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Review article

A review of factors surrounding the air pollution exposure to in-pram babies and mitigation strategies

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ABSTRACT

Air pollution exposure to in-pram babies poses a serious threat to their early childhood development, necessitating a need for effective mitigation measures. We reviewed the scientific and grey literature on in-pram babies and their personal exposure to traffic generated air pollutants such as particulate matter ≤10 µm (PM_{10}), ≤2.5 µm ($PM_{2.5}$), ≤0.10 µm (ultrafine particles) in size, black carbon and nitrogen oxides and potential mitigation pathways. In-pram babies can be exposed up to ~60% higher average concentrations depending on the pollutant types compared with adults. The air within the first few meters above the road level is usually most polluted. Therefore, we classified various pram types based on criteria such as height, width and the seating capacity (single versus twin) and assessed the breathing heights of sitting babies in various pram types available in the market. This classification revealed the pram widths between 0.56 and 0.82 m and top handle heights up to ~1.25 m as opposed to breathing height between 0.55 and 0.85 m, suggesting that the concentration within the first meter above the road level is critical for exposure to in-pram babies. The assessment of flow features around the prams suggests that meteorological conditions (e.g., wind speed and direction) and traffic-produced turbulence affect the pollution dispersion around them. A survey of the physicochemical properties of particles from roadside environment demonstrated the dominance of toxic metals that have been shown to damage their frontal lobe as well as cognition and brain development when inhaled by in-pram babies. We then assessed a wide range of active and passive exposure mitigation strategies, including a passive control at the receptor such as the enhanced filtration around the breathing zone and protection of prams via covers. Technological solutions such as creating a clean air zone around the breathing area can provide instant solutions. However, a holistic approach involving a mix of innovative technological solutions, community empowerment and exposure-centric policies are needed to help limit personal exposure of in-pram babies.

1. Introduction

A wide range of scientific literature signifies the negative effects of air pollution exposure on the health of babies (Bates, 1995; Giles et al., 2011; Harrison and Yin, 2000; Heal et al., 2012; Janssen et al., 2012; Lim et al., 2013; Morgan et al., 1997; Sydbom et al., 2001; Watt et al., 1995; World Health Organization, 2005, 2011). Young children are more vulnerable to the health effects of traffic-related air pollution (TRAP) such as particulate matter ≤10 µm (PM_{10}), ≤2.5 µm ($PM_{2.5}$) and nitrogen oxides (NO_x). Positive correlations are reported between the elevated risk of acute lower respiratory tract infections and asthma in young children and their measured levels (Iskandar et al., 2011; World Health Organization, 2011). UNICEF (2017) revealed that almost 17 million children < 1 year old live in highly affected regions of the world where air pollution levels exceed World Health Organization recommended values of $PM_{2.5}$ by at least six times. Of which, approximately 12 million affected babies are from South Asia (UNICEF, 2017). Young children, especially those from the poor socio-economic background, are most vulnerable to the impacts of toxic air pollutants (Mehta et al., 2014; Perera, 2017).

The terms baby and infant are synonyms and usually refer to those below 1 year old (FarlexInc., 2003; MediLexicon, 2018) while the

Abbreviations: BC, black carbon; CCS, congestion charge scheme; CI, confidence interval; IQR, interquartile range; LEZ, low emission zone; NO_x, nitrogen oxides; PNCs, particle number concentrations; PM_x, particulate matter less than or equal to x µm in aerodynamic diameter; SO_2, sulfur dioxide; TiO_2, titanium dioxide; TI, traffic intersection; TRAP, traffic-related air pollution; TSP, total suspended particle; UFP, ultrafine particle; UNECE, United Nations Economic Commission for Europe; VOCs, volatile organic compounds

