CHAPTER 4 -- CONCLUSIONS AND DISCUSSION
4.1 INTRODUCTION

This chapter summarises the results of the Inner Sydney Child Blood Pressure Study, then discusses the implications of the results of the study in relation to hypotheses outlined in the methods chapter, to some of the literature reviewed and, in more detail, to the extant equivalent child BP studies conducted with regard to Los Angeles and Munich Airports. This is followed by a discussion of the sources of bias in the Sydney study and countermeasures taken to minimise these. Finally, some implications for future directions for research of BP and aircraft noise are outlined and discussed.

4.2 SUMMARY OF FINDINGS

The present study found no consistent statistically significant cross-sectional correlations between mean resting BP and exposure to aircraft noise at school or in total (school and home exposure combined), either at baseline or follow-up. Nor were consistent statistically significant cross-sectional correlations found between BP and domestic, at-home exposure to aircraft noise, either at baseline or follow-up. Overall, higher BP was not contemporaneously associated with higher exposure to aircraft noise, at baseline or follow-up. Accordingly, hypotheses 1 and 2, of a positive cross-sectional association between BP and aircraft noise exposure, at baseline and follow-up respectively, were not confirmed.

BP increases occurring between baseline and follow-up were not statistically significantly associated with corresponding baseline-to-follow-up increases in school or domestic aircraft noise exposure, but evidence of effect modification was found. Baseline-to-follow-up increases in total aircraft noise exposure were significantly negatively associated with systolic BP changes in boys, and significantly positively associated with systolic BP changes in girls. This finding was not replicated with regard to diastolic BP or with regard to school aircraft noise exposure. Significant negative associations were found between systolic and diastolic BP and recent prior school and total aircraft noise exposure changes at baseline, while at follow-up the estimates of association were similar in magnitude, although statistical significance was not reached. The finding of recent increases in aircraft noise exposure being associated with lower BP was consistent across the sexes, under different modelling assumptions and in relation to total and school aircraft noise exposure. This represents evidence of confirmation, in the negative, of the
hypothesis that recent changes in aircraft noise exposure are positively associated with BP.

All regression models incorporated the measured known confounders of BP, and all models of changes in BP accounted for individual baseline BP levels.

Despite the BP measurements not being conducted in sound-proof booths, which potentially would have been a source of exposure bias, possible acute BP reactions to aircraft flyovers in highly exposed schools during BP measurement were not found. That is, there was no evidence of spurious associations between aircraft noise and “resting” BP when the measurement conditions were such that an acute BP reaction to noise from aircraft overflights was possible.

A number of laboratory studies of adult subjects have found acute BP effects to be associated with exposure to recorded noise, including recorded aircraft noise. Such BP effects have manifested as increases in peripheral resistance (measured variously), and raised BP and pulse rates in response to the noise stimulus. While the findings of the Inner Sydney Child Blood Pressure Study cannot be related directly to those of laboratory studies, they do have implications for theories of adaptation to noise. That is, if acute BP effects were not detected in noisy environments in naturalistic settings to which the subjects have been exposed for periods ranging from months to years, then this is evidence either for adaptation taking place or that the noise levels were not sufficiently intense to reproduce the acute BP effects found in the laboratory.

Adaptation to noise has been shown to be related to its perceived annoyance and the degree of individual sensitivity to noise, and to the context of exposure. Borsky’s survey of 2,000 residents living proximate to New York’s John F Kennedy Airport found that almost 2/3 of those who reported fear of aircraft also reported listening to all overflights until they passed, compared to approximately 1/3 of those who did not report fear of aircraft [Borsky, 1979]. Borsky recounts also that those who reported being indifferent to the noise source, despite it being unavoidable, also reported that they ignored the sound. In other words, according to the individual attitude to the noise source the attention mechanism (the cochlear inhibitory reflex) may or may not prevent the sound being received for processing by the higher brain centres.
No measures of personality, noise annoyance or attitude to aircraft noise were taken of the children in the present study, and these represent major non-measured effect modifiers. However, evidence for BP adaptation was found in the present study, in that BP was negatively associated with recent changes to aircraft noise exposure, while at the same time BP was found not to be significantly associated cross-sectionally and contemporaneously with aircraft noise exposure, at baseline or follow-up. That the negative confirmation of the hypothesis of a positive association between BP and recent change in aircraft noise exposure, was consistent across different regression modelling assumptions and with regard to both school and total aircraft noise exposure suggests evidence for BP adaptation to pre-existing levels independent of exposure to aircraft noise, as a homoeostatic response. This finding is congruent with Selye’s reaction stage in his generalised adaptation syndrome (GAS) framework of the stress response, where somatic responses to a stressor attempt to restore a pre-existing equilibrium in the body.

