Hazelwood HEALTH STUDY

The Latrobe Early Life Follow-up (ELF) Cohort Study
Volume 5

A description of sources of air pollution inside and outside the home environments of children in the Latrobe ELF Cohort

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Caveat

This report presents a preliminary analysis which has not been submitted to independent peer review. Subsequent scientific manuscripts which undergo independent peer review may vary in their findings or interpretation.

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Executive Summary

The Hazelwood Health Study (HHS) was commissioned by the Victorian Department of Health and Human Services in response to the 2014 coal mine fire in the Latrobe Valley, Victoria; a major pollution event that caused significant community concern. The HHS aims to identify any medium- or long-term health impacts among residents of the affected communities, and to inform policy and planning in the event of future similar events. This report is part of The Latrobe Early Life Follow-up (ELF) Study, one stream of the HHS, which is investigating the impact of the mine fire smoke exposure during pregnancy and infancy on perinatal outcomes and the subsequent health and development of children in the Latrobe Valley. The ELF identified cohort comprises 571 children from the Latrobe Valley; approximately a third of whom were exposed to the mine fire smoke as young children (aged between birth and two years), a third exposed to the mine fire smoke *in utero*, and a third not exposed to the mine fire smoke (conceived in the year after the fire).

Previous ELF reports have described perinatal and early child health outcomes in association with exposure to fine particulate matter ($PM_{2.5}$) from the coal mine fire. This fifth report aims to provide context for understanding the exposure of participants to the mine fire smoke by describing the distribution of common airborne environmental hazards among the cohort including:

(1) The differences between mine fire related $PM_{2.5}$ exposure estimates for ELF participants estimated using two different approaches:

- $PM_{2.5}$ concentrations assigned to the child's residential address during the fire,
- $PM_{2.5}$ concentrations calculated for the child based on detailed daily diaries of day and night locations throughout the fire period.

(2) Available data about the magnitude and spatial variation of background $PM_{2.5}$ and nitrogen dioxide (NO_2) in the Latrobe Valley during the study period

(3) Participants' residential history, housing characteristics, exposure to environmental tobacco smoke, and other important sources of combustion-related air pollutants in the homes.

As described in previous reports, mine fire smoke emissions were greatest in the early days of the fire and reduced significantly in the later weeks. Exposure to smoke emissions was not experienced equally by all residents of the Latrobe Valley. Residents of Morwell and Traralgon and some smaller populated areas such as Driffield and Hazelwood were exposed to the greatest concentrations of smoke, due to both proximity to the fire and the prevailing wind direction. Participants in the Latrobe ELF study came from all parts of the Latrobe Valley and there was a large gradient of exposure to smoke from the mine fire within the cohort influenced by their town of residence and individual movements during the fire period.

When accounting for travel within the Latrobe Valley during the fire period, exposure to extreme peaks in $PM_{2.5}$ pollution during the fire was lower than what would be expected based on primary residential address alone but mean overall exposure during the fire period was largely unaffected by individual travel status. This suggests that while participants were able to manage their activities to reduce their exposure to the periods of worst air quality, this did not influence the overall average exposure to air pollution from the fire throughout the entire fire period.

Background $PM_{2.5}$ in the Latrobe Valley, from sources other than the mine fire (e.g. traffic and industrial emissions), was found to be typical of exposures measured in similar geographic areas across Australia, and well below the national air quality standard of 25μg/m^3 (annual average $PM_{2.5}$ was 6.7 μg/m^3 in the Latrobe Valley, 7.6 μg/m^3 in East Melbourne and 6.9 μg/m^3 in West Melbourne). Background nitrogen dioxide (NO_2) concentrations were similarly below the national standard of 30 parts per billion (ppb) and lower than the average values for Melbourne (annual average NO_2 was 6.0 ppb in the Latrobe Valley, and 10.0 ppb in East and West Melbourne).