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toddlers are those between 1 and 3 years (CDC, 2017). In this review, we refer young children to both the above categories. Furthermore, the terms pram, buggy and stroller are used interchangeably and a detailed classification of these is provided in Section 2. Here, our focus remains on ultrafine particles (UFPs), $PM_{2.5}$, PM_{10} and NO_x emissions exposure to in-pram babies. These pollutants are considered because of their greatest impact on the health of young children (Iskandar et al., 2011). PM_x and NO_2 are focus of this work since these are commonly seen as the most harmful air pollutants due to their high concentrations and negative health impacts (Heal et al., 2012; Sunyer et al., 2015). For example, the long-term health impacts of PM concentrations is quantified in the range of 340,000 life years lost in the UK whereas short-term exposure to NO_2 is linked with inflammation of the airways and greater vulnerability to respiratory infections and to allergens. It worsens symptoms of lung or heart conditions by reducing their lives (DEFRA, 2018).

Only a small portion of NO_x emitted by motor vehicles is in the form of NO_2 while NO remains the dominant component (Berkowicz, 2000). Therefore, we have included both NO_2 and NO in our analysis, as reported by reviewed studies. UFPs carry higher toxicity per unit mass and potential to cause adverse respiratory and wide-ranging health effects upon entering the lungs (Branco et al., 2014; Donaldson et al., 2005; Harrison and Yin, 2000; Kumar et al., 2010; Sioutas et al., 2005). These particles have greater surface area, unique chemical composition, higher pulmonary deposition efficiency and subsequent inflammation, ability to penetrate deep in the body and enter the circulation system (including cardiovascular system) through the skin, lung and gastro-intestinal tract and can accumulate in lymph nodes and brain tissues; and have potential to cause asthma, allergies and respiratory diseases in children (Heal et al., 2012; Kumar et al., 2014). All these negative health impacts of UFPs are more prevalent in children due to the following reasons: (i) children inhale a higher dose of airborne particles relative to their lung size and body weight in comparison with adults; the respiratory rate of child per body weight is generally two-fold higher than that for adults (Ginsberg et al., 2005); (ii) they have immature tissues, lungs, immune system, and brain which continue developing quickly; and (iii) they have permeable cell membrane lining inside their respiratory tract (Bates, 1995; Buonanno et al., 2013; Burtscher and Schüepp, 2012; Mendell and Heath, 2005; World Health Organization, 2005). In particular, children from poor socio-economic groups are disproportionately affected by exposure to higher level air pollution because of lack of proper nutrition, access to routine medical care, lack of air-conditioning in houses, exposure to indoor emissions from tobacco smoking as well as use of kerosene stoves in houses (Bates, 1995; Beate Ritz, 2008; World Health Organization, 2005).

PM_{10} have a potential to deposit in the tracheobronchial region while fine particles ($PM_{2.5}$) can go deeper into the respiratory bronchioles (Kim et al., 2015; Löndahl et al., 2006). $PM_{2.5}$ is usually more toxic than PM_{10} while UFPs shows the highest toxicity per unit mass which increases with decreased size range (Harrison and Yin, 2000; Heal et al., 2012). Likewise, the long-term exposure of BC reduces cognitive function among young children (Suglia et al., 2007), affect negatively their respiratory health (Janssen et al., 2012) and lead to cardiopulmonary mortality (Janssen et al., 2011; WHO, 2012). Ambient $PM_{2.5}$, PM_{10} and NO_x are regulated via the ambient air quality standards. Despite significant scientific evidence demonstrating negative health effects of BC and UFPs, the ambient air quality regulations are missing for these pollutants (Kumar et al., 2018a).

Table 1 presents the summary of relevant studies that show limited work assessing the air pollution exposure to in-pram babies. However, these studies provide meaningful insights on their elevated exposures in comparison with adults and quantify their exposure levels at different breathing heights. For example, Kumar et al. (2017) revealed that in-pram babies are exposed to higher $PM_{2.5}$ concentrations during the afternoon pick-up hours of children from school compared with morning drop-off hours. Earlier Garcia-Algar et al. (2015) reported a higher exposure of infants in strollers (a type of baby pram; see Section 2) to particles in the 20–1000 nm size range than adults during walk mode in an urban area. Similarly, a USA based study by Buzzard et al. (2009) found that children or infants breathing UFPs and PM_1 at heights similar to that of a passing vehicle's tailpipe are exposed to higher PM concentrations than adults breathing at higher heights in standing position. Although some studies have reported that in-pram babies are not exposed to higher concentrations of $PM_{2.5}$ than adults (Galea et al., 2014) and highlight the need for more studies to develop a diverse database. To build a holistic view on the topic, we evaluated both the scientific studies such as journal and conference papers and the grey literature that included online published material such as technical reports, policy statements, catalogues, and brochures.