It is not clear why boys would have had negative longitudinal BP associations with regard to total aircraft noise exposure changes and girls have opposite, positive, longitudinal associations. Although the associations in the girls were not statistically significant in some of the analyses, they were nonetheless consistent. Whether differences in personality proportions between the sexes played some role in this is moot. However, some control for personality was achieved by use of BP and pulse variations as a proxy for BP reactivity which has been shown to be positively linked to personality. However, BP reactivity and personality may be similar to the relationship of BP reactivity and BP: BP reactivity could be a sensitive marker for hostility or Type-A personality, but it is probably also not very specific. In other words, most Type-A personalities may have higher levels of BP reactivity but Type-As may not comprise the majority of those with high BP reactivity.

4.3 Los Angeles and Sydney Airport Studies

The overall design of the Sydney school blood pressure study was similar to that of the Los Angeles study in that the BPs of primary school children were compared cross-sectionally and longitudinally for differing school and domestic exposures to aircraft noise. While exposure levels in the Cohen et al study were static and measured on a continuous scale, the comparisons between school or domestic exposures were based on ‘exposed’ versus ‘unexposed’ categories in which mean blood pressures between
exposure categories were compared using t-tests or multivariate F-tests. The Cohen et al. study was therefore not capable of producing a dose-response relationship in relation to a scale of existing noise exposure levels but did produce a dose-response relationship vis-a-vis cumulated exposures as measured by the length of time the children attended the noisy or quiet schools.

The Sydney study examined both cross-sectional and longitudinal exposure dose-response relationships. No statistically significant correlation between BP and exposure to aircraft noise by either continuous or categorical (ordinal) dose-response measures was found. As there were 75 participating schools in the Sydney study (compared to 7 schools in the Los Angeles investigation), and 1,230 children in the Sydney study compared to 242 children in the Los Angeles study, there was sufficient variation in noise exposures to examine contemporaneous dose-response relationships with noise exposure analysed as a continuous variable.

The chief advantage of the Sydney study over the Los Angeles investigation was not so much that it had greater participant numbers or a continuum of exposures but that it was a quasi-experimental design in that it was conducted under conditions of major changes in exposure to aircraft noise. BPs of the same children were measured at 2 different time points under which whole populations of inner Sydney became alternately newly exposed and unexposed to aircraft noise. During the course of the Sydney study, some populations experienced relief from aircraft noise only to have the noise reimposed as the runway configurations and landing and take-off conditions were changed in response to community reactions to increased exposure to aircraft noise initially following the opening of the new runway.

The Los Angeles study is the most widely quoted study of aircraft noise and child blood pressure, not least because it is 2 decades old and that its findings were positive and statistically significant. The initial baseline Los Angeles results were an approximately 3 mm Hg BP elevation (systolic and diastolic, both statistically significant) in children from schools exposed to high levels of aircraft noise compared to children in quieter schools [Cohen et al., 1980]. The Los Angeles study also found that the differences between noisy and quiet schools to lessen with increasing period of attendance at the noisy schools. These results were not replicated in the Inner Sydney Child Blood Pressure Study. In the analysis of BP at baseline, the time each child attended the school was found not to be
significantly associated with BP.

The Los Angeles study had a number of drawbacks, the first and most obvious was why the authors reported adjusting statistically for the confounders not accounted for by matching, most notably ethnicity, but only reported unadjusted BP results. The most obvious confounder of child BP in the study was the significantly higher proportion of African-American children in the noisy schools and this could have accounted for the BP difference between the noisy and quiet schools. At the time of the Los Angeles study it had already been established in at least one major study that African-American children had higher mean resting BP than Caucasian children [see for example, Berenson et al, 1980].

BP readings from the Berenson et al study are pertinent as they are directly comparable to those of Cohen et al because both studies used the same brand and model of automated BP measuring instrument (Physiometrics SR-2). Moreover, Berensen et al compared child BP measurements from the Physiometrics instrument with those from mercury sphygmomanometry, and found both systolic and diastolic BPs of African-American children to be significantly higher than Caucasian children using the Physiometrics instrument, with the difference emerging before the age of 10 years, and most pronounced in children in the top 5% of BP rankings.