Regarding sources of indoor air pollution, around 30% (n=168) of ELF participants had been exposed to environmental tobacco smoke either *in utero* and/or in early childhood. Around 35% had lived in a home with un-flued gas heating (n=216 *in utero*, 199 in early childhood), and 75% of the children had lived in a home with a gas cooktop (n=440 *in utero*, 426 in early childhood). Approximately 50% of households regularly used candles, incense, or BBQs (n=264 *in utero*, 255 in early childhood), also known to be important sources of exposure to combustion-related air pollutants. Air conditioning was used in almost half the ELF children's homes during the fire period, which may have reduced their exposure indoors to infiltrated mine fire smoke.

In summary, the exposures of some of the participants in the ELF study to the mine fire smoke were extremely high, and day to day travel patterns influenced peak but not average exposure to the mine fire smoke. Concentrations of other outdoor air pollutants (such as emissions from traffic and industrial activities) were, on average, similar to or lower than other parts of Victoria including the capital city of Melbourne, while exposure to indoor sources of air pollution (such as second hand tobacco smoke and un-flued gas heaters) was higher than for Victorians overall.

1. Introduction

The 2014 Hazelwood coal mine fire in the Latrobe Valley, Victoria, was a major pollution event that caused significant community concern. In response, the Victorian Department of Health and Human Services commissioned the Hazelwood Health Study (HHS), which aims to identify any medium- or long-term health impacts among residents of the affected communities, and to inform policy and planning in the event of future similar events. This report is part of The Latrobe Early Life Follow-up (ELF) Study, one research stream of the broader HHS, which is investigating the impact of the mine fire smoke exposure during pregnancy and infancy on perinatal outcomes and the subsequent health and development of children in the Latrobe Valley.

Previous reports [1-4] from the Latrobe ELF Study have investigated perinatal and early childhood health outcomes in association with exposure to fine particulate matter ($PM_{2.5}$) emissions from the Hazelwood coal mine fire. This report provides a more detailed description of the variation in mine fire related smoke exposure between children living in different areas in the Latrobe Valley, including an analysis of how much the children's smoke exposure was affected by day to day travel during the fire period. In addition, it summarises other sources of air pollution, both indoor and outdoor, to which the ELF children were exposed throughout their lives, as reported by the children's parents in the baseline survey. Some of these results, particularly the exposure estimates for mine fire related particulate air pollution, have already been reported in previous papers focusing on health outcomes. The purpose of this report is to summarise all available exposure information in one place and to provide further context for interpreting previous and future results of the study. The report is in four sections as described below.

(1) Mine fire pollution exposure estimates and the influence of reported travel during the fire period

The accurate measurement of individual exposures to air pollution events is a challenge in epidemiological studies. Variation in participants' individual daily activities and time spent within the pollution plume created a high degree of variability in individual exposure estimates. Residential address is the simplest location to measure or model air pollution exposure, and this is often used in air pollution health studies [5]. However, because the spatial variability of the smoke was so extreme during the Hazelwood coal mine fire, daily travel for education, work, or to escape extreme air pollution might have a large influence on overall individual exposure [6-8]. For this reason, the exposure estimates used in most of the ELF studies to date have taken into account the recalled daily travel made by the participants, using individual time activity diaries to assign real-time location data to each participant. This location data was then mapped to detailed spatiotemporal pollution data, providing a more accurate exposure estimate and reducing the risk of misclassification [9, 10]. In this report we compare the results of air pollution assignment based on place of usual residence with estimates which accounted for travel patterns during the pollution episode.

(2) Background air pollution in the Latrobe Valley

Ambient (background) air pollution is ubiquitous as a result of road traffic, power generation, wood and oil heater use, and other human activities. Ambient air pollution consists of a range of pollutants, including coarse and fine particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3) and sulphur dioxide (SO_2). High concentrations of ambient air pollution are associated with a range of health problems in children, from preterm birth and low birthweight to impaired lung development, asthma exacerbation and increased respiratory symptoms [11-15].