As for health effects, Pujol et al. (2016) assessed the potential effects of TRAP on child brain development in the school environments. They measured concentrations of NO_2 and BC (a component of $PM_{2.5}$) as common markers of vehicle exhaust and used combination of imaging techniques such as functional Magnetic Resonance Imaging technique for quantifying various brain activities (e.g., regional brain volumes, tissue composition, myelination, cortical thickness, neural tract architecture, membrane metabolites, functional connectivity in major neural networks and activation/deactivation dynamics) during a sensory task. They found that children from schools with higher exposure to TRAP showed lower functional integration and segregation in key brain networks as well as slower brain maturation. Likewise, Sunyer et al. (2015) studied the effects of TRAP (NO_2, BC, and UFPs) on young children (7 to 10 years old) from 2715 schools in Barcelona (Spain) and found that children with higher levels of exposure had a smaller growth in cognitive development over time (Sunyer et al., 2015). Similarly, Suglia et al. (2007) assessed the relation between long-term BC exposure (produced from mobile sources) and cognition functioning of children in a cohort study (1986–2001) for Boston, Massachusetts. The study was performed for selected 202 children (mean age ~ 9.7 ± 1.7 years) and the BC concentrations were estimated utilising a verified spatio-temporal land-use regression model as the annual mean of $0.56 \pm 0.13\,\mu g\,m^{-3}$. The study reported that BC exposure to children resulted in weakening of their cognitive functioning across memory, verbal and nonverbal intelligence constructs. The above discussion clearly suggests that TRAP exposures to young children affect their early brain development and those from the poor socio-economic background are more vulnerable to such risks compared with their counterparts from relatively affluent socio-economic backgrounds.

Iskandar et al. (2011) found a significant positive association between hospital admissions for asthma in children and TRAP (NO_x, NO_2, PM_{10} and $PM_{2.5}$) as opposed to a weak positive and non-significant association was detected with UFPs. The following highest risk estimate per increase in interquartile range (IQR) of 5-day mean air pollution levels prior to hospital admission for asthma was observed: NO_x (1.11; 95% CI 1.05–1.17), followed by NO_2 (1.10; 95% CI 1.04–1.16), $PM_{2.5}$ (1.09; 95% CI 1.04–1.13) and PM_{10} (1.07; 95% CI 1.03–1.12). These findings are also supported by a recent meta-analysis conducted by Khreis et al. (2017) where they presented statistically significant associations between TRAP (NO_2, NO_x, $PM_{2.5}$, PM_{10}) exposures and risk of asthma development. The overall risk reported at 95% CI was as follows: NO_2 (1.05; 95% CI 1.02–1.07) per $4\,\mu g\,m^{-3}$; NO_x (1.48; 95% CI 0.89–2.45) per $30\,\mu g\,m^{-3}$ nitrogen oxides (NO_x); $PM_{2.5}$ (1.03; 95% CI 1.01–1.05) per $1\,\mu g\,m^{-3}$; PM_{10} (1.05; 95% CI 1.02–1.08) per $2\,\mu g\,m^{-3}$. Recent work of Deng et al. (2018) studied the particle deposition in human tracheobronchial airways for infants, children, and adults through computation fluid dynamics modelling and reported that infants are potentially at a greater health risk from exposure to airborne particulate matter and the particle deposition decreases with increasing age.

There are numerous studies on the exposure assessment of young children but similar studies for in-pram babies are very limited and call to highlight the gaps in existing literature that could be filled by future