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Outdoor and indoor air quality and cognitive ability in young children

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ABSTRACT

Background: This study examined outdoor and indoor air quality at ages 9 months and 3 years and their association with cognitive ability at age 3 in England and Wales.

Method: Data from 8198 Millennium Cohort Study children were analysed using multilevel regression. Outdoor air quality was assessed with mean annual estimates of nitrogen dioxide (NO_2) levels within a standard small area (ward). Indoor air quality was measured with parent-reports of damp or condensation in the home and exposure to secondhand smoke in the home. Cognitive ability was assessed with the British Ability Scales Naming Vocabulary subscale and the Bracken School Readiness Assessment.

Results: In adjusted models, consistent exposure to high levels of NO_2 at age 9 months and age 3 years was associated with lower verbal ability at age 3 years. Damp/condensation and secondhand smoke in the home at either age or at both ages were correlated with lower school readiness at age 3 years. Exposures to damp/condensation at age 3 years or at both ages and secondhand smoke at either age or at both ages were associated with lower verbal ability at age 3 years.

Conclusion: Young children's exposures to indoor damp or condensation and secondhand smoke are likely to be detrimental for their cognitive outcomes. However, there do not appear to be any short-term effects of NO_2.

1. Introduction

In the last decade, research into the role of prenatal and postnatal outdoor and indoor air quality in child cognitive functioning has grown substantially (Chen et al., 2013; Clifford et al., 2016; Jedrychowski et al., 2011; Kicinski et al., 2015; Sánchez-Rodríguez et al., 2006; Tonne et al., 2014; Wang et al., 2009). Prenatal exposures to outdoor air pollutants including particulate matter (PM), nitrogen dioxide (NO_2), polycyclic aromatic hydrocarbons (PAHs) and benzene have been linked to infant psychomotor and cognitive functioning (Chiu et al., 2016; Lertxundi et al., 2015; Perera et al., 2006). A number of studies have also found effects of postnatal exposures to traffic-related pollutants in school-aged children. For example, higher levels of black carbon predicted decreased cognitive functioning in middle childhood in a US city sample (Suglia et al., 2008). In a study of school-aged children in China, researchers found significant differences in performance on sensory, motor and psychomotor functioning assessments for children living in more and less (NO_2) polluted areas (Wang et al., 2009). A more recent study in Spain found significant associations between general markers of road traffic pollution and slower cognitive growth in a large sample of children (Sunyer et al., 2015). Another study examined primary school children's recent and chronic exposure to PM at home and in the classroom (Saenen et al., 2016). It showed links between recent exposure at home and visual information processing speed as well as between chronic exposure at home and measures of attention. However, not all studies have found significant effects. Clark et al. (2012) examined the associations between noise levels, air pollution and cognition and health in children residing in areas surrounding a major airport in London, UK. In that study, air pollution (NO_2) did not significantly predict child cognition. It is not easy to compare these studies, however, given their variations in pollutant and cognitive measures and differences in confounding variables accounted for.

It is also difficult to estimate the true effect of outdoor air pollution on child cognition as most studies do not account for indoor sources of air pollution which may confound these associations (Clifford et al., 2016). Children, especially young children, spend the majority of their time indoors which may protect them somewhat from harmful exposures to outdoor air pollutants. However, air pollutants generated indoors such as those from activities like smoking, cooking, heating, and use of paints, varnishes and cleaning products may adversely affect child cognition (Clifford et al., 2016). Indoor air quality may also be related to outdoor air quality as pollutants from outdoors (e.g., by industrial processes and traffic emissions) may migrate inside the home through windows or other forms of ventilation.

It seems however that we know similarly little about the role of

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indoor air quality in cognitive functioning in children (Chen et al., 2013; Jedrychowski et al., 2011), although the few studies into this to date have shown promising findings. For example, a cohort study carried out in Poland found that persistent exposure to mould in the home was related to poorer cognitive ability in children of school age (Jedrychowski et al., 2011). Another study explored the impact of indoor NO_2 exposure from gas appliances on child cognition in Spain, and found a dose-response relationship between NO_2 levels and cognitive outcomes including overall cognitive function, verbal abilities and executive functioning (Morales et al., 2009). About young children we know even less. Even among the studies into the role of exposures to secondhand smoke (SHS) in cognition in young children (Jedrychowski et al., 2009; Julvez et al., 2007; Lee et al., 2011), those linking indoor air quality to early childhood outcomes (Chen et al., 2013; Yolton et al., 2005) are few. They also tend to produce null findings after adjustment for appropriate confounders.

1.1. Effect mechanisms

The lack of research into the role of air quality in cognition in young children is unfortunate in view of the evidence that air quality is implicated in physiological mechanisms which may directly affect cognition. For example, exposure to air pollutants may deleteriously affect young children's cognitive ability through promoting neuroinflammation and oxidative stress (Calderón-Garcidueñas et al., 2013; Guarnieri and Balmes, 2014). Experimental studies have shown that air pollutants can penetrate the blood brain barrier and cause direct neuronal and white matter injury as well as systematic inflammation that adversely impacts the developing nervous system (Block et al., 2012). Furthermore, exposure to air pollutants can exacerbate or cause asthma and wheezing (Esposito et al., 2014; Guarniari and Balmes, 2014). Respiratory problems such as asthma, in turn, can impede upon children's cognition (Blackman and Gurka, 2007).