From the graphs supplied by Berenson et al [1980, p. 246], for children aged 9 years, the mean BP excess in African-American over Caucasian children was approximately 2 mmHg systolic and 2.5 mmHg diastolic.

Another drawback to the Los Angeles study was that there was no allowance taken for possible effects of cluster sampling. This perhaps is understandable, given the date of the study [1978 and 1979] where cluster sampling effects were generally ignored, or unheard of, in the medical and health literature. The magnitude of clustering effects is determined by the degree of intra cluster correlation and the mean cluster size [see Methods for more detail].

Elementary or primary schools may be particularly prone to clustering design effects since they tend to have localised catchments of similar populations and the pupils are subject to a common esprit de corps consciously promoted by school principals. Given
that the quoted p-values for the excess of systolic and diastolic BP in the noisy schools were 0.03 for both, a design effect of just 1.24 or more would have rendered the main findings of the Los Angeles study statistically non-significant at alpha = 0.05. The design effect found in the Sydney study was 1.74 and 1.77 for systolic BP at baseline and follow-up respectively, and for diastolic BP it was 3.08 at baseline and 1.89 at follow-up. It is highly probable that the design effect for the Los Angeles study would have been higher than 1.24 since the mean cluster size was ~ 37 (= 242 / 7), and if the schools had a similar intra-cluster correlation coefficient as in the Sydney child BP study, then the design effects would have been greater than 1.24. This is estimated from the formula for design effects due to cluster sampling, below, from which the p-value accepted as the level of statistical significance is adjusted:

\[ \text{DEFF} = 1 + (\bar{c} - 1) r_i \]
\[ \bar{c} = \text{mean cluster size} \]
\[ r_i = \text{intra cluster correlation coefficient} \]

In the Sydney study the intra cluster correlation coefficient for systolic BP was estimated as 0.047, and for diastolic BP was 0.135 (see Methods, section 2.3). If these values are used for the Los Angeles data, the resulting design effects are:

\begin{align*}
\text{Systolic BP: } & 1 + (37 - 1) * 0.047 = 2.69, \quad \text{and} \\
\text{Diastolic BP: } & 1 + (37 - 1) * 0.135 = 5.86
\end{align*}

If these design effect values applied to the Los Angeles study, then the accepted p-value for statistical significance equivalent to \( \alpha = 0.05 \) would be 0.0014 for systolic BP and 3.2*10^{-6} for diastolic BP. It is probable that the larger mean cluster sizes in the Los Angeles study would also produce lower intra cluster correlation coefficients than those found in the Sydney study. However, the above calculation implies that the results of the Los Angeles study are not as statistically significant as reported.

Reasons for the Sydney BP study failing to replicate the results of Cohen et al can be categorised into: (i) differences in control of confounding factors; (ii) differences in noise exposure measurements and categories; (iii) differences in study sample and noise exposure range; (iv) differences in allowance for cluster sampling design effects.
(i) Differences in control of confounding factors

As mentioned in the literature review, the Cohen et al. study [1980] reported unadjusted mean BP elevations in children attending schools exposed to aircraft noise compared to children in quiet schools. Adjusted BP differences were not reported. While the samples for comparison were matched on socio-economic and ethnic criteria, there was no control for possible anthropometric differences in the samples. Without knowing that the elevated BP in children from the noisy schools was not due to differences in mean weights and heights, for example, it is not possible to discount anthropometric differences as an explanation for the BP difference. Given that there was a preponderance of African-American children in the noisy schools compared to quiet schools, despite attempts at matching, it is possible that ethnic-based differences in anthropometric measures may explain some of the BP difference, over and above the BP differences found between African-American and white children by Berenson et al. [1980], where such adjustment was carried out. In the Sydney study weight was the most consistent and significant anthropometric predictor of BP, similar to the Minneapolis Children’s Blood Pressure Study [Prineas et al., 1980]. Non-English speaking background of child, in the presence of other predictors of BP including weight, was also consistently predictive of higher BP. This parallels the finding of Berenson et al. with regard to African-American children.