Studies of the effects of specific pollutants have shown that NO_2 and $PM_{2.5}$ particularly impact children's health [16]. NO_2 is a marker of traffic and other combustion-derived pollution (e.g. industry, airports) [17], and $PM_{2.5}$ is also a result of combustion sources, mostly domestic wood burning in winter, planned burns in autumn and wildfires in summer. Understanding the exposure of the ELF children to these chronic sources of air pollution is important, as it provides a context for their exposure to smoke from the Hazelwood mine fire, enabling associations with this medium-term pollution episode to be distinguished from the influence of long-term background air pollution.

(3) Exposure to sources of combustion-related air pollution inside participant homes

Because people spend up to 90% of their time indoors, depending on social, seasonal and local environmental factors, it is important to understand sources of indoor air pollutants [18-21]. Indoor air pollution is a combination of outdoor pollution that has moved indoors, and pollution that is emitted from indoor sources. Indoor sources of air pollution include tobacco smoke, gas or wood heating, cooking, burning of candles or incense, and emissions from outdoor barbeques or attached garages [20, 22]. We focus on combustion-related indoor air pollution because these exposures are common and have known health effects. For example exposure of children to second hand tobacco smoke decreases lung growth and increases rates of respiratory tract infections, otitis media, and childhood asthma [23, 24]. Household gas heating and gas cooking also has a clear association with respiratory symptoms in children, especially when gas is used without a flue or extraction fan [20, 25-27].

(4) Housing characteristics that affect infiltration of outdoor air pollution

Housing characteristics such as the age of the building and the materials from which it was constructed affect the infiltration of outdoor pollution, that is, how much outdoor air pollution can move indoors. Older buildings generally allow more infiltration [28-30]. Infiltration is also influenced by human activities. For example, opening doors and windows negatively affects the indoor air quality when outdoor pollutant levels are higher than indoor pollutant levels. The use of air conditioners, in contrast, can recirculate the indoor air and filter the air, reducing the concentration of indoor pollutants [31].

2. Methods

Study Participants

The identified cohort of the Latrobe ELF Study consists of 571 children who were born between 1 March 2012 and 31 December 2015. The children were recruited from across the Latrobe Valley, Victoria, and were exposed to a gradient of smoke from the 2014 Hazelwood mine fire at different developmental periods: 198 of the children were *in utero* during the mine fire, 203 children were under the age of 2 years during the mine fire, and 170 children were conceived after the mine fire and therefore not exposed to the mine fire smoke [32]. The children's parents or carers completed a comprehensive baseline survey in 2016, detailing demographic, health, smoke exposure and housing characteristics [3]. The baseline survey is the main source of data used for this report. Of the 571 children in the ELF identified cohort, only 566 were included in these analyses (99% of the cohort). The parents of the other five children did not complete the survey sections relevant to their housing characteristics and travel during the fire period.

(1) Mine fire pollution exposure estimates and the influence of reported travel during the fire period

Estimation of individual exposure to the mine fire-related $PM_{2.5}$ has been described in detail in other reports [1, 2]. In brief, we combined the spatially resolved output of a pollution dispersion and atmospheric transport model at 12-hourly time steps with the information about the corresponding day and night location of participants reported in the baseline survey of participants [33, 34]. We used these data to calculate the mean and the maximum exposures for each participant during the fire period. We also evaluated participants' confidence in their recall of their travel during the fire period. We further calculated participants' exposure based on the simpler approach using the primary residential address without adjustment for reported travel during the fire period.

Exposures calculated using the time activity diaries were analysed to describe patterns in participants' movements during the fire period. We calculated the difference between exposure estimates based on residential exposures and those based on the travel data. A positive difference indicated that the time activity exposure estimate was higher than the residential exposure estimate, while a negative difference indicated the opposite. Confidence of participants in their recall of travel during the fire was reported on a continuous scale from 'not at all confident' to 'very confident'. We used logistic regression modelling to see if there was an association between exposures based on the changes from using residential locations to time activity exposures, and participants' confidence in their diary reports.

