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# Environmental lead exposure risks associated with children's outdoor playgrounds

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ABSTRACT

This study examines exposure risks associated with lead smelter emissions at children's public playgrounds in Port Pirie, South Australia. Lead and other metal values were measured in air, soil, surface dust and on pre- and post-play hand wipes. Playgrounds closest to the smelter were significantly more lead contaminated compared to those further away ($t(27.545) = 3.76$; $p = .001$). Port Pirie post-play hand wipes contained significantly higher lead loadings (maximum hand lead value of 49,432 μg/m$^2$) than pre-play hand wipes ($t(27) = 3.57$, $p = .001$). A 1% increase in air lead (μg/m$^3$) was related to a 0.713% increase in lead dust on play surfaces (95% CI, 0.253–1.174), and a 0.612% increase in post-play wipe lead (95% CI, 0.257–0.970). Contaminated dust from smelter emissions is determined as the source and cause of childhood lead poisoning at a rate of approximately one child every third day.



## 1. Introduction

This study examines childhood exposure risks associated with environmental lead emissions from the Port Pirie (South Australia) lead smelter at four of the city's outdoor playgrounds. Port Pirie is home to the world's third largest lead–zinc smelter, which was established in 1889. The Nyrstar Port Pirie Pty Ltd smelter site and its emissions are the dominant source of atmospheric lead in Port Pirie, with The National Pollutant Inventory (NPI) reporting 44,000 kg of lead being released in 2010–2011 (NPI, 2012). The smelter also emitted significant amounts of other aerosol pollutants during 2011–2012 including arsenic (1100 kg), cadmium (1200 kg), copper (690 kg), zinc (49,500 kg) (NPI, 2012).

The sources of lead, and their local and regional distribution at Port Pirie have been studied extensively (Baghurst et al., 1992; Body et al., 1991; Calder et al., 1994; Cartwright et al., 1977; Esterman and Maynard, 1998; Maynard et al., 2006, 2003; van Alphen, 1999). Esterman and Maynard's (1998) and van Alphen's (1999) studies were fundamentally important in terms of addressing the environmental lead problem in Port Pirie. Prior to these studies, the prevailing view was that the source of exposure was predominantly due to the 'lead sink'; that is, the contaminated legacy of lead in soils in and around Port Pirie (Body et al., 1991). Esterman and Maynard (1998) and van Alphen's (1999) studies showed that elevated concentrations of atmospheric lead dust (and other metal contaminants) from smelter emissions were the likely dominant source of elevated blood lead levels in Port Pirie children.

*Abbreviations:* ABS, Australian Bureau of Statistics; ACCLPP, Advisory Committee on Childhood Lead Poisoning & Prevention; As, arsenic; AS, Australian Standard; ASTM, American Society for Testing and Materials; ATSDR, Agency for Toxic Substances and Disease Registry; Cd, cadmium; Cu, copper; EPASA, Environment Protection Authority, South Australia; NEPC, National Environmental Protection Council; NHMRC, National Health Research and Medical Council; NPI, National Pollutant Inventory; NTP, National Toxicology Program; Pb, lead; TA LUFT, Technical Instructions on Air Quality Control; WA Health, Western Australia Health; WHO, World Health Organisation; Zn, zinc.

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The city of Port Pirie has a population of 18,076 of which, approximately 21.0% are <14 years old (ABS, 2010b). The long history of smelting in the city has resulted in generations of children having long-term, elevated blood lead levels (Maynard et al., 2006; Taylor, 2012; Simon et al., 2013). This is in spite of the ongoing efforts to reduce exposure via the city's lead awareness and education programs 'Tenby10' and the more recent 'Ten for Them' initiative (TenforThem, 2012), the aims of which are to reduce blood lead levels in all children below 10 μg/dL. Blood lead levels remain elevated with 24.9% (excluding maternal blood lead as surrogate values) for children less than 5 years of age having a blood level >10 μg/dL in 2012 (Simon et al., 2013). The geometric mean blood level in children aged 24 months in 2012 was 6.3 μg/dL. The percentage of children exceeding 10 μg/dL, the current Australian goal for blood lead (NHMRC, 2009), is more than double the most recent surveys from Broken Hill (Lesjak, 2011) or Mount Isa (Queensland Health, 2010), Australia's two other primary locations with known blood lead problems in children.

