The effect of aircraft noise exposure on long-term memory: a report of the Bangkok Airport Study

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INTRODUCTION

Previous studies suggest that aircraft noise exposure impairs cognitive performance such as reading, attention, and long-term memory (Evans et al. 1995, 1998; Haines et al. 2001a, 2001b; Hygge et al. 2002; Hiramatsu et al. 2003; Matsui et al. 2004; Stansfeld et al. 2005, 2010; Clark et al. 2006; Matheson et al. 2010). The Munich Airport Study (Evans et al. 1995, 1998; Hygge et al. 2002) was, for example, a longitudinal study conducted during the Munich Airport relocation to analyse the effect of aircraft noise exposure on cognitive function. The Munich Airport Study suggests that there might be a causal relationship between aircraft noise exposure and deficits in long-term memory and reading comprehension, and that these effects might be reversible.

Suvarnabhumi Airport in Bangkok, Thailand, officially opened in September 2006 to replace Don Muang Airport as the city's main international airport. The replacement of one inland international airport by another provided an opportunity for assessing the effect of aircraft noise exposure on cognitive function of primary school children. In order to investigate the effects of aircraft noise exposure on long-term memory, we measured the long-term memory of primary school children twice: before the opening of the new airport and 16 months after its opening.

MATERIALS AND METHODS

Airport and community

Figure 1 shows the map of Bangkok Metropolitan Area showing locations of the two airports. Don Muang Airport, which opened in 1914, was the first international airport in Thailand. It was located in the northern suburb of Bangkok and covered an area of 6.21 km^2 (Airport Authority of Thailand 1998). Initially, the surrounding areas comprised rice fields, but due to the rapid expansion of the urban area of Bangkok, people moved to the areas surrounding the airport, while the airport itself was also expanding with an increasing number of flights. This airport was reportedly used by nearly 80 airlines, more than 250,000,000 passengers in 160,000 flights, and 700,000 tons of cargo annually (Airport of Thailand Public Company Limited 2009a). Don Muang Airport was closed on 28 September 2006, and it became a facility for charter flights, military aircraft and civil aviation. However, it resumed service on 25 March 2007 to be used by domestic flights. It is estimated that there were approximately 90,000 flights in 2007 (Aeronautical Radio of Thailand 2009).

In order to create an aviation hub for Southeast Asia, the Royal Thai Government constructed a new international airport. The new airport, Suvarnabhumi Airport, is located in the eastern suburb of Bangkok, adjacent to Samutprakarn province, 25 km east of Bangkok. This inland airport covers approximately 32 km^2 (8,000 acres) of land (New Bangkok International Airport Co. Ltd. 2002) and has two runways, which can support 76 flights per hour, and can accommodate 45 million passengers and 3 million tons of cargo annually (Airport of Thailand Public Company Limited 2009b). In 2007, the number of flights passing through Suvarnabhumi Airport was recorded to be 270,283 (Aeronautical Radio of Thailand 2009).

Don Muang Airport is surrounded by town houses and apartments of middle-class families who moved to the area after the airport was opened. On the other hand, the area surrounding Suvarnabhumi Airport, previously well known for its fresh water fish farming, was used for agriculture; it consists of low- to middle-class families. A majority of these residents had lived there for 2–3 generations before the opening of the new airport.

