The influence of noise on performance and behavior – 5 year update

Charlotte Clark

Centre for Psychiatry, Barts & the London School of Medicine, London, EC1M 6BQ, United Kingdom

Corresponding author: e-mail: c.clark@qmul.ac.uk

INTRODUCTION

This paper attempts to highlight some of the recent developments in the field of noise effects on performance and behavior. It by no means represents a systematic review of the field due to the difficulties of conducting accurate literature searches caused by the broad scope of the field.

The most recent ICBEN review of this field (Hygge et al. 1998) concluded that there was a need for further field studies of children's cognition and irrelevant sound and speech; greater consideration should be given to the possible mechanisms underlying effects of noise on performance; and further studies on individual differences of the effects of noise on performance should be conducted.

Over the past five years, studies detailing new developments in the fields of irrelevant sound and noise effects on children's cognition have been published. Studies examining mechanisms for effects are emerging, alongside studies of individual differences in noise effects on performance (Hygge et al. 2003; Enmarker et al. 2006; Söderlund et al. 2007), indicating that individual differences may be helpful in elucidating the mechanisms for effects.

Recent developments in the field of irrelevant sound and speech are summarised in a separate paper for Team 4 at this conference by Dylan Jones and colleagues. The current paper describes recent findings relating to noise effects on performance and behavior.

Effects on cognitive performance

The effect of noise exposure on children's cognitive performance and learning continues to be a focus of research. Chronic noise exposure has been examined by methodologically robust epidemiological studies; acute noise exposure has been examined in experimental, laboratory studies. 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 noise on children's memory and reading (Evans & Hygge 2007).

Epidemiological studies:

The past five years has seen the publication of the findings of the large scale RANCH study (Road traffic and aircraft noise exposure and children's cognition and health) (Stansfeld et al. 2005; Clark et al. 2006). The RANCH study compared the effect of road traffic and aircraft noise on the cognitive performance of over 2000 9-10 year old children attending 89 schools around three major airports in the Netherlands, Spain and the United Kingdom. The study represents the largest cross-sectional study of its type to date and is the first to derive exposure-effect associations and to compare effects across countries. Cognition was measured using the same paper and pencil tests of cognition across the countries, administered in the classroom. Reading comprehension, recognition memory, conceptual recall, information recall, working memory and sustained attention were examined. Parents and children also completed questionnaires to obtain information about socioeconomic and demographic factors, and noise annoyance. The data were pooled and analysed using multi-level modeling.

There was a linear exposure-effect relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after taking a range of confounding and socioeconomic factors into account including mother's education, long-standing illness, extent of classroom insulation against noise, and acute noise during testing (Stansfeld 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. In terms of the magnitude of the effect of aircraft noise on reading comprehension, a 5 dBA L_{Aeq16} 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 et al., 2006): this association remained after adjustment for aircraft noise annoyance and cognitive abilities including recognition memory, working memory and attention.

The findings of the RANCH study, along with previous findings (Haines et al. 2001; Hygge et al. 2002) suggest that noise may directly affect reading comprehension or could be accounted for by other mechanisms including teacher and pupil frustration (Evans & Lepore, 1993), learned helplessness (Evans & Stecker 2004) and impaired attention (Cohen et al. 1973; Evans & Lepore 1993). It has been suggested that children may adapt to chronic noise exposure by filtering or tuning out the unwanted noise stimuli: this filter may then be applied indiscriminately to situations where noise is not present, leading to learning deficits through lack of attention. Future research needs to focus on the mechanisms for the effects.

Whilst aircraft noise appears to only have a small effect on reading comprehension, it is 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 conducted by Clark & Stansfeld, to examine the long-term effects of aircraft noise exposure at primary school on children's reading comprehension. The findings of the study, funded by the Economic and Social Research Council (UK), will be available in 2009.

One further contribution of the RANCH study is that the exposure-effect associations identified between aircraft noise and reading comprehension and recognition memory, make it possible to start to quantify the magnitudes of noise induced impairments on children's cognition. Figure 1 shows the exposure-effect association between aircraft noise exposure and reading comprehension in the RANCH study (Stansfeld 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.

