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The Australian Child Health and Air Pollution Study (ACHAPS): A national population-based cross-sectional study of long-term exposure to outdoor air pollution, asthma, and lung function

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ABSTRACT

Most studies of long-term air pollution exposure and children's respiratory health have been performed in urban locations with moderate pollution levels. We assessed the effect of outdoor nitrogen dioxide (NO_2), as a proxy for urban air pollution, on current asthma and lung function in Australia, a low-pollution setting.

We undertook a national population-based cross-sectional study of children aged 7–11 years living in 12 Australian cities. We collected information on asthma symptoms from parents via questionnaire and measured children's lung function (forced expiratory volume in 1 s [FEV_1], forced vital capacity [FVC]) and fractional exhaled nitric oxide [Fe_{NO}]). We estimated recent NO_2 exposure (last 12 months) using monitors near each child's school, and used a satellite-based land-use regression (LUR) model to estimate NO_2 at each child's school and home.

Our analysis comprised 2630 children, among whom the prevalence of current asthma was 14.9%. Mean (± SD) NO_2 exposure was 8.8 ppb (± 3.2) and 8.8 ppb (± 2.3) for monitor- and LUR-based estimates, respectively. Mean percent predicted post-bronchodilator FEV_1 and FVC were 101.7% (± 10.5) and 98.8% (± 10.5), respectively. The geometric mean Fe_{NO} concentration was 9.4 ppb (± 7.1).

An IQR increase in NO_2 (4.0 ppb) was significantly associated with increased odds of having current asthma; odds ratios (ORs) were 1.24 (95% CI: 1.08, 1.43) and 1.54 (95% CI: 1.26, 1.87) for monitor- and LUR-based estimates, respectively. Increased NO_2 exposure was significantly associated with decreased percent predicted FEV_1 (−1.35 percentage points [95% CI: −2.21, −0.49]) and FVC (−1.19 percentage points [95% CI: −2.04, −0.35], and an increase in Fe_{NO} of 71% (95% CI: 38%, 112%).

Exposure to outdoor NO_2 was associated with adverse respiratory health effects in this population-based sample of Australian children. The relatively low NO_2 levels at which these effects were observed highlight the potential benefits of continuous exposure reduction.

1. Introduction

Compared with adults, the growth and development that characterise childhood potentially places children at greater risk of adverse respiratory health effects due to air pollution (McConnell et al., 2002; Morgenstern et al., 2007; Bateson and Schwartz, 2008; Goldizen et al., 2016). The evidence for acute, short-term (e.g., days to weeks) effects of air pollution on children has grown markedly in recent years (e.g. Samoli et al., 2011; Spira-Cohen et al., 2011). In comparison, studies on the association between long-term (i.e., one or more years') exposure to

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outdoor air pollution and children's respiratory health are relatively few, and largely confined to North American and European cities with moderate air pollution levels (e.g. McConnell et al., 2002; Morgenstern et al., 2007; Gauderman et al., 2015; Dales et al., 2008; Eckel et al., 2011; Gehring et al., 2013; Gauderman et al., 2004; Janssen et al., 2003; Jerrett et al., 2008; Penard-Morand et al., 2005; Penard-Morand et al., 2010; Peters et al., 1999). For example, most studies of childhood asthma have been performed in settings with annual average nitrogen dioxide (NO_2) levels between ~12 and ~30 ppb (Favarato et al., 2014). Empirical evidence on the effects of exposure below that range, and the extent to which the findings of those studies may be generalisable to lower levels, is comparatively limited (Khreis et al., 2017).

A potential limitation of some previous studies of childhood asthma is the reliance on surrogates of pollutants, mostly traffic sources (e.g., road density near the home), in lieu of pollutant measurements or modelled exposures. Surrogates may adequately reflect relatively high or low traffic-related exposures, but they do not inform the concentration-response function for specific air pollutants. This is relevant to health impact assessment and meta-analyses, which require health outcomes for a pollutant to be expressed on a continuous scale (e.g., per $\mu g/m^3$ increase) (Favarato et al., 2014; Khreis et al., 2017; Khreis and Nieuwenhuijsen, 2017).

Moreover, most studies that did estimate pollutant exposure used a single method for assigning exposure. For example, in a meta-analysis of 18 studies on NO_2 and prevalent asthma in children, published in 2014, four different exposure assessment methods were used, but no study used more than one method (Favarato et al., 2014). A more recent systematic review of exposure assessment in 42 studies (cross-sectional, case-control, and cohort) of traffic-related air pollution (TRAP) and childhood asthma reported that 28/42 (66%) used a single exposure assessment method (Khreis and Nieuwenhuijsen, 2017). That review also found that only 10/42 (24%) studies considered both the home and school or daycare address when assigning exposure, which may more realistically reflect the exposures of school-aged children than home addresses alone (Khreis and Nieuwenhuijsen, 2017). More detailed exposure assessment methods have been suggested as one way to increase the utility and generalisability of studies assessing air pollution and childhood asthma, including in health impact assessments (Khreis and Nieuwenhuijsen, 2017).