(ii) Differences in noise exposure measurements and categories

In the Los Angeles study two exposure categories, noisy versus quiet, were used in analysing BP in relation to aircraft noise. While this is adequate for establishing if a noise-BP relationship might exist, it is also prone to possible inherent sample differences in BP, as was illustrated in the Evans et al. [1998] Munich Airport study (see below). In the Munich example the initially unexposed sample which later became exposed had a higher mean BP at baseline than the sample which remained unexposed. As the Munich Airport study was a natural experiment like the Sydney study in which before-and-after exposure changes and BPs could be ascertained, initial BP differences in the comparison samples could be taken into account. The Sydney study had the advantage of individually measured aircraft noise exposures, for each school and for the residential address of each child. These exposures allowed the establishment of a dose-response relationship, both cross-sectionally and over time. As a dose-response relationship is one of the key criteria for establishing causation [Bradford Hill, 1984], a continuum of exposures is a pre-
requisite for establishing a dose-response relationship.

(iii) Design effects due to cluster sampling were not accounted for in the Los Angeles study. As shown above, these may have significantly modified any statistical inferences derivable from the Los Angeles study.

4.4 The Munich Airport study

The opening of a new international airport in a rural area 35 km outside of Munich occasioned a longitudinal physiological response study of school children in exposed versus unexposed control schools [Evans et al., 1998]. BPs, epinephrine, norepinephrine and cortisol responses in school children aged 9-11 years (n = 217) were measured on three occasions in two noise exposure groups (quiet/noise), 6 months prior to the new airport’s opening (‘Wave 1’), 6 months after the opening (‘Wave 2’), and again 18 months after the opening (‘Wave 3’). On each measurement occasion 4 BP measurements were taken on 2 consecutive days. The first BP measurement on each day was discarded and the mean of the remaining 6 was used in the analysis. Twelve-hour overnight urine samples were collected by parents covering the evening of the initial BP measurement day and were assayed for epinephrine, norepinephrine and cortisol, measured as excretion rates in nanograms (epinephrine, norepinephrine) or micrograms (cortisol) per hour.

Children in the noisy and quiet areas were matched on socio-economic criteria, and climate and noise controlled measurement chambers were used for taking automated BP measurements. The main findings of the Munich study were: significantly larger increases in BP in the children who became exposed to aircraft noise than in the unexposed children from Wave 1 to wave 2, but not from wave 2 to wave 3. Wave 1 to Wave 2 BPs in the noise-exposed children increased by 4.4 mmHg systolic (from 97.2 mmHg to 101.6 mmHg) and by 2.7 mmHg diastolic (from 60.5 mmHg to 63.2 mmHg), compared to 1.4 mmHg systolic (100.8 mmHg to 102.2 mmHg) and 1.0 mmHg diastolic (62.6 mmHg to 63.6 mmHg) in the unexposed children. Epinephrine and norepinephrine output rates showed correspondingly significantly larger increases in the noise-exposed children between Waves 1 and 2, with epinephrine increasing from 229 ng/hour to 328 ng/hour in the noise exposed group, compared to an increase from 252 ng/hr to 281 ng/hr in the unexposed group; and norepinephrine increasing from 611 ng/hr to 1229 ng/hr in the
exposed compared to an increase from 660 ng/hr to 880 ng/hr in the unexposed children. Subsequent epinephrine and norepinephrine increases between Waves 2 and 3 were not significantly different between exposed and unexposed children, while cortisol level changes were not systematically related to changes in noise exposure conditions.

No further attempts to control for confounders of BP or physiological responses were reported [Evans et al, 1998]. Possible differences between noise-exposed and unexposed children in anthropometric/physical measurements, racial/ethnic backgrounds, family history of high BP, sex, and so on were not reported. Unlike the Los Angeles study which did report deviations in matching of controls on racial/ethnic criteria, the extent of ethnic variability, or matching, on socio-economic or ethno-demographic criteria across the noise exposure groups was not reported.

The Munich results are open to further scrutiny: (i) cross-sectionally, BPs in the noise-exposed children were consistently lower than in the unexposed children on each of the 3 measurement occasions, suggesting systematic differences in the samples in spite of matching on socio-economic grounds; (ii) it is conceivable that the higher noise groups were from a different ethnic or other socio-cultural background who may have had lower baseline BPs or earlier and/or greater growth changes which could also explain the differences in longitudinal BP changes between the exposed and unexposed children. That is, on the first measurement occasion BPs in the noise-exposed children were lower because of differences in body size to the unexposed children but at which time very few children in either the exposed or unexposed groups were going through rapid growth changes associated with puberty. At Wave 2, a higher proportion of noise-exposed children conceivably may have been experiencing more rapid growth rates than in the unexposed group, such that mean BPs increased more sharply in the exposed group.

Without controlling for changes in body size, it would be difficult to attribute differences and changes in BP to other putative causes.