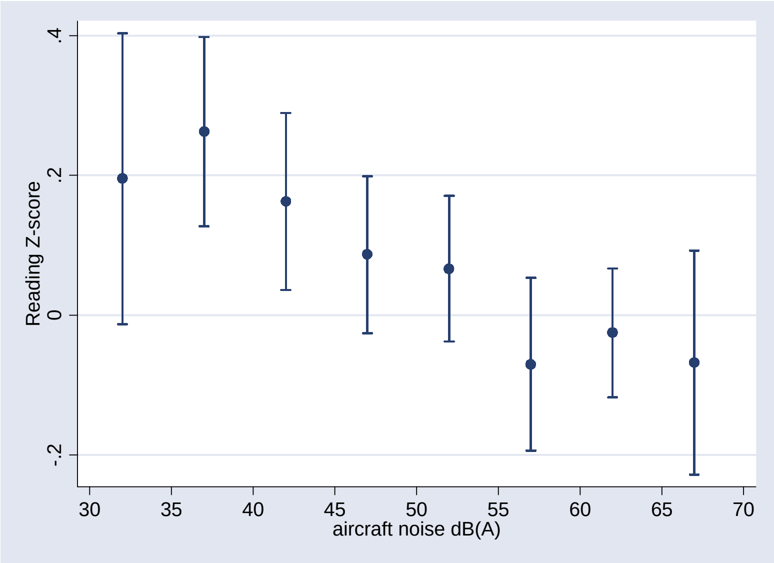

Figure 1: Adjusted mean reading Z score (95 % Confidence Intervals) for 5 dB bands of aircraft noise (adjusted for age, sex and country)

Given the increasing evidence for noise effects on children's cognition, several papers examining the role of classroom acoustics in noise effects have been published in the past five years (Shield & Dockrell 2004, 2008; Dockrell & Shield 2004, 2006; Sato & Bradley 2008; Bradley & Sato 2008; Astolfi & Pellerey 2008; de Oliveira Nunez & Sattler 2006). 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. Interestingly, studies of speech intelligibility which traditionally fall within the remit of Team 2 'Noise and Communication' at ICBEN are becoming increasingly pertinent for Team 4 as they have relevance for the mechanisms for performance effects, as well as for building design and policy. For example, one important issue to take into account when considering noise effects on children's learning is that speech intelligibility may vary with age. Bradley & Sato (2007) found that 6 year old children needed a 7 dBA higher signal-to-noise ratio to achieve the same speech intelligibility scores as 11 year old children.

A series of studies by Shield and Dockrell (Shield & Dockrell 2004, 2008; Dockrell & Shield 2004, 2006) have focused on characterising the classroom acoustics of typical schools in the United Kingdom. Knowledge about typical exposures and acoustics has great relevance for policy as most previous studies focus on high noise exposure situations near airports and major roads, rather than typical exposures. For external noise exposure they found that the average external noise outside of school was 57 dB L_{Aeq}, with 86% of schools being exposed to road traffic noise (Shield & Dockrell 2004). For internal noise, the average L_{Aeq} of occupied classrooms was 72 dBA, with levels fluctuating by approximately 20 dB according to classroom activity (Shield & Dockrell 2004). External noise levels affected children's reports of how easy it was to hear their teacher (Dockrell & Shield 2004).

These findings were then applied to examine associations between classroom acoustics on the performance of primary school children on a series of verbal literacy and non-verbal speed tasks. Children completed the tasks under one of three experimental conditions; quiet, babble (noise of children at 65 dBA L_{Aeq}), or babble and environmental noise (65 dBA L_{Aeq}). 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, whilst 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 & Dockrell 2008). External noise showed a greater effect on the performance of older children and L_{Amax} showed the strongest association with test scores, suggesting that individual noise events may play an important role on performance effects. The latter finding is supported by Astolfi & Pellerey (2008) who found that pupil's subjective assessments of noise disturbance and noise intensity showed a stronger relationship with L_{Amax} than with L_{Aeq} or L_{A90} noise measurements. Astolfi & Pellerey concluded that pupils seem to be disturbed more by intermittent loud noises than by constant noise.

Experimental studies:

In the past five years, as well as further demonstrating effects of noise exposure on performance, experimental studies have focused on trying to develop a greater understanding of how memory processes are affected by noise. A series of experiments have tried to account for the findings of epidemiological and experimental studies in relation to noise effects on cognition (Hygge et al. 2003; Boman et al. 2005; Enmarker et al. 2006). These papers all exploit the same experimental data from a study 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, whilst exposed to one of three noise conditions: meaningful irrelevant speech, 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. (Hygge et al. 2003; Boman et al. 2005). Interestingly, there was no evidence that the youngest group (13-14y) were more vulnerable to the effects of noise on task performance than the older age groups. These analyses suggest that noise may affect memory by impairing the quality with which information is rehearsed or stored in memory (Hygge et al. 2003).

