the long-term memory recall task, children from noisy areas performed worse than their counterparts, and there were also slight reductions in working memory span in the children from the higher noise area. In terms of reading ability, children from noisy areas made significantly more errors on the German standardised reading test than children from quiet communities.

3.5 As has been reported by Cohen (1981), the findings showed that children from noisy locations persisted less than children from quiet areas, on an insolvable puzzle task, suggesting that there is a degree of helplessness associated with this group. With regard to annoyance measures, children living in noisier areas were significantly more annoyed by noise in their communities than children in quieter areas.

3.6 This study was important in being the first of its kind to integrate measures of physiological markers of stress with tests for cognitive performance in children exposed to chronic aircraft noise. The results raised questions as to whether the effects of aircraft noise in children persist or continue to widen with increased aircraft noise, and whether the deficits exhibited are reversible in the affected populations. The authors suggested that children might cope with adverse noise by developing coping strategies such as 'tuning out' ambient noise, which may have implications for language acquisition and speech processing.

3.7 Evans and Maxwell (1997) followed this idea up and examined the effect of chronic noise exposure on reading deficits in children, specifically speech perception and phoneme comprehension. The authors hypothesised that the reason chronic noise exposure interferes with the development of reading skills is because it disrupts language acquisition. A secondary aim was to examine whether the link between noise exposure and reading deficits is the result of chronic or acute noise exposure. Acute interference occurs during the actual testing sessions, whereas the term chronic refers to long-term exposure to noise.

3.9 116 fist and second graders from two elementary schools in New York participated in the study. The target school was within the $65L_{eq}$ flight contour of a major New York metropolitan airport, with the control school located in a quiet neighbourhood.

Both were matched for percentage of children receiving subsidised lunches, ethnicity, and the percentage of pupils with English as a second language.

3.10 Reading skills were assessed, using the Woodcock reading subscales, along with language acquisition and speech perception. An embedded phoneme test was also given to each participant. The results showed that chronic noise exposure is significantly correlated with reading scores, and secondly speech perception was related to reading linkage. Speech perception and reading ability were also correlated. Interestingly, the mother's educational levels were correlated with noise exposure and with reading ability, however noised remained a significant predictor of reading scores after statistically controlling for mother's education. Income was not significantly correlated with either measure. Noise exposure affected speech perception, which in turn affected reading ability, yet even when speech perception was partialed out of the analysis, noise remained a significant contributor to reading ability.

3.11 The authors concluded that the association between noise exposure levels and reading was due to chronic exposure and not to acute inference by noise during the actual test session. There was also partial support for the hypothesis that language acquisition is an underlying, intervening mechanism accounting for the noise-reading deficit link. Evans *et al* also made the point that social and interpersonal processes should also be considered in the future, such as noise disrupting actual teaching time, the behaviours of teachers and primary caregivers, and also the effect of noise as an irritant, thereby possibly contributing to increased hostility and aggressive behaviours. They suggested that more rigorous, longitudinal studies are necessary, coupled with further analysis of underlying cognitive and social processes that can contribute to the adverse effects of chronic noise exposure of health and children's development.

3.12 Evans *et al* (1998) conducted a longer-term study over a two-year period, and assessed the physiological responses in children to chronic noise exposure. The timing of the study was such that a natural experiment was created due to the opening of the new International Airport in Munich. Resting blood pressure, overnight levels of neuroendocrine hormones, and quality of live were measured over a 2-year period among elementary school children in the flight paths, before and after the opening of the airport. Subjects were 217 third and fourth grade children (mean age 9.90 years) living either close to Munich International Airport or in nearby communities outside the noise impact zone of the new facility. Following the opening of the airport L_{eq} was 62dBA, with an L_{01} (the dBA) level exceeded 1% of the time over the sampling method i.e. 24 hours) of 73dBA in the noise-impacted communities. In the quiet communities at the same time, dBA L_{eq} was 55, with a dBA L_{01} of 64. Prior to the opening of the airport, dBA L_{eq} was 53 with a L_{01} of 63 in the noisy areas, and noise levels were comparably low in the comparison areas (dBA L_{eq} = 53; dBA L01 = 64). The matched samples did not differ in terms of socioeconomic status, type of occupation, parental education, or family size. Again,

testing was performed in a noise-proof trailer outside the schools, and blood pressure, adrenaline and noradrenaline, and cortisol levels were measured. Data were collected 6 months prior to the opening of the airport (Wave 1), 6 months after opening (Wave 2) and again 18 months after opening (Wave 3).