In the Sydney study, BPs in NESB children were found to be consistently and significantly higher than in ESB children after controlling for body size and skinfold measures of adiposity, at both baseline and follow-up. The persistence of these BP differences longitudinally and after controlling for body size and adiposity suggests that not controlling for ethnicity in BP studies could lead to spurious inferences despite
controlling for anthropometric differences.

A further drawback to the Munich study is that the design effects of the sampling frame are difficult to assess, as there was not a description of how subjects were chosen, particularly whether individuals were the primary sampling unit or a school, or a class in a school. And if schools were the primary sampling unit, the number of participating schools in the Munich study was not reported. Thus it was not possible to estimate the possible effects of clustering design effects in the Munich study, unlike the Los Angeles study.

In spite of the above reservations, the present study did produce a result roughly congruent with findings in the Munich study. The present study found BP to be negatively associated with recent aircraft noise change accompanied by a significant positive association between pulse rate and recent aircraft noise exposure change. It was posited that the higher pulse rates were perhaps evidence of sympathetic reactions to the new exposure regime which were countervailed by other mechanisms to reduce BP, as part of a homoeostatic response. In the Munich study, the significantly higher sympathetic hormonal outputs found in the newly-exposed versus the non-exposed group may have been partly due to this possible mechanism. The fact that BPs over time in the newly exposed group in the Munich Airport study approached the initially higher BPs of the unexposed group may still point to increases in body size in this group occurring faster than in the unexposed group, but the higher hormonal output levels also may be partly related to the sympathetic BP response to the new aircraft noise exposure regime. The fact the hormonal levels between the two exposed and unexposed group in the Munich study were not significantly different at ‘Wave 3’, 18 months after the new airport was opened is suggestive of a short-term sympathetic adaptation effect.

4.5 Biases and Measurement Issues in the Sydney Study

Sources of bias in the Sydney study can be divided into measurement and selection biases.

4.5.1 Measurement Bias

Potential measurement biases in the Sydney study centre on BP and noise measurements.
Sources of BP measurement bias stem from different BP measurers and automated BP machines used; different measurement conditions including ambient temperature and possible BP acute effects associated with aircraft overflights. Bias in noise measurements centre on the issue of regression dilution bias on the one hand, and the extent to which the measures of aircraft noise exposure represent an aggregate ecological variable (“cross-level bias”) that may be differentially modified according to noise exposure level, on the other.

4.5.1.1 Inter-BP measurer (inter-rater) bias

Significant bias due to different BP measurers was found in the analysis, despite the use of automated sphygmomanometers. While much of the work on inter-measurer biases has centred on the phenomenon of “whitecoat hypertension”, there also is a possible mechanical explanation for systematically lower or higher BPs being recorded by a measurer with other factors held equal. For instance, at baseline ‘BP measurer 5’ tended to produce significantly lower BP readings than the referent BP measurer. This may have been due to the sphygmomanometer cuff being too tightly applied to the child’s arm. The mechanics of this perhaps can be seen in the case of a loosely applied cuff. The looser the cuff the earlier the beating sound of systole will be heard and thus a higher systolic BP will be recorded as the beating sound returns earlier than with a tighter cuff. As the cuff deflates further the recorded diastolic BP will also be higher since the blood flow will return to the laminar state earlier than with a more tightly applied cuff. Conversely, the tighter the sphygmomanometer cuff, the lower the recorded BP will be.

Another source of inter-measurer bias can stem from individual measurer decisions on the use of appropriate cuff sizes. Three different-sized sphygmomanometer cuffs were used in the BP measurements to cover the range of different arm sizes in the children. The recommended cuff size for BP measurement ideally is a bladder width equal to 120% of the diameter of the arm at the acromion-olecranon midpoint, and a bladder length sufficient to encircle 90% of the circumference of the upper arm midpoint [Rose, et al 1982]. The three cuff sizes used in the study were for adult, child and small child. Bias from this source possibly can stem from some of the BP measurers more than others using cuff sizes which may have been too large for some children. The bias, overall, would be expected in the direction of BP under-estimation, other factors such as how tightly applied held equal, because it is more difficult to gain a BP measurement with a
cuff length grossly too short for an arm circumference because it tends to come off the arm when inflated, but a cuff which is grossly too large for an arm does not come off under inflation.