(2) Background air pollution in the Latrobe Valley

This section summarises background air quality in the region by reporting $PM_{2.5}$ and NO_2 data for the Latrobe Valley in 2015, which was a typical year for air quality in the region in the absence of a major pollution event such as the 2014 coal mine fire. Daily and annual $PM_{2.5}$ and NO_2 data were available from the Environment Protection Authority (EPA)'s monitoring stations in the Latrobe Valley. Additional data was available from national satellite-based models that have been developed to predict the spatial distribution of NO_2 and $PM_{2.5}$ across Australia at a fine scale (the census mesh-block level) using land use regression modelling [17, 35, 36]. Land-use regression (LUR) is a technique that can improve the accuracy of air pollution exposure assessment in epidemiological studies. The model used to predict NO_2 was developed for all of Australia by using satellite observations of tropospheric NO_2 columns combined with other predictor variables such as traffic data and industrial emissions. We used the EPA data to compare air quality in the Latrobe Valley with Victoria as a whole and the city Melbourne in particular [17, 36], and the modelled LUR data to estimate individual exposures to NO_2 and $PM_{2.5}$ using the ELF participants' residential addresses within the Latrobe Valley.

(3) Exposure to sources of combustion-related air pollution inside participant's homes

We collected information in the baseline survey on sources of indoor air pollution that might affect children's health. These included the presence of an adult smoker in the household, the use of gas or open wood heating, type of cooking fuel, the use of BBQs, incense and candles, and whether the home had an attached garage. This information was recorded for all houses the child or their pregnant mother had lived in between the start of pregnancy and the date of the survey. The children were aged between 6 months and 3 years at the date of survey.

To provide a meaningful comparison between children of different ages, we have only presented information about exposures in the houses the child lived in during pregnancy and during their first year of life. An exception to this is for tobacco smoking: Participants were asked to report any tobacco smoking by the child's mother while pregnant and by the mother or other adults inside each of the child's previous homes or in the car, including during pregnancy. For the child's current house only, the survey asked about the presence of an adult smoker in the household and whether they usually smoked inside or outside the home. We report the information on current smoking, noting that children were different ages at the time of survey.

(4) Housing characteristics that affect how much outdoor air pollution can move indoors

We collected information about the factors that could influence the child's exposure to the mine fire emissions, such as the age of the building the child lived in during the fire period, the materials from which it was built, and frequency of air conditioner use. The same factors may also influence how easily background air pollution moves indoors. These factors were recorded for all houses the child or their pregnant mother had lived in between the start of pregnancy and the date of survey.

All statistical analyses were conducted in the statistical software program R (version 3.4.0) [37].

The ELF study was approved by the Tasmanian Health and Medical Human Research Ethics Committee (reference H14875). Additional approval was received from the Human Research Ethics Committees of Monash University, Monash Health, the University of Melbourne, the University of Sydney and Edith Cowan University.

3. Results

(1) Mine fire pollution exposure estimates and the influence of reported travel during the fire period

The following section on mine fire pollution exposure only includes the 399 children who were young children or *in utero* at the time of the mine fire, not the 167 who were conceived after the fire period and therefore had no exposure to the mine fire smoke.

The following mean and maximum daily mine fire smoke exposures were averaged over the six-week fire period and take into account daily movements within and beyond the smoke-affected area, as recorded in the participants' time activity diaries. Averaged mean daily mine fire smoke exposure over the fire period was estimated to be 8.4 $\mu g/m^3$ (range 0.0 to 52.9 $\mu g/m^3$), and averaged maximum daily mine fire smoke exposure was estimated to be 147.7 $\mu g/m^3$ (range 0.0 to 991.3 $\mu g/m^3$). Mean and maximum mine fire smoke exposure values were highly correlated (Spearman's r=0.92). Participants living in Morwell had higher mean and maximum exposures than those living further from the mine fire (averaged mean exposure was 16.1 $\mu g/m^3$ in Morwell and 2.8 $\mu g/m^3$ elsewhere ($p<0.001$), averaged maximum exposures were 238.0 in Morwell and 81.6 $\mu g/m^3$ elsewhere, $p<0.001$) (Figures 1 and 2).

3.1.1 Impact of incorporating information about daily location on individual mine fire smoke exposure estimates.

The relationship between exposure estimates derived using the individual time activity data compared to those using residential address is shown in Figure 3.