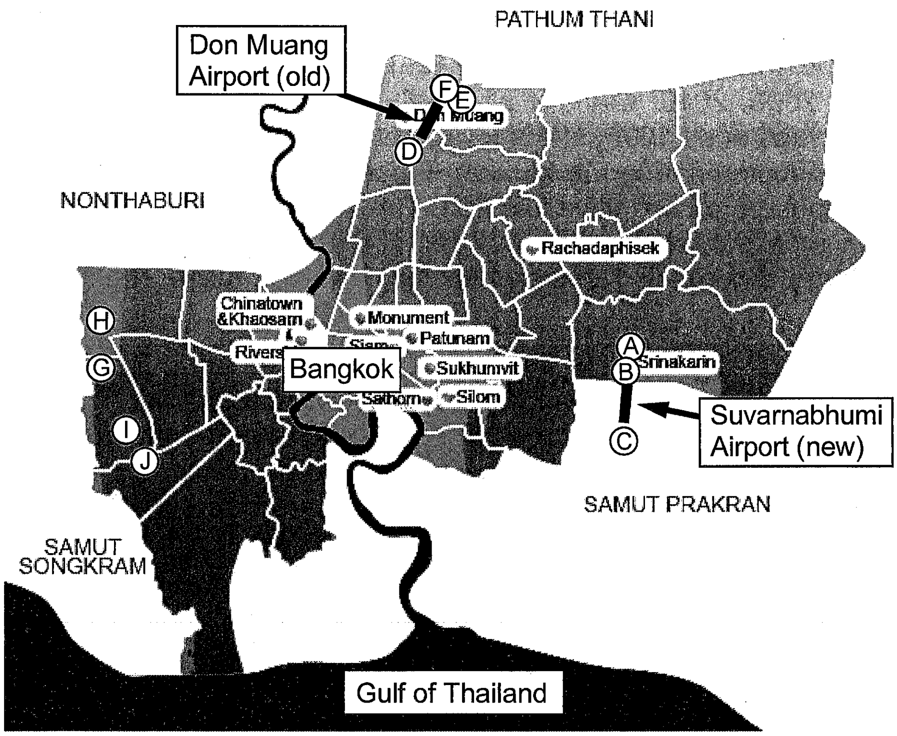

Figure 1: Map of Bangkok Metropolitan Area showing locations of two international airports and ten participating schools.

Participants and aircraft noise exposure

Six primary schools from the area of NEF (Noise Exposure Forecast) 30–35 around the two airports were chosen for the study. Three private schools in Don Muang and 3 public schools in Suvarnabhumi participated in this study (see Figure 1). Primary school children studying in the fourth grade, aged 9–10 years, were recruited.

The control group comprised fourth grade students from 4 primary schools (3 public schools and 1 private school). All 4 schools were located in a western suburb of Bangkok where there was little aircraft noise exposure (see Figure 1).

In total, 684 primary school children studying in the fourth grade participated in this study: 205 from Suvarnabhumi (3 schools), 144 from Don Muang (3 schools), and 335 from the control area (4 schools).

Noise levels were measured twice at each school in Don Muang for a duration of 24 hours each: before the opening of the new airport (September 2006) and after its opening (April–May 2008). For each school in Suvarnabhumi, noise levels were measured after the opening of the new airport (March 2008) for a duration of 24 hours. The aircraft noise exposure level ($L_{Aeq,\ 24\ hours}$) at each school was calculated. Table 1 shows the aircraft noise exposure level at each school.

Table 1: Aircraft noise exposure level at each school

		$L_{Aeq,\ 24\ hours}$ (dB)	
Area	School	In 2006	In 2008
Suvarnabhumi	A (public)	Not available	60
	B (public)		62
	C (public)		63
Don Muang	D (private)	73	61
	E (private)	63	54
	F (private)	63	54

Memory test

Short-term and long-term memories were measured twice: the first test was conducted on 7–13 September 2006 before the opening of Suvarnabhumi Airport, and the second test was conducted on 7–11 January 2008, 16 months after its opening.

For the short-term memory test, the students were asked to memorize 15 disyllabic words, with each word being shown to them for 4 seconds. Next, a set of 30 words, 15 previously shown words and 15 new words, were shown to them. They were then asked to identify each word and mark '/' for a previously seen word and 'X' for a new word, on the answer sheet. The calculated percent difference between the 'right' and 'wrong' answers was considered as the memory score. The right answer was the number of previously seen words that the children remembered, while the wrong answer was 15 minus the number of new words that they could identify (Chaiyaporn 1977).

Long-term memory was assessed by a task (story C) adapted from the Child Memory Scale applied in the RANCH Study (Road traffic and aircraft noise exposure and children's cognition and health) (Stansfeld et al. 2005, 2010; Clark et al. 2006; Matheson et al. 2010). This task was translated into Thai language by one of the present authors (Nuchpongsai et al. 2009). The children were asked to read a short story in 50 seconds and write down everything they remembered of the story immediately. After 30 minutes of an interference activity such as drawing, playing games, puzzles, or intelligence quotient test, they were asked to write down again. The second writing was then scored with 1 point for each keyword similar to that of the guideline.

Intelligence quotient (IQ) test

Intelligence was measured by using Progressive Matrices. Coloured Progressive Matrices are multiple choice tests of abstract reasoning, originally developed by John and Raven (Anastasi 1976). Thai versions of these tests developed by the Counseling Centre of Srinakharinwirot University were used in this study to adjust for the effect of intelligence factors on long-term memory scores. The test included 3 sets—sets A, AB, and B—consisting of 12 items. In each item, the children were asked to identify the missing segment required to complete a larger pattern from the choice of 6 pictures in 30 seconds.