3.13 Blood pressure increased in the noise-impacted areas after Wave 1, and a sharp increase in adrenaline and noradrenaline levels were seen in those children living under the flight path following Wave 1, compared to the children in quieter areas. Cortisol levels were unaffected. Quality of life decreased significantly in the noise-impacted areas in after Wave 3, but remained stable in the quieter areas. The authors concluded that in young children chronic noise exposure appeared to cause increased psychological stress, as measured by cardiovascular, neuroendocrine, and affective indicators and these effects occur even among children who suffer no detectable hearing damage while living in the immediate vicinity of an airport. Bullinger *et al* (1999) also reported that motivational deficits were seen in those children exposed to aircraft noise in this study, compared to children living in quieter areas, as assessed by the number of attempts made to solve an insolvable puzzle task at the three time points.

4 Recent studies

The West London Schools Study

4.1 In 2001, Haines *et al* published the findings of a study into chronic aircraft noise exposure, stress responses, mental health and cognitive performance in 340 school children aged 8-11 around London Heathrow Airport. Children in four schools exposed to outdoor L_{eq}>66dBA were matched with those in lower noise areas, with outdoor L_{eq}<57dBA. The results indicated that chronic noise exposure was associated with higher levels of noise annoyance and impaired reading comprehension, but there was no effect on mental health problems or elevated cortisol levels. The authors concluded that the association between aircraft noise exposure and decrements in reading comprehension could not be accounted for by the mediating role of annoyance, confounded by social class, deprivation, main language or acute noise exposure.

4.2 The results of a follow-up study to this one were also published in 2001 by Haines *et al*, and included the results found a year later to the original study. It was hypothesized that:

- The effects of aircraft noise exposure on reading comprehension and noise annoyance at baseline would be replicated in the same sample of school children who were tested at follow-up a year later
- Chronic aircraft noise exposure produces an increased delay in reading comprehension over a period of a year, compared to pupils not exposed to aircraft noise during that year

- Chronic aircraft noise exposure in children would be associated with impairments in sustained attention and high levels of self-reported stress.

4.3 Sustained attention was tested as a mediating factor in the association between noise exposure and reading impairment. The initial study was conducted in 1996, with the follow-up study a year later in 1997. The initial response rate was 340 participants, with 275 completing the follow-on. Testing procedures were the same in each study, and were carried out inside classrooms to assess indoor sound levels of aircraft noise during testing, using a sound level meter on a tripod and a portable DAT recorder.

4.4 The results indicated that chronic exposure to high levels of noise exposure was associated with higher levels of annoyance, perceived stress, and poorer reading comprehension ability. Aircraft noise exposure was also associated with deficits in sustained attention. Over time, performance in reading comprehension was significantly different between the high and low noise groups, however following adjustments for age, main language spoken, and deprivation the difference failed to reach significance. The authors suggested that this might have been due to the reduced sample size in the follow-on study, and therefore a reduction in statistical power. The same result was found for annoyance, with significance failing to be reached after adjustments. Sustained attention did not explain the significant association between aircraft noise exposure at school and reading comprehension, as the main effect was not altered following adjustment for sustained attention.

4.5 The main results of this study can be summarised in the following points:

i) The associations between chronic aircraft noise and reading comprehension, noise annoyance and mental health were replicated at follow-up.

ii) The within-subjects analyses indicated that children's development in reading comprehension might be adversely affected by chronic aircraft noise exposure. Noise annoyance remained constant over a year with no strong evidence of habituation, and the effect of noise on children's progress in reading over time may be influenced by sociodemographic factors.

iii) The association between aircraft noise exposure and reading comprehension could not be accounted for by the sustained attention mediation hypothesis.

iv) Chronic aircraft noise exposure was associated with poorer sustained attention in children.

v) Chronic aircraft noise exposure was associated with higher levels of self-reported stress in children.