A later paper by the group, attempts to structure the findings of experimental and epidemiological studies into theoretical models (Enmarker et al. 2006) to examine whether noise effects on memory are caused by a reorganisation of the memory system. The paper tests the theory that noise may impair memory through causing the redistribution of memory systems by examining the latent structure of memory. Analyses confirmed Nyberg et al.'s (2003) model of declarative memory (see Figure 2). Semantic and episodic memory were second order factors across the noise conditions, suggesting that noise exposure does not alter the structure of the different aspects of declarative memory, despite the fact that noise exposure was related to the magnitude of memory impairment in the previous analyses of the dataset. The findings suggest that noise does not influence performance via a change in resource allocation or strategy. Further analyses of this dataset will be presented as a separate paper for Team 4 at this conference by Staffan Hygge and colleagues.

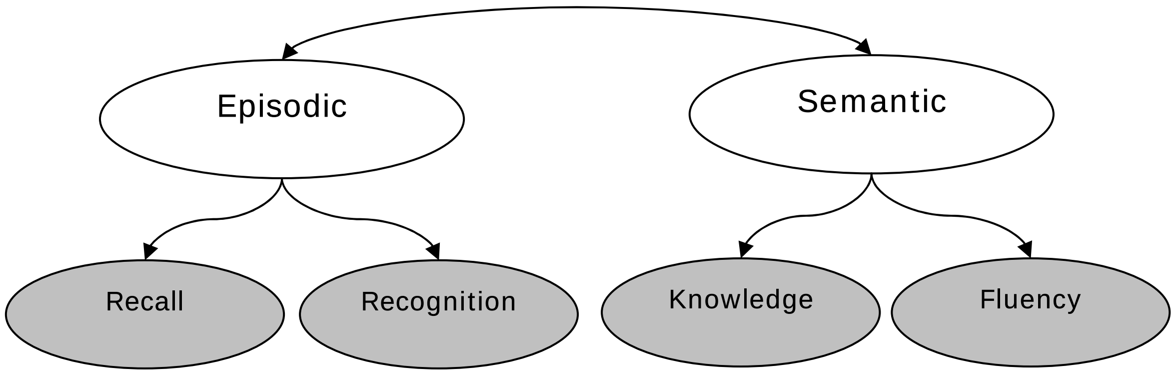

Figure 2: Nyberg's Conceptual model of declarative memory supported by Enmarker et al. (2006)

A further mechanism which has been applied to explain noise effects on performance is the Moderate Brain Arousal model (MBA; Sikström & Söderlund 2007), which is also the subject of a further paper at the conference. In an experimental study, Söderlund et al. (2007) found that noise improved the cognitive performance for a group of children with Attention Deficit Hyperactivity disorder (ADHD) but impaired performance for a control group, suggesting that ADHD children require greater noise exposure for optimum cognitive performance. These results were explained in terms of the MBA model which suggests that the low dopamine levels in ADHD children shifts performance on the stochastic resonance curve (the inverted U-curve between noise exposure and performance, where performance peaks at a moderate noise level) to the right, so that the ADHD children are operating on the part of the curve where noise is beneficial, whilst for control group this represents the part of the curve where performance declines.

CONCLUSIONS

The studies reviewed in this paper are indicative of the breadth of the research which has been published in the field of noise effects on performance and behavior within the past five years. Research has been very much focused on noise effects on children's performance. Future directions within this field include establishing further evidence of exposure-effect associations between noise exposure and performance, as well as further assessment of the associations between classroom acoustics, speech intelligibility and noise effects on performance. Further knowledge, in both of these areas would be informative for policy and decision making in relation to school environments. Furthermore, whilst the past five years has seen the publication of excellent experimental studies that aim to develop a greater understanding of the mechanisms underlying noise effects on cognition, there remains much still to be learnt about mechanisms and individual differences in the effects.

Two notable areas of research have been overlooked in the past few years. Firstly, studies of noise effects on adult performance are few and restricted to experimental studies (Hygge et al. 2003; Hongisto 2005). Noise could potentially influence many aspects of adult working performance especially given the predominance of open plan offices, as well as mobile working practices. Whilst studies of noise effects within adult working environments may prove methodologically challenging, they would make an important contribution to knowledge, policy and design. Secondly, without doubt, research has focused on noise effects on performance to the cost of noise effects on behavior. Well designed studies of noise effects on human behavior and relations should therefore become a focus of future research in this field.