For the noise-exposed group (Suvarnabhumi and Don Muang), this test was conducted 3 months after the first memory test. On the other hand, for the control group children, this test was conducted as an interference activity between the short-term and long-term memory tests.

Statistical analysis

To investigate the effects of aircraft noise exposure on long-term memory, the differences in the long-term memory scores of the children in each group (Suvarnabhumi, Don Muang, and the control area) before and after the opening of the new airport were evaluated by using Wilcoxon signed rank test.

Further, the relationship between the change in the long-term memory scores due to the replacement of one inland international airport by another and the three groups (Suvarnabhumi, Don Muang, and the control area) was analyzed by using multiple logistic regression analysis. Two types of logistic regression models were used. The first model was unadjusted, while the second model was fully adjusted model. The fully adjusted model included gender, IQ, and the change in short-term memory scores, as explanatory variables. The IQ and the change in the short-term memory scores were included in the model as interval scales. In the fully adjusted model, the change in the short-term memory score was used as a measure of the change in motivation for learning.

All statistical analyses were performed by using SPSS software, version 17.0, at a $p<0.05$ (two-tailed) level of significance.

RESULTS

The comparison of the long-term memory scores obtained before and after the opening of the new airport showed that the long-term memory scores of the children in Suvarnabhumi did not become significantly higher (Wilcoxon signed rank test, $p=0.182$), whereas those of the children in the control group became significantly higher (Wilcoxon signed rank test, $p<0.001$). The long-term memory scores of the children in Don Muang also became significantly higher (Wilcoxon signed rank test, $p<0.001$), but the increase was lesser than in the control group.

Figure 2 represents the change in the long-term memory scores in the three groups (Suvarnabhumi, Don Muang, and the control area). In this figure, the minimum, 25th percentile, median, 75th percentile, and maximum are shown for each group. As is evident from the figure, a significant difference was observed in the change in the long-term memory scores among the three groups (Kruskal-Wallis test, $p<0.001$). In the control group, approximately 77 % of the children showed an increase in their long-term memory score, while in Suvarnabhumi, only about 51 % showed an increase in their long-term memory score.

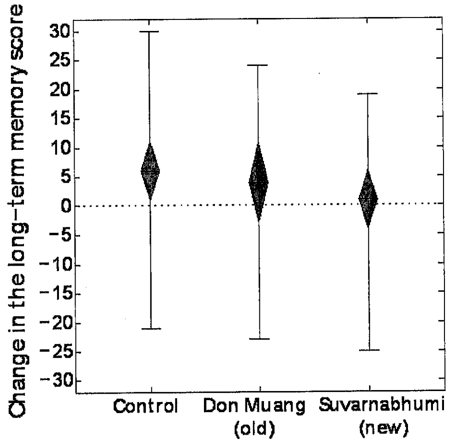

Figure 2: Change in the long-term memory score in the three groups. For each group, the minimum, 25th percentile, median, 75th percentile, and maximum are shown.

The relationship between the change in the long-term memory scores and the three groups was analysed by using multiple logistic regression analysis. In the analyses, the median value of the control group (6 points) was used as a cut-off point to convert it into a dichotomous variable for the logistic regression models.

Figure 3 illustrates the odds ratios with their 95% confidence intervals. In the figure, the asterisks indicate statistically significant odds ratios (*: $p<0.05$, ***: $p<0.001$). The unadjusted model showed that the children in Suvarnabhumi showed a significantly high odds ratio. The children in Don Muang also showed a significantly high odds ratio; however the odds ratio was lower than in Suvarnabhumi. As is evident from the figure, the fully adjusted model yielded similar results. Table 2 represents the results of the fully adjusted model. The relationship between the change in the long-term memory scores and the three groups was not affected by gender, IQ, or the change in the short-term memory score, the latter of which was used as a measure of the change in motivation for learning.

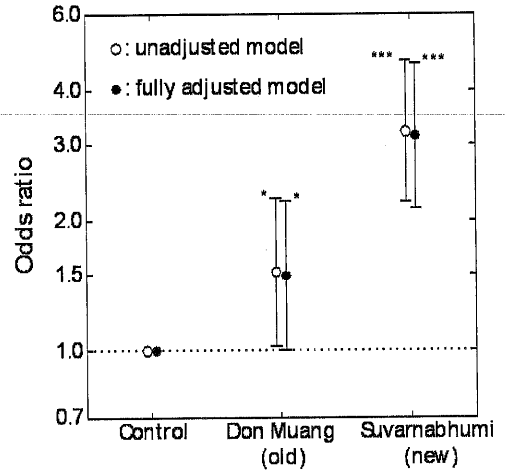

Figure 3: Relationship between odds ratios of long-term memory (less than 6 points) and the three groups. The asterisks indicate statistically significant odds ratios (*: $p<0.05$, ***: $p<0.001$).