With regard to indoor exposures in particular, damp or condensation often results in mould and bacteria that can produce microscopic airborne particles (Górny et al., 2002). Some of these particles contain allergens or chemicals with the potential to induce neuroinflammation. Secondhand smoke has high concentrations of many toxic chemicals that are harmful to the brain (Chen et al., 2013). For example, carbon monoxide in the bloodstream can reduce oxygen in the brain (Mezzacappa et al., 2011) and nicotine can affect the cholinergic system (Slotkin, 1999, 2004) which may result in overstimulation of neurons implicated in learning and memory.

1.2. The present study

The existing research has several limitations that this study was carried out to address. First, no studies, to our knowledge, have explored the role of postnatal exposures to air pollution in preschool children when the developing brain may be most susceptible to environmental toxins (Block et al., 2012). Second, the studies to date utilised relatively small samples and most are cross-sectional. Third, a major omission in the literature is the simultaneous exploration of *both* outdoor and indoor air quality in child cognition. Fourth, the existing research neglected to examine the nature of the relationship between pollution and child cognition (e.g., whether the relationship is dose-response or not), assuming air pollution is unsafe at all levels (Lanphear, 2015). Last, no study has accounted for the amount of green space in the neighbourhood, which may confound the association between outdoor air pollution and children's cognition. Green space has been shown to improve air quality (Beckett et al., 1998) and to be related to children's cognitive functioning including attentional capacities (Wells, 2000) and academic performance (Wu et al., 2014).

The present study aims to address these gaps in the literature through a secondary analysis of data from the Millennium Cohort Study (MCS), a longitudinal survey of 19,519 UK children born during the year 2000 or shortly thereafter and their families. It explores the nature of the relationship between neighbourhood-level (i.e., ward[1]) NO_2 and two indicators of indoor air quality – damp or condensation and secondhand smoke - measured twice in early childhood (at ages 9 months and 3 years) with child cognitive ability at age 3 years (when first measured in MCS) in England and Wales. NO_2 is mainly caused by the combustion of fossil fuels (Katsouyanni, 2003). Nitrogen oxides are emitted as NO which quickly reacts with oxygen and ozone forming NO_2. NO_2 is emitted primarily from road traffic and energy production processes. Its main sources are diesel engines. In the UK, the level of NO_2 has regularly exceeded the legal levels set by EU air quality standards, such as those set out in the EU Ambient Air Quality Directive and the fourth Daughter Directive. In 2013, 34.5% of licensed cars in the UK were diesel (Department for Transport, 2014). This has become a major concern for citizens as well as policymakers, particularly in London where levels are highest. Therefore, identifying air pollution effects on young children has important implications for UK transport policy. At the same time, air quality standards in the UK currently apply to outdoor rather than indoor air. Hence, there is a case for developing guidelines for indoor air quality based on our understanding of the risks posed by indoor air pollutants.

2. Method

2.1. Sample

The Millennium Cohort Study (MCS; www.cls.ioe.ac.uk/mcs) is a longitudinal survey drawing its sample from all births in the UK over a year, beginning on 1 September 2000 (Plewis, 2007). To date, six sweeps (waves) of data have been carried out. A total of 19,519 children participated in at least one of these six sweeps. The MCS sample is disproportionately stratified, firstly by country and then type of electoral ward. The sample design over-represented families living in areas of high child poverty, areas with high proportions of ethnic minority populations across England and the three smaller UK countries. In MCS, children and their families were sampled from 338 wards across the UK (Plewis, 2007). Ethical approval was gained from NHS Multi-Centre Ethics Committees and parents gave informed consent before interviews took place.

We used data from Sweeps 1 and 2 (at ages 9 months and 3 years, respectively). We started with the total sample (n = 19,519) and retained only singletons and first born twins/triplets resulting in n = 19,244, making the number of children equal to the number of families. Our analytic sample comprised children who lived in England or Wales in both Sweeps 1 and 2 and who had complete data on all variables used in the analysis including outdoor and indoor air quality indicators, cognitive functioning at age 3 and all covariates (n = 8198).

2.2. Measures

Cognitive ability at age 3 was measured with scores on two assessments, one of verbal ability and the other school readiness. *Verbal ability* was assessed with the British Ability Scales II Naming Vocabulary test, which assesses the spoken vocabulary of children aged 2 years 6 months to 7 years 11 months. The test items consist of coloured pictures of objects shown to the child, one at a time. The test measures expressive language ability, vocabulary knowledge of nouns, general knowledge and language development and stimulation. In MCS, standardised scores on the Naming Vocabulary scale are adjusted for the child's age group. They have a mean of 50 and a standard deviation of

[1] Electoral wards are the key building block of UK electoral geography (http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/administrative/england/electoral-wards-divisions/index.html). The average population is around 5500, though counts can vary substantially. Census area statistical (CAS) wards in particular are used in this study. They are a type of ward created for the 2001 census.