Cuff lengths too small for the arm circumference have been shown to result in higher BP readings than with use of appropriate cuff lengths [Conceicao et al, 1976], and cuff widths too narrow for a given upper arm length also have been shown to over-estimate BP [Okahata et al, 1987]. While there was a continuum of arm sizes in children in the Sydney Airport BP study, but a discontinuum of 3 discrete cuff sizes used, not all children measured would have conformed strictly to the recommendation of Rose et al. A BP measurer may have consistently lower BP readings through use of cuff sizes which, on average, were too large for the child, while another BP measurer may have, on average, used cuff sizes too small for their subjects. Recording of BP measurer in data collection and controlling statistically for systematic differences between BP measurers in the modelling of BP tend to neutralise inter-measurer bias.

4.5.1.2 BP machine bias

At each BP measurement the machine used was recorded to control for possible systematic differences in BP measurements. It transpired that BP machine #2 tended to record lower values for BP than BP machine #1. A plausible explanation for this source of bias is there was a difference in the sensitivity of the BP machines in detecting the first and fifth Korotkov sounds. Cuffs and air-lines were checked regularly for leaks and none were found during the study, baseline or follow-up. This source of bias was also controlled for statistically in the modelling of BP.

4.5.1.4 Noise measurement variability, “cross-level” and “regression dilution” bias

Aircraft noise measurements can be subject both to bias and be involved as an effect modifier of BP. Noise measurement bias stems from a number of sources. The first of these includes the inherent hour-to-hour, day-to-day and week-to-week variability of aircraft noise exposure, depending on, among other things, weather conditions and seasonal differences in passenger aircraft flight patterns. While such measurement error in the independent predictor variable can result in regression dilution bias, which in the case of a univariate relationship between outcome and study variable is toward the null
[MacMahon et al., 1990], the measures of aircraft noise exposure used in the Sydney study were mean noise levels averaged over a calendar month. Accordingly, regression dilution bias from aircraft noise measures used in the study should be minimal.

The measures of aircraft noise exposure used in the Sydney study can be subject to “cross-level” bias. While individual values of aircraft noise exposure were calculated for each school and for each domestic residence of the study participants, these measures were nonetheless ecological in that they were based on outside noise measurements and assigned to the individual school and house locations. Such an ecological variable might be characterised as “fine-grained”. In other words, the individual values of noise exposure were not the result of individual noise measurements conducted at each house and school location, but were derived from noise values corresponding to geocoded address locations as interpolated from calculated noise contours produced by the National Acoustic Laboratories using the Integrated Noise Model [see Peploe, 1996].

The Integrated Noise Model takes good account of the noise characteristics of the different types of jet aircraft in operation but does not take account of local topography and alternative noise sources which can attenuate substantially an individual exposure to aircraft noise. Accordingly, the individually calculated aircraft noise exposure values used in the Sydney study may not accurately reflect the true noise values at each location, even if account were to be taken of house structure and so on, as was the case in the present study. Individual aircraft noise measurements, averaged over suitable periods and taken inside and outside each residence and school, used in conjunction with time weightings spent inside and outside, at home and at school, would be a superior exposure measure. However, it was well beyond the resources available to the Sydney study to conduct such measurements.

Factors which may cause individual aircraft noise exposures to deviate from calculated values include the structure and sound insulation status of the domestic accommodation or the school; the surrounding soundscape, particularly differences in secondary shielding of noise by neighbouring buildings or geographical features for example; and other noise sources such as road and rail traffic. The measures taken to counter these potential effect modifiers in the Sydney study included: (i) collecting information via the parental questionnaire on the structural and insulation properties of individual domestic residences so that these could be controlled for in the regression modelling of BP; (ii) gaining information on each school’s noise insulation status at each BP measurement.
occasion, and controlling for this in regression models; and (iii) controlling for non-aircraft noise sources at each school through the school’s proximity to busy roads and railway lines. These measures could only partly address the ‘real world’ problems of assessing aircraft noise exposure at an individual level, as outlined in the paragraph above. However, there was no reason to expect that these sources of effect modification of the exposure variable would have been a source of systematic bias in noise-exposed versus non-exposed areas. And in the case of noise insulation of schools in high aircraft noise areas, this was taken into account explicitly in the multiple regression models and found not to be statistically significantly associated with BP.

4.5.2 Selection bias

A potential source of selection bias in the Sydney study with bearing on its findings is differential response and attrition rates according to school aircraft noise exposure level. While differential response rates are not easily accounted for, more information on sample attrition can be gained since exposure, confounder and outcome characteristics of those lost to follow-up are known at baseline. In the follow-up phase of the Los Angeles Airport child BP study [Cohen et al., 1981], the lack of longitudinal association between aircraft noise and BP was attributed to children from the noise-exposed schools with higher BPs at baseline being lost to follow-up.