Although several studies have examined the link between blood lead exposures and elevated levels of lead-enriched dust in Port Pirie (Baghurst et al., 1992; Calder et al., 1990; Esterman and Maynard, 1998; Simon et al., 2007), no research has been undertaken to investigate the potential risks associated with lead contaminated dust at Port Pirie's outdoor public playground environments. Outdoor environments such as children's recreational or kindergarten facilities represent a potentially hazardous environment for children in lead contaminated communities because of their potential interaction with contaminated surfaces and soils (Duggan et al., 1985; Gulson et al., 2006; Mielke et al., 2011; Nielsen and Kristiansen, 2004). Thus, the primary purpose of this study is to investigate exposure to lead at children's outdoor playground facilities in the lead and zinc smelting city of Port Pirie following a timed period of play activity. To measure exposures pre- and post-play hand wipes were collected using a standard process after child-simulated play by an adult. Surface soils and dusts were also sampled to provide a better understanding of other potential sources of lead exposure. In addition to lead concentration values, arsenic, cadmium, copper and zinc concentration values were also measured in the samples to provide complementary data on environmental contamination and possible exposure risks.

## 2. Methods and approach

Exposure risks at the playground sites were determined using surface and subsurface soil samples, dust wipes on outdoor surfaces, and hand wipes before and after a 20 min timed child-simulated play activity by an adult at each playground. Lead-in-air data was provided by the Environment Protection Authority, South Australia (EPASA).

### 2.1. Field sampling methods

Dust data was collected from four outdoor playground facilities at Port Pirie over a 7-day period between 26 June to 3 July, 2011. The four playgrounds in Port Pirie were all within 3.0 km of the smelter stack: Foreshore Playground (1.0 km); Memorial Park Playground (1.2 km); Sports Park Playground (2.4 km); Woodward Park Playground (3.0 km), Fig. 1. A reference playground site in Port Augusta, situated 85 km NNW of Port Pirie was subject to the same sampling procedures (Fig. 1). Port Augusta was deemed to be a suitable reference site as it has no lead smelting and its population of 14,669 (ABS, 2010a) is similar to Port Pirie, the principal study site.

Surface wipes ($n = 72$) were collected using a Ghost Wipe™ following the methods described in ASTM E1728-03 (ASTM, 2003), with values transformed to μg/m$^2$. Surface dust wipe samples were collected daily from the same two flat, unpainted, horizontal surfaces at each playground site (details of the wiped surfaces are provided in the Supplementary Data, Table S1). The sampled sites were not accessible during normal play routines and therefore did not influence the post-play hand wipe measures. The only exceptions were at Sports Park and Woodward Park where one of the surfaces was swapped at each location on day two because they were partially covered by an adjacent structure, and were deemed unsuitable. The original surfaces were also sampled on day two, producing an extra sample at each of those sites, giving a total of 72 samples for the 7-day study period.

For the hand wipe samples, the same person (L. Kristensen) conducted the child-simulated play at each of the playground sample sites for a fixed 20 min timed period each day over the 7-day study period. The objective of the pre- and post-play hand wipes was to measure exposures that were representative of each playground. Given that each of the playgrounds were comprised of different structures (see Supplementary Data, Fig. S2a–e), it was not possible to replicate the same exact play activities at each of the facilities. However, a standard protocol was applied to each location for the child-simulated play activities that meant each structure within the playground e.g. slide, ladder, climbing apparatus was utilized at least twice over the set 20 min timed play period. L. Kristensen simulated the play of a five year old using her four years of childcare work experience involving supervising play equipment and also participating with children during their activities (see Supplementary Data S2a-e for more information). Hand wipe samples were collected from the child-simulated play participant each day before and after the timed play period ($n = 70$). Playgrounds were selected to be as close as possible to the EPASA lead-in-air monitoring stations to facilitate correlation between atmospheric lead concentrations and those in surface and hand wipes (Fig. 1). A single sample consisted of two wipes (i.e. one wipe per hand). The play participant's anterior surface area of a single hand was calculated as 1% of the total body surface area (BSA) using the DuBois and DuBois (1916) method.