Australia has a small population (~24.5 million in 2017), approximately 10% of which has prevalent asthma, one of the world's highest rates. Asthma is the leading contributor to disease burden in Australian children aged ≤ 14 years (AIHW, 2011). As an island continent, Australia is not subject to significant trans-boundary air pollution. Australia has relatively low pollutant levels compared with North America and many European countries (e.g., annual average NO_2 in urban areas during 2006–2011: ~7 ppb) (Knibbs et al., 2014).

Previous Australian investigations of air pollution and children's respiratory health have focused on short-term effects, mostly in small or localised studies (e.g. Henry et al., 1991; Jalaludin et al., 2000; Lewis et al., 1998; Pereira et al., 2010). An exception in both size and geographic extent was a large national time-series case-crossover study that examined the association between air pollutants and respiratory hospital admissions of children in five Australian (and two New Zealand) cities (Barnett et al., 2005). That study reported a 6.0% increase in asthma admissions (95% CI: 0.2, 12.1) for children (5–14 years old) per 5.1 ppb increase in 24-h NO_2. While short-term respiratory effects of air pollution on Australian children have been demonstrated, to our knowledge, there have been no nationally representative studies of long-term effects.

We sought to better define the role of long-term outdoor air pollution exposure on children's respiratory health in Australia via a national study. We sought to add to the international evidence, largely based in locations with higher concentrations than Australia, by focusing on a low pollution setting, using two exposure assessment methods, and estimating exposure at school and home.

2. Methods

2.1. Study design

2.1.1. Site selection

We undertook a national, cross-sectional study of Australian children aged 7–11 years during 2007–2008: the Australian Child Health and Air Pollution Study (ACHAPS). We targeted the six most populous states and territories of the eight in Australia (New South Wales, Victoria, Queensland, South Australia, Western Australia, and the Australian Capital Territory). Tasmania and the Northern Territory were excluded due to their small population and limited air quality monitoring.

We first identified all regulatory ambient air quality monitors that: (a) had at least five years' measurements of criteria pollutants using standard reference methods (ozone (O_3), carbon monoxide [CO], NO_2, sulphur dioxide [SO_2], particulate matter < 2.5 μm [$PM_{2.5}$] and < 10 μm [PM_{10}]; (b) had at least three potentially eligible primary (elementary) schools within approximately 2 km; and (c) were considered by the relevant pollutant monitoring authorities to be at a site representative of general population exposure in surrounding areas (e.g., not influenced by a major road or industrial emission source, for example).

We calculated the annual average levels of each pollutant during 2004–2005 and ranked the monitoring sites. We aimed to ensure maximum variability in the diversity of air pollutants and their concentrations. A quota of the highest- and lowest-ranked sites for each pollutant was selected (approximately six), which yielded 29 sites in total after allowing for overlap. We used the 2 km distance threshold as a balance between the need for a sufficient number of schools while aiming to limit exposure measurement error introduced due to spatial variability of pollutants. We also investigated an additional exposure assessment method (described in Section 2.4).

We targeted state government-run public schools, which educate approximately 71% of primary school students in Australia, and have sufficiently large numbers of children aged 7–11 years (Australian Bureau of Statistics, Schools, Australia, 2012). We also targeted independent (non-government) Catholic schools in the state of Victoria due to limited government schools proximate to each monitor. We randomly selected two schools per monitoring site to approach, then contacted the principal and invited their school to participate. Refusing schools were randomly replaced, where possible, and 86 schools were approached in total.

Fifty-five schools (64%) agreed to participate, all of which (except two) were within 2 km of a monitor. The remaining two schools were 2.1 and 2.8 km from the monitoring site, respectively. The median distance of schools from the monitoring site was 1.4 km. The 55 schools spanned the major state capital cities in Australia: Sydney (population in 2006 = 4.3 million; 6 schools), Melbourne (3.6 million; 10 schools), Brisbane (1.8 million; 6 schools), Perth (1.5 million; 7 schools), and Adelaide (1.1 million; 6 schools). Seven other cities (20 schools total) were also included, spanning a population range of ~20,000 to ~500,000); these cities are not named to minimise the potential for re-identification of schools. An overview map of the schools located in large cities is presented in Fig. 1.

2.1.2. Recruitment and questionnaire

We randomly selected whole classes within each of the 55 schools to obtain at least 100 children per school. No exclusions were made on the basis of race, ethnicity or socio-demographic factors. Background information, questionnaires and consent forms were distributed to parents. In total, 7618 children were invited to take part.

The questionnaire was derived from items in the International Study of Asthma and Allergies in Childhood (ISAAC) (ISSAC, 2000), and other relevant studies (Peters et al., 1999; Toelle et al., 2004; Marks et al., 2006; Centre for Epidemiology and Research, N. D. O. H., 2003). We