4.6 Although the results of this study were not conclusive, they did provide evidence to suggest that noise exposure affects child cognition, and stress responses and these effects do not habituate over time. The authors suggested that further research should examine the long-term implications of the effects of noise, and an exploration of the underlying mechanisms involved should be conducted.

4.7 In their review of the three field studies conducted by Cohen *et al* (1980, 1981), Evans *et al* (1995, 1998) and Haines *et al* (2001), Matheson *et al* (2003) summarised the main findings as previously discussed, and concluded that despite occurring in different parts of the world (Los Angeles, Munich and London), a number of findings were consistent in terms of the effects reported. Matheson *et al* concluded that it appeared that children chronically exposed to high levels of aircraft noise consistently experienced raised annoyance levels, and raised blood pressure. Evidence also suggested that there are increased stress response levels, in terms of neuroendocrine measures such as adrenaline and noradrenaline levels, in children exposed to chronic aircraft noise. The studies also provided evidence that motivation may be impaired and noise-exposed children may experience a sense of helplessness. In terms of cognitive performance, the studies suggested that chronic noise exposure affected reading ability and attention, along with some evidence for effects on memory.

4.8 Matheson *et al* suggested that an important direction for future research should be to examine the long-term effects of aircraft noise i.e. do the results persist, become more severe, or whether children are able to adapt to noise and catch-up with their non-noise exposed counterparts. It was also suggested the question of dose-response relationships should be addressed, i.e. at what levels of noise do effects begin to appear?

4.9 Hygge (2003) looked at the effects of noise in the classroom on 1358 children aged 12-14 years. They were tested for recall and recognition of a text exactly one week later. Single and combined noise sources were presented for 15 minutes at L_{eq} 66dBA, and single source presentations of aircraft and road traffic noise were also presented at 55dBA. A strong effect of noise on recall was found, along with a smaller, but significant effect on recognition. Aircraft noise and road noise impaired recall at both noise levels, with train and verbal noise having no effect. Some of the pair-wise combinations of aircraft noise with train or road traffic, with one as the dominant source, also interfered with recall and recognition.

4.10 Haines *et al* (2003) reported the qualitative responses of children to environmental noise in two studies. The first was the Millennium Conference Study, which used focus group interviews with an international sample, unselected by exposure. 36 children aged 10-13 years, from 12 countries took part, with approximately 12 children in each group. The second study was the West London Schools Study (Haines *et al* 2001), which involved individual interviews, conducted with a purposively selected sample exposed to aircraft noise. 18 children were interviewed from 10 schools near Heathrow Airport. Nine children were from schools exposed to high levels of aircraft noise (L_{eq}>63dBA) and nine were from schools exposed to lower levels of aircraft noise (L_{eq}<57dBA) The aims of the studies were to explore children's:

- Perception to noise exposure
- Perceived risk of and attitudes towards noise pollution

- Coping strategies
- Annoyance response

4.11 In the Millennium Conference Study, children listed the most frequent noises they heard as being made by people, e.g. screaming and crying, followed by noise made by animals and then traffic noise. Negative emotions were associated mainly with traffic noise, industrial noise, sirens, alarms etc. Positive emotions were linked to natural sounds such as the wind and household noises such as washing up, fans and the television. Many children felt that the amount of control they had over noise pollution depended on the source of the noise. The majority (n=19) felt in control of noise made in their own homes, but did not feel as though they had control over noise generated outside their homes such as planes flying overhead, or traffic noise. In terms of coping strategies, the most popular was by blocking out the unwanted noise, by wearing headphones or playing music. The second most reported strategy was by 'thinking about something else', and thirdly to take action such as telling someone to turn the noise down, or off. Two thirds of the sample wanted to change their environment and make it quieter, whilst a third thought it was acceptable at the present level.