In the Sydney study there were some differences between those in the original sample lost to follow-up and those who participated in the follow-up. Post hoc analyses showed that at baseline the follow-up sample had a slightly more positive relationship between its BP and exposure to aircraft noise than did the children lost to follow-up. It was also found that the attrition rate in noisier schools was lower than in quieter schools. This may be a reflection of less mobility in lower SES groups which tend to be located in noisier areas due to lower real estate prices.

4.6 Measures of BP and sources of BP variability

Even in the absence of intra- or inter-observer variation in BP measurement (in machine or field worker), the particular measure of BP chosen as the outcome is subject to variability. The sources of BP variability range from possible acute BP effects emanating from exposure to noise from aircraft overflights in noisy schools during BP measurement,
to unmeasured confounders of BP, particularly personality. The measure of BP used for the Sydney study was the mean of the 2nd and 3rd successive BP readings of each child. This mean was considered a more reliable and valid measure of resting BP than using the mean of all 3 BP readings. The first BP reading often is disregarded in BP studies, mainly because it is often elevated compared to subsequent readings and is thought to be associated with stress in the subject initially not knowing how the BP measurement procedure will feel. In children this can be exacerbated especially if they have never previously experienced a BP measurement.

However, the first BP reading also can be utilised in conjunction with the remaining BP readings as a measure of BP variability in a subject under the potentially stressful situation of the BP measurement procedure itself. This serves to control both for innate BP variability which may be associated with higher BP, and for differences in personality which, as the literature suggests, are associated with higher BP reactivity to stress situations in those with higher hostility and aggression ratings in personality tests [eg, Henrotte et al, 1985], including in children [eg, Hunter et al, 1982].

The measure of within-subject BP variability intended for the Sydney Airport BP study was the standard deviation of the 3 systolic and diastolic readings. This measure of BP variability was implied from reactivity studies suggesting that absolute deviations from a reference value are more highly correlated with elevated BP than proportional BP variations [eg, Mancia et al, 1980]. Proportional measures of within-subject BP variability, for example the coefficient of variation of MAP readings used by Mancia et al [1980], necessarily decrease with higher BP readings due to the limitations of the underlying biology of BP variation. After all, if the maximum achievable BP of a human is of the order of 300 mmHg systolic, then a hypertensive with a resting systolic BP of 150 mmHg can have a maximum systolic BP equal to 100% increase over the resting value, while a normotensive with 100 mmHg resting systolic BP can achieve a possible 200% increase in their systolic BP.

The variability of within-subject BP readings was also used to test if aircraft overflights were associated with acute BP effects which could produce artefactually elevated BP readings. The reasoning behind this was that successive BP readings, on average, should decline toward a resting value as the subject becomes more familiar and less anxious with the BP measurement procedure. Possible differences in this expectation were used as a
test for possible acute BP effects associated with aircraft overflights. As soundproof booths were not used in BP measurements, the possible overflight scenarios for 3 BP measurements were acute BP effects found to be associated with overflights then, on average, the expected decline in BPs should be less.

Another source of child BP variability which potentially can confound a BP-noise exposure relationship, is ambient temperature, as established in Australia by Jenner et al [1988] to be inversely related to BP. In the present study ambient temperature was recorded in two ways and potentially could have reduced the extent of control of this source of confounding in regression modelling. At baseline, ambient temperature was inferred from meteorological data during the 1994 measurement phase, using 2-hourly temperature data from local weather stations and matching this as closely to the time of BP measurement of the children as possible. Thereafter ambient temperature was measured directly during the 1995 measurement phase and during study follow-up in 1997. However, in the present study ambient temperature showed no consistent association with BP when 1997 BP data were analysed. Since all ambient temperatures were directly recorded in 1997 and since ambient temperature was inconsistently associated with BP at baseline also, it is concluded that the control of ambient temperature in the modelling of BP and aircraft noise exposure was not compromised by the two different methods of ambient temperature measurement.

The present study did not find a consistent relationship between fitness and activity levels and BP, although the measures of fitness used were based only on self-report. However, even under conditions of rigorous measures of fitness, the relationship has been found not to be consistent in children, as shown by Dwyer et al [1994] and Harshfield et al [1994], for example.