The average difference between each individual's mean exposure based on their daily locations during the fire and their corresponding mean exposure based on residential address was -0.6 $\mu g/m^3$.

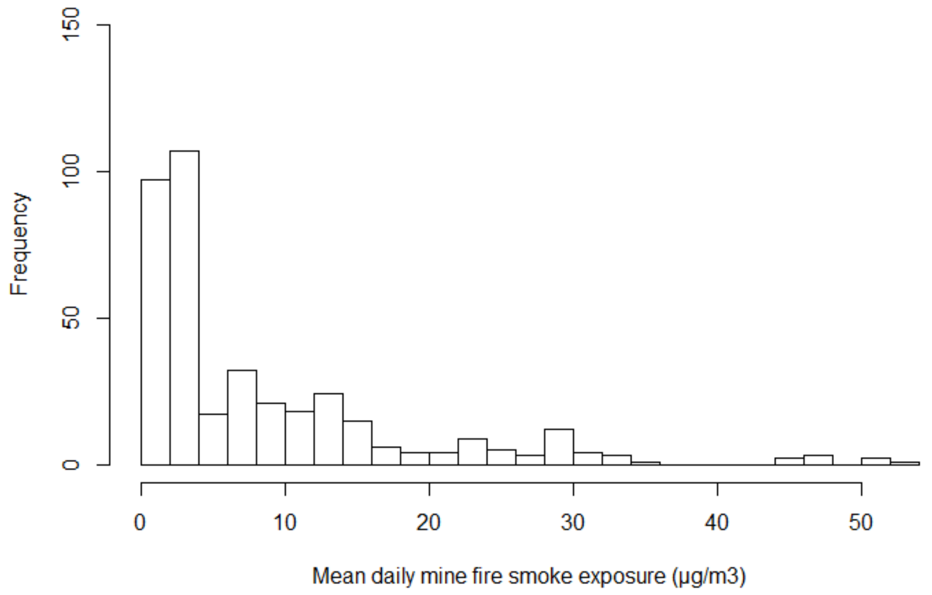
In contrast, ninety-four percent of the maximum exposure estimates derived using daily location data were lower than the corresponding maximum exposure estimates derived using residential address, with a mean difference of -102 $\mu g/m^3$.

While most residents of Morwell were exposed to greater concentrations of both mean and maximum mine fire smoke than residents of surrounding towns, a small group of approximately nine residents from Traralgon had much higher exposures when using their time activity data than when using their home address exposures, likely reflecting daily travel to higher exposure areas than their home address for activities such as work (for pregnant women) or childcare.

These results suggest that while some participants were successfully able to reduce their exposure to peak concentrations of air pollution from the mine fire, this did not result in a reduction in their overall mean exposure.

Figure 1. Histograms of ELF participants' mean (a) and maximum (b) daily mine fire smoke exposure, using exposure estimated from the time-activity diaries.

(a)



(b)