4.12 In the West London Schools Study, half of the high aircraft noise exposed children (n=5) and a third of the low aircraft noise exposed children (n=4) expressed that there were aspects of their school environment that made them feel stressed. Four of these claims related to environmental stressors, two concerning aircraft (high noise), one cars (high noise) and one trees (low noise). A negative attitude was expressed towards aircraft noise by more low noise exposure children (n=7) than high noise exposure children (n=4). A majority of the high noise group expressed they were disturbed while thinking or doing schoolwork. In terms of coping strategies, covering the ears was the most popular method for dealing with aircraft noise for both the high and low noise populations. Doing nothing and ignoring it were the second and third most popular strategies from both noise groups. A negative emotional reaction to aircraft noise was voiced by all low noise (n=9), and most high noise (n=7) children. The children defined annoyance as, 'disturbing, being bothered, annoyed, feeling stressed out and upset, and even fear'. This emotional response of children was consistent with adult reactions and the authors suggest that child noise annoyance is the same construct.

4.13 A limitation of these studies were the relatively small sample sizes, and it was suggested that future research should focus on an international sample of children, with larger sample sizes, longer in-depth interviews and a measure of cultural expectation of ideal noise exposure in environments should be included.

4.14 Lercher *et al* (2003) examined ambient noise and cognitive processes among primary school children. Although this work did not focus on aircraft noise, the study showed interesting findings relating to the effect of noise on children's developmental cognitive process, in particular memory, which may be pertinent to

aircraft noise also. 123 primary school children (mean age 9.7 years) were selected from a large, representative sample of children living in the lower Inn Valley of Tyrol, Austria. The sub-sample was selected on the basis of ambient noise exposure at the child's home. In this study the noise sources were road and rail, with one half of the sample living in neighbourhoods below 50dBA and the other half living in areas above 60dBA. Data was collected individually in a mobile, sound-attenuated laboratory, and consisted of annoyance, psychological and physiological stress, and cognitive processes.

4.15 No effect of noise exposure was found on visual search performance, although the authors did suggest that the overall low error rates might mean this task was too easy. Chronic noise exposure was significantly related to both intentional and incidental memory, with intentional, explicit recall for the target text being significantly better in the low noise group than the high noise group. Incidental, free recall was impaired by chronic noise exposure, as was recognition memory. The authors suggested that chronic noise exposure has a detrimental effect on the developmental cognitive processes in children, particularly with regard to explicit or intentional memory. They suggested that a longitudinal study should be addressed in future research, allowing for each child to serve as his or her own control with changes in noise exposure. Such designs provide stronger causal inference and yield greater statistical power due to the lack of unexplained variance due to individual differences.

4.16 Interestingly, Matsui *et al* (2004) published the results from the West London Schools Study on children's cognition and aircraft noise exposure at home shortly after the findings by Lercher *et al.* Children from 20 schools around Heathrow Airport took part, ten from high-aircraft noise urban areas (L_{eq}>63dBA) and ten from low aircraft noise-impact urban areas. (L_{eq}<57dBA). The cognitive performance tests were group-administered in the classrooms, and parents were given questionnaires enquiring about the children's health and socioeconomic background, which may have affected performance. Reading comprehension was assessed, along with long term memory recall and recognition, and sustained attention. Confounding factors were measured by the calculation of a household deprivation score, incorporating: income, home tenure, car ownership, employment, status, central hearing, social class and household crowding. The mother's educational level was also asked.

4.17 The results showed significant trends of dose-response relationships with noise level on immediate recall, and delayed recall after adjustment for age, sex, deprivation score, language spoken at home, mother's education level and school. The other three measures (reading mean score, reading on difficult questions and sustained attention) did not show a significant dose-response relationship, however the odds ratios on the other three outcomes were greater than one in the highest noise groups. The authors concluded that there was a dose-response relationship between noise level at home and the ratio of pupils having decreased scores on

delayed and immediate recall after adjustment for age, sex, spoken language at home, deprivation, mother's education level and school. It was suggested that further memory studies were needed to clarify and confirm the effect of aircraft noise on this particular cognitive process.

4.18 In the same year, Bowman (2004) looked at the effects of meaningless speech and traffic noise on episodic and semantic memory in 96 children aged 13-14 years. Equal groups of 32 pupils were randomly assigned to a silent or two noise conditions (meaningless irrelevant speech, or traffic noise) at L_{eq} of 66dBA in each of the noise conditions. Effects of noise were found in terms of impairments from meaningless speech on recognition and cued recall of a text in episodic memory and of word comprehension in semantic memory. There were no significant interactions between road noise and memory processing, although female pupils performed better on episodic and semantic memory tasks but this result did not interact with noise.