The present study also found no consistent relationship between skinfold thickness, as a measure of adiposity, and BP. Some studies have found positive associations with diastolic BP [eg, Stines et al, 1975], while others have shown an apparent association to disappear after weight and height were taken into account [eg, Stallones et al, 1982]. Measures of body mass index (BMI), for example quetelet and ponderal, in children have been shown to not be consistently correlated with BP. Inconsistent associations have been found according to sex, systolic BP or diastolic BP, and the index used [Thomas et al, 1989].
The measure of socio-economic status (SES) used in the present study bore no relationship to child BP, with regression point estimates consistently vanishingly close to zero. This may have been due to the fact that the SES measure used was an aggregate measure assigned at the postcode level, due in turn to advice from schools that collection of individual parental SES indicators would substantially lower the response rate. However, the lack of any association between the SES measure and child BP may be due to SES differences in children that require longer periods, decades perhaps, to manifest as elevated BP in adulthood where most of the SES differences in CVD, etc, are found.

4.7 **IS THERE A POSITIVE RELATIONSHIP BETWEEN CHILD BP AND AIRCRAFT NOISE EXPOSURE?**

This study has found little consistent evidence of a positive relationship between child BP and aircraft noise exposure, either cross-sectionally or longitudinally in the same individuals under changing exposure conditions. The evidence to emerge from the present study is that there may be some negative longitudinal associations of BP in boys and positive longitudinal associations in girls. This does not rule out acute BP effects, especially if the exposure to noise is occurring in the context of task performance, particularly classroom learning activities, as evidenced in the literature. However, there was no consistent or significant evidence that long-term exposure to aircraft noise was associated with elevated resting BP. If a significant cross-sectional relationship between aircraft noise and BP at baseline or follow-up were found, then this would have been evidence for possible acute noise-BP effects under learning conditions cumulating into higher mean resting BP in noise-exposed schools. That this association was not found suggests that even with the occurrence of acute noise/BP effects in children under cognitive challenge, long-term BP differences have not ensued in differently exposed schoolchildren.

The only consistent association found between child BP and aircraft noise to emerge in the present study was a negative association between recent noise exposure change and BP. The implications of this finding have been discussed above.

4.8 **IMPLICATIONS FOR FURTHER RESEARCH IN THE HEALTH OF POPULATIONS EXPOSED TO DOMESTIC JET AIRCRAFT NOISE**

The findings from the Inner Sydney Child Blood Pressure Study do not conclusively rule
out a possible association between BP exposure to domestic jet aircraft noise, but they
do provide the best evidence to date that there is no link between higher child blood
pressure and higher exposure to aircraft noise. In fact, the most consistent findings point
to evidence of short-term BP adaptation to recent exposure changes such that BP is
restored to pre-existing levels unrelated to the new exposure regime.

Other factors were found to be significantly associated with BP which were consistent
across different analyses or modelling assumptions, included weight, being from a non-
English speaking background and pulse rate. Height was also predictive of BP but less
so than weight, and accordingly weight was used as a physical confounding factor for BP
in regression models. The most telling evidence that no link exists between aircraft noise
exposure and child BP is that if one existed it would have also held consistently across
the different regression modelling assumptions.

Where an association may exist between child BP and aircraft noise exposure centres on
a major limitation of the Sydney study, its restriction to the purely physical determinants
of BP (eg, body size, exercise, exposure to noise, and so on) without regard to the major
effect modifiers of attitude to the noise source and to personality. While measurement
of these parameters directly was beyond the resources of the present study, future
investigations of child BP and aircraft noise exposure would need to take account of
these subjective aspects to rule out, or in, with more certainty whether exposure to
aircraft noise is associated with child blood pressure.

While within-subject BP variability was used as a rough proxy for personality, it is not
clear that all those with higher BP variability have Type A personality, or all those with
the Type A personality construct have higher BP variability. In any case, aircraft noise
exposure was not significantly positively associated with blood pressure when BP
variability was controlled for in multiple regression models of BP and aircraft noise
exposure.

From a public health perspective the evidence thus far either does not bear strong
scrutiny, as in the Los Angeles and Munich Airport studies; or, under good study
conditions, does not point to permanent cardiovascular health deficits in children being
associated with exposure to domestic passenger jet aircraft noise. The studies conducted
thus far are sufficiently flawed to be unable to rule in or out such an association. The
evidence presented in this thesis tends more toward the view that children exposed to domestic aircraft noise do not have elevated resting blood pressure compared to those not exposed, and that the public health implications of child exposure to domestic jet aircraft noise accordingly appear benign.