ACKNOWLEDGEMENTS

The author would like to thank Bridget Shield for her assistance with suggesting and providing papers for this review.

REFERENCES

Astolfi A, Pellerey F (2008). Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms. J Acoust Soc Am 123: 163-173.

Boman E, Enmarker I, Hygge S (2005). Strength of noise effects on memory as a function of noise source and age. Noise & Health 7(27): 11-26.

Bradley JS, Sato H (2008). The intelligibility of speech in elementary school classrooms. J Acoust Soc Am 123: 2078-2086.

Clark C, Martin R, van Kempen E, Alfred T, Head J, Davies H, Haines MM, Lopez Barrio I, Matheson M & Stansfeld SA (2006). Exposure-effect relations between aircraft noise and road traffic noise exposure at school and reading comprehension: The RANCH project. Am J Epidemiol 163: 27-37.

Cohen S, Glass DC, Singer JE (1973). Apartment noise, auditory discrimination, and reading ability in children. J Exp Soc Psychol 9: 407-422.

de Oliveira Nunes MF, Sattler MA (2006). Aircraft noise perception and annoyance at schools near Salgado Filho International Airport, Brazil. J Build Acoust 13: 159-172.

Dockrell JE, Shield BM (2004). Children’s perceptions of their acoustic environment at school and at home. J Acoust Soc Am 115: 2964-2973.

Dockrell JE, Shield BM (2006). Acoustical barriers in classrooms: the impact of noise on performance in the classroom. Brit Educ Res J 32: 509-525.

Enmarker I, Boman E, Hygge S (2006). Structural equation models of memory performance across noise conditions and age groups. Scand J Psychol 47: 449-460.

Evans GW, Hygge S (2007). Noise and performance in children and adults. In: Luxon L, Prasher D (eds.): Noise and its effects. London: Whurr Publ.

Evans GW, Lepore SJ (1993) Non-auditory effects of noise on children. Children's Environ 10: 51.

Evans GW, Stecker R (2004). The motivational consequences of environmental stress. J Environ Psychol 24: 143-165.

Haines MM, Stansfeld SA, Brentnall S, Head J, Berry B, Jiggins M, Hygge S (2001). The West London Schools Study: the effects of chronic aircraft noise exposure on child health. Psychol Med 31: 1385-1396.

Hongisto V (2005). A model predicting the effect of speech of varying intelligibility on work performance. Indoor Air 15: 458-468.

Hygge S, Jones DM, Smith AP (1998). Recent developments in noise and performance. In: Noise effects ’98. Congress proceedings, Vol. 1. 7th International Congress on Noise as a Public Health Problem, Australia (pp 321-328).

Hygge S, Evans GW, Bullinger M (2002). A prospective study of some effects of aircraft noise on cognitive performance in school children. Psychol Sci 13: 469-474.

Hygge S, Boman E, Enmarker I (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. Scand J Psychol 44: 13-21.

Nyberg L, Maitland SB, Rönnlund M, Bäckman L, Dixon RA, Wahlin Å. Nilsson L-G (2003). Selective adult age differences in an age-invariant multifactor model of declarative memory. Psychol Aging 18: 149–160.

Sato H, Bradley JS (2008). Evaluation of acoustical conditions for speech communication in working elementary school classrooms. J Acoust Soc Am 123: 2064-2077.

Shield BM, Dockrell JE (2004). External and internal noise surveys of London primary schools. J Acoust Soc Am 115: 730-738.

Shield BM, Dockrell JE (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. J Acoust Soc Am 123: 133-144.

Sikström S, Söderlund G (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. Psychol Rev 114: 1047-1075.

Söderlund G, Sikström S, Smart A (2007). Listen to the noise: noise is beneficial for cognitive performance in ADHD. J Child Psychol Psychiatry Allied Discipl 48: 840-847.

Stansfeld SA, Berglund B, Clark C, Lopez Barrio I, Fischer P, Ohrstrom E, Haines MM, Head J, Hygge S, van Kamp I, Berry B (2005). Aircraft and road traffic noise and children’s cognition & health: exposure-effect relationships. The Lancet 365: 1942-1949.