4.19 The psychosocial effects of community noise were examined in Macedonia by Ristovska *et al (*2004). Two groups of 10-11 year old children living in areas of 8hour L_{eq} >55dBA (n=266) and in areas of 8hour L_{eq} <55dBA (n=263) were tested for attention, anxiety and Attention Deficit Disorder. Children in the higher noise areas had significantly decreased attention, decreased social adaptability, and increased opposing behaviour in their relations to other people. There was no correlation between socioeconomic characteristics and the development of psychosocial effects.

The RANCH Project

4.20 One of the largest-scale studies to be conducted on aircraft noise and children's learning over recent years is the RANCH project (Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health), by Stansfeld *et al* (2005). Between April and October in 2002, 2844 children aged 9-10 years were studied in a cross-sectional study from primary schools near Schiphol (Netherlands), Barajas (Spain), and Heathrow. Schools were selected due to their increasing exposure to aircraft and road traffic noise, and were classified by a four-by-four grid of noise exposure in each country. Two schools were randomly selected within every cell to allow the effects of increasing aircraft noise within low traffic noise, increasing road traffic noise within low aircraft noise, and the effects of combinations of aircraft noise and road traffic noise, to be examined. The socioeconomic status of the pupils was matched, as measured by the eligibility for free school meals, and language spoken at home.

4.21 Aircraft noise exposure was assessed by 16h outdoor L_{eq} in the UK, with road traffic noise being assessed by a simplified form of the UK standard Calculation of Road Traffic Noise (CRTN) prediction method, using a combination of information including proximity to motorways, major roads and traffic flow data. Noise assessments were provided by modelled data on road and aircraft noise exposure linked to school locations with geographical information systems, in the

Netherlands. In Spain, the researchers visited the 96 pre-selected schools and made direct measurements of road traffic noise, with aircraft noise being based on predicted contours.

4.22 Cognitive performance was assessed in reading comprehension, using nationally standardised tests, episodic memory (recognition and recall) and sustained attention. Working memory was assessed with a revised version of the search and memory task, and prospective memory was assessed by asking children to write their initials in the margin when they reached two predefined points in two of the tests. Health outcomes and perceived annoyance were assessed by questionnaire, and parents were asked to complete questionnaires on child psychological distress, sociodemographic context variables, environmental attitudes, and noise annoyance.

4.23 Testing occurred in two-hour slots under a standardised protocol, and took place in the morning in each country. In terms of cognitive performance, the results indicated that exposure to chronic aircraft noise was associated with a significant impairment in reading comprehension, and this effect size was consistent across countries. A 5dB increase in aircraft noise was equivalent to a 2-month reading delay in the UK, and a 1-month delay in the Netherlands. No national data was available in Spain. In terms of memory performance, exposure to aircraft noise was associated with a significant impairment in recognition, but not information or conceptual recall. Aircraft noise was not associated with deficits in working memory, prospective memory, or sustained attention.

4.24 Road traffic noise was associated with an increase in the number of scores for episodic memory scales of information and conceptual recall, which was an unexpected finding. No effects of road noise were seen in terms of reading comprehension, recognition, working memory, prospective memory or sustained attention. In terms of health effects, increased exposure to both types of noise resulted in increased annoyance in children, however no effects of aircraft or road noise were seen in terms of self-reported health or mental health.

4.25 The authors suggested that the unexpected finding of increased episodic memory performance in areas of high road noise might require further investigation. This study was cross-sectional in design, but it is suggested that longitudinal studies may provide further insight into the impact of noise on the cognitive developmental systems in children.

4.26 In response to the publication on this study, Smith (2005) suggested that the results may be influenced by the different geographical distribution of children's intelligence by noise exposure level, and that there could be a state-dependent effect occurring, whereby the testing situation may be more typical of everyday conditions for road traffic noise than for aircraft noise. If this was the case, performance would be better in road traffic noise where and chronic exposure match, and would deteriorate for exposure to aircraft noise where acute noise exposure may differ from chronic exposure.