At all playgrounds and EPASA air monitoring stations, three surface soil samples (0–2 cm) were collected to provide average soil arsenic, copper, lead and zinc concentrations. In total, 29 surface soil (0–2 cm) samples (26 in Port Pirie and 3 in Port Augusta) were collected using the Australian Standard AS4874 (Australian Standard AS4874-2000, 2000) method. In order to approximate background concentrations for the Port Pirie area, subsurface soils were also analysed from two pits excavated to a depth of 50 cm at opposite ends of Port Pirie city (Fig. 1). Samples were collected at 0–2; 2–10; 10–20; 20–30; 30–40; 40–50 cm (total for both pits: $n = 12$). Soil samples were analysed for metal concentrations in the <2 mm fraction, which is the recommended Australian method (NEPC, 1999). Soil and dust lead measures were benchmarked against relevant Australian guidelines and standards. Arsenic and cadmium dust concentrations were compared to the German TA Luft (TA Luft (Technical Instructions on Air Quality Control), 2002) dust guideline values to provide environmental quality benchmarks.

### 2.2. Laboratory analyses

A total of 39 soil samples, 70 hand wipes and 72 surface dust wipe samples were analysed using a Varian Vista-Pro Inductively Coupled Plasma Optical Emission Spectrometer for arsenic, cadmium, copper, lead and zinc concentrations. Dust wipes were digested using the National Institute for Occupational Safety and Health Method 7303 (NIOSH, 2003). Six procedural wipe blanks returned average concentrations of 0.78 μg/wipe for arsenic, 1.45 μg/wipe for copper and 66 μg/wipe for zinc. Cadmium and lead blanks were <0.5 μg/wipe. Field blank wipes were collected during sampling. Lead concentration was significantly higher in field blanks (1.25 μg/wipe on average), compared to laboratory blanks (<0.5 μg for all wipes); $t(6) = 4.43$, $p = .004$. No significant differences were observed for arsenic, cadmium, copper and zinc. Soil samples were digested using a modified procedure based upon United States Environmental Protection Agency Method 3050 for sediments, sludges and soil (Edgell, 1989). Duplicate analyses for soils ($n = 4$) and wipes ($n = 16$) returned relative percent deviations (RPD) for all elements of <11%. Recovery rates were measured using matrix spikes. Spike recovery rates for soil ($n = 2$) were 79–110% and those for the wipes ($n = 8$) were 84–107%.

## 3. Results

### 3.1. Soil lead concentrations

The summary statistics for soil metals are provided in the Supplementary Data, Table S3. A one-way analysis of variance (ANOVA) showed that there were no significant differences in soil lead levels across all Port Pirie playgrounds ($F(24, 1) = 159.952$, $p = .062$). Soil metal results show that 69% ($n = 18$) of the Port Pirie playground surface soil (0–2 cm) samples were greater than or equal to the Australian 300 mg/kg guideline health investigation level (HIL-A) for residential soil lead (NEPC, 1999). The mean concentration of lead in Port Pirie surface soils (0–2 cm) was 1443 mg/kg ($n = 26$). No soil samples ($n = 3$) from the Port Augusta reference site exceeded the NEPC residential soil lead guidelines (NEPC, 1999). Independent samples $t$-tests on soils demonstrated that there were significant differences between Port Pirie and Port Augusta for lead levels in surface soil ($t(25.002) = 3.630$, $p = .001$). Other soil metal concentration values displayed similar patterns of