Table 2: Results of the fully adjusted logistic regression model on long-term memory (less than 6 points)

Factor	Category	N	Odds ratio	95% CI	p value
Group	Control	335	1		
	Don Muang (old)	144	1.490	1.004–2.212	0.048
	Suvarnabhumi (new)	205	3.140	2.132–4.623	<0.001
Gender	Male	350	1.131	0.826–1.547	0.443
	Female	334	1		
IQ	Interval scale		1.004	0.984–1.024	0.701
Change in the short-term memory score (Change in motivation for learning)	Interval scale		1.002	0.997–1.006	0.410

DISCUSSION

In summary, a significant association was found between the change in the long-term memory scores and the three groups (Suvarnabhumi, Don Muang, and the control area). In contrast with the long-term memory scores of the children in the control group, the long-term memory scores of the children in Suvarnabhumi did not become significantly higher, whereas those of the children in Don Muang became significantly higher, but to a lesser degree. Therefore, the increase in the long-term memory scores of the control group can be attributed to cognitive development in the children; moreover, it seems plausible that aircraft noise exposure might have hindered cognitive development in the children in Suvarnabhumi. The results of this longitudinal study strongly suggest that aircraft noise exposure might have adverse effects on long-term memory of primary school children.

The results of the present study, which suggest an effect of aircraft noise exposure on deficits in long-term memory, are consistent with previous findings from a longitudinal study, the Munich Airport Study (Evans et al. 1995; Hygge et al. 2002). In the Munich Airport Study, primary school children were instructed to read a text, and their memory was assessed by means of a free recall test on the following day. The results suggest that there might be a causal relationship between aircraft noise exposure and the deficits in long-term memory and that these effects might be reversible.

Several cross-sectional studies also suggest adverse effects of aircraft noise exposure on long-term memory (Hiramatsu et al. 2003; Matsui et al. 2004); for example, in the Okinawa Study (Hiramatsu et al. 2003), primary school children were asked to listen to a fictitious story and answer some questions asked on that day and the following day. The long-term memory tests used 15 common questions on the first and second days and an additional 5 questions asked on the second day. With regard to the additional 5 questions asked on the second day of the long-term memory test, a significant dose-response relationship was found between aircraft noise exposure and the deficits in long-term memory. The result obtained in the Okinawa Study suggests that chronic aircraft noise exposure lowers long-term memory of primary school children, which can hamper their learning ability.

Physiological mechanisms of how aircraft noise exposure affects children's cognition have been suggested. For example, McEwen & Sapolsky (1995) state that stress affects cognition in a number of ways, when acting slowly via cortisol, which biphasically modulates synaptic plasticity for over hours and also produces longer-term changes in the dendritic structure that last for weeks. Moreover, prolonged exposure to stress leads to the loss of neurons, particularly in the hippocampus, which is an important component of brain and plays important roles in memory consolidation. This suggests that the deficits in long-term memory might be due to the effect of cortisol on the hippocampus. On the other hand, recent physiological studies suggest that alpha-melanocyte-stimulating hormone (alpha-MSH), which is produced by sleep disorders, has a similar effect on the hippocampal neurons (Ogawa et al. 2009). This implies that sleep disturbance due to aircraft noise exposure may be correlated with the deficits in long-term memory.

Stansfeld et al. (2010) also pointed out that sleep disturbance due to aircraft noise exposure might mediate the association of aircraft noise exposure and cognitive impairment in children. However, many previous studies, including the present study, have not differentiated between day or night time noise exposure. Further studies specifically designed to address the effects of night time noise exposure on long-term memory are required.

CONCLUSION

A longitudinal study of the effects of aircraft noise exposure on long-term memory of primary school children was conducted in the area around the two airports in Bangkok, Thailand. As compared to the significant increase of long-term memory scores of the children in the control group, those of the children in Suvarnabhumi did not become significantly higher, whereas those of the children in Don Muang became significantly higher, but to a lesser degree. It seems reasonable to suppose that the increase in the long-term memory scores of the children in the control group was caused by their cognitive development and that aircraft noise exposure might have hindered the cognitive development of the children in Suvarnabhumi. We therefore conclude that aircraft noise exposure has adverse effects on long-term memory of primary school children.

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