4.27 The authors responded to these points (Stansfeld *et al,* 2005) by clarifying that a brief measure of intelligence was included on the Spanish and UK samples, but this was not included due to the co-linearity of intelligence with the other cognitive measures, and that the school matching procedure would partly control for intelligence as well as socioeconomic status. After further analyses, it was reported that neither exposure to aircraft noise nor road noise was associated with intelligence. The association between aircraft noise and reading comprehension was not changed by further adjustment for intelligence. In addition, running the previous analyses excluding pupils with learning difficulties did not alter the results. In response to the state-dependent comment, the authors explain that the naturalistic design of the study should have allowed for this possibility, and following adjustment for acute noise as measured by two microphones in the classroom, the results remained unchanged.

4.28 Clark *et al* (2006) also reported the results from the RANCH project. In addition to the results reported above, the effect of aircraft noise exposure at home on reading comprehension was also described. In all three countries, aircraft noise at home was highly correlated with the exposure level at school. Increasing aircraft noise at home was also significantly correlated with poorer reading comprehension, but there was no additional effect of home aircraft noise exposure after adjustment for aircraft noise exposure at school. Although in the West London Schools Study, the effect of noise and reading performance was confounded by socioeconomic status, the RANCH project did not produce similar results. The UK sample, despite being of lower socioeconomic status, responded to noise exposure similarly to the more affluent Dutch and Spanish samples, and the authors suggest that socioeconomic factors do not explain the primary effects of noise on reading ability. The authors suggest that an important area to examine in the future would be to assess the relative contribution of home and school noise exposure over a full 24-h period, to cognitive performance.

4.29 It is also noted that the road traffic noise levels were not as high as previous studies, with the annual equivalent levels reaching a maximum of 71dBA around schools. The authors note that the road traffic noise exposure levels at home may also contribute to cognitive performance, and should also be studied alongside exposure at school. It was proposed that the greater effect of aircraft noise on cognition decrements may be due to the intermittent characteristic of aircraft noise, with typically more intense and less predictable noise events causing distraction, compared to the more continuous nature of road noise which may allow children to habituate and not be as distracted. It was suggested that aircraft noise might also produce higher arousal levels, which is more likely to interfere with tasks such as reading comprehension.

4.30 A recent study by Shield and Dockrell (2008) looked at the effects of environmental and classroom noise on the academic performance of primary school children. The aim of the study was to examine the effects of chronic internal and external noise exposure on the standardised test results of children aged 7-11yrs in London primary schools. The tests involved literacy, mathematics and science.

4.31 External noise was found to have a significant negative impact on performance, with a larger effect being seen in older children. The analysis suggested that children are particularly affected by the noise of external effects. Internal classroom noise background levels also significantly affected the test scores. Negative relationships between performance and noise levels were maintained when the data were corrected for socio-economic factors relating to social deprivation, language, and special educational needs.

5. Summary

5.1 This review has aimed to describe the main contributions in the field of aircraft noise and cognitive ability in children. The results are not completely in agreement, but there is evidence to suggest that chronic aircraft noise has a deleterious effect on memory, sustained attention, reading comprehension and reading ability. Early studies highlighted that aircraft noise was also implicated in children from noisy areas having a higher degree of helplessness i.e. were more likely to give up on difficult tasks than those children in quieter areas. This motivational decrement was reported in various studies, and it was suggested that this should be an area for future research over a longitudinal study protocol.

5.2 Reports often indicated that children exposed to chronic aircraft noise showed a higher degree of annoyance than those children from quieter areas. Evidence has been presented to suggest that children do not habituate to aircraft noise over time, and that an increase in noise can be correlated with a delay in reading comprehension compared to those children not exposed to high levels of aircraft noise.

5.3 It was suggested that language acquisition deficits may be related to the decrement in reading comprehension in children from noisy areas, but there is no agreement as to how these mechanisms are directly affected by noise.

5.4 It is largely recommended that future research needs to focus on longitudinal studies, to assess the long-term effects of chronic aircraft noise exposure on learning and cognitive ability in children. More detailed exploration of the mechanisms underlying the development of memory, attention and reading processes is needed, and how exposure to noise affects these. It would be useful to include measures of noise levels at home as well as at school. This would allow for the relative contribution of noise exposure at home to be assessed as well as at school, and allow for comparison between the two.

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