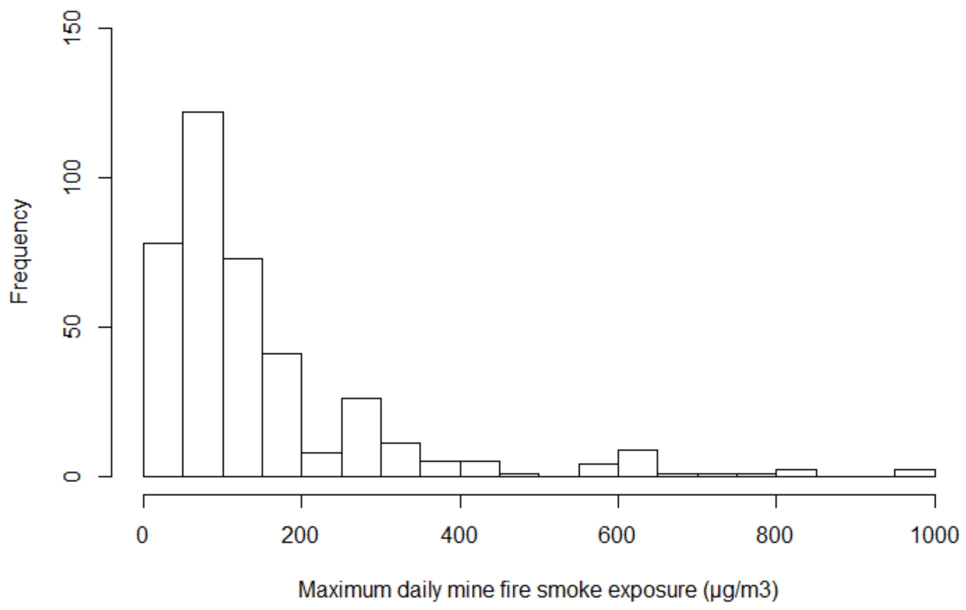


Figure 2. Mean (a) and maximum (b) exposure to $PM_{2.5}$ during the fire period by town of residence during the fire period, using exposure estimated from the time-activity diaries.

(a)

(b)

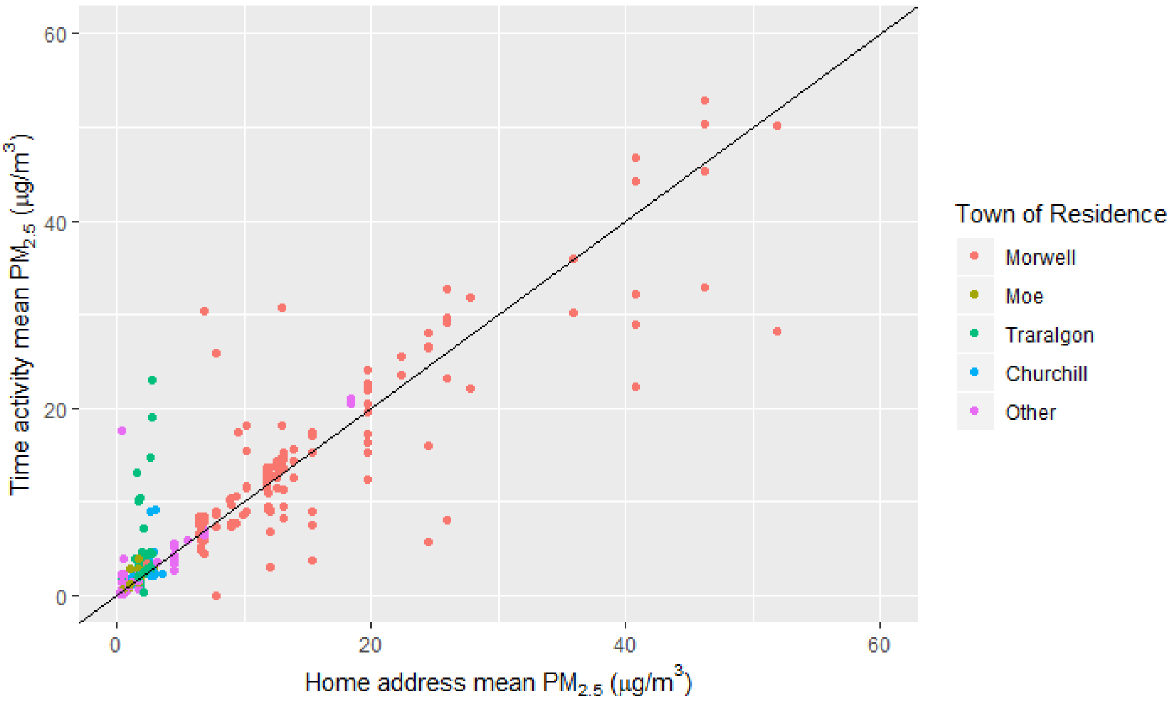
3.1.2 Confidence of participants' recall about their movements during the fire, as reported in the time activity diaries.

Overall, 86% of the 399 participants who were exposed to the mine fire smoke answered that they were very confident (n=254) or confident (n = 90) in their responses. Less than 5% said that they were not sure (n=12) or not at all confident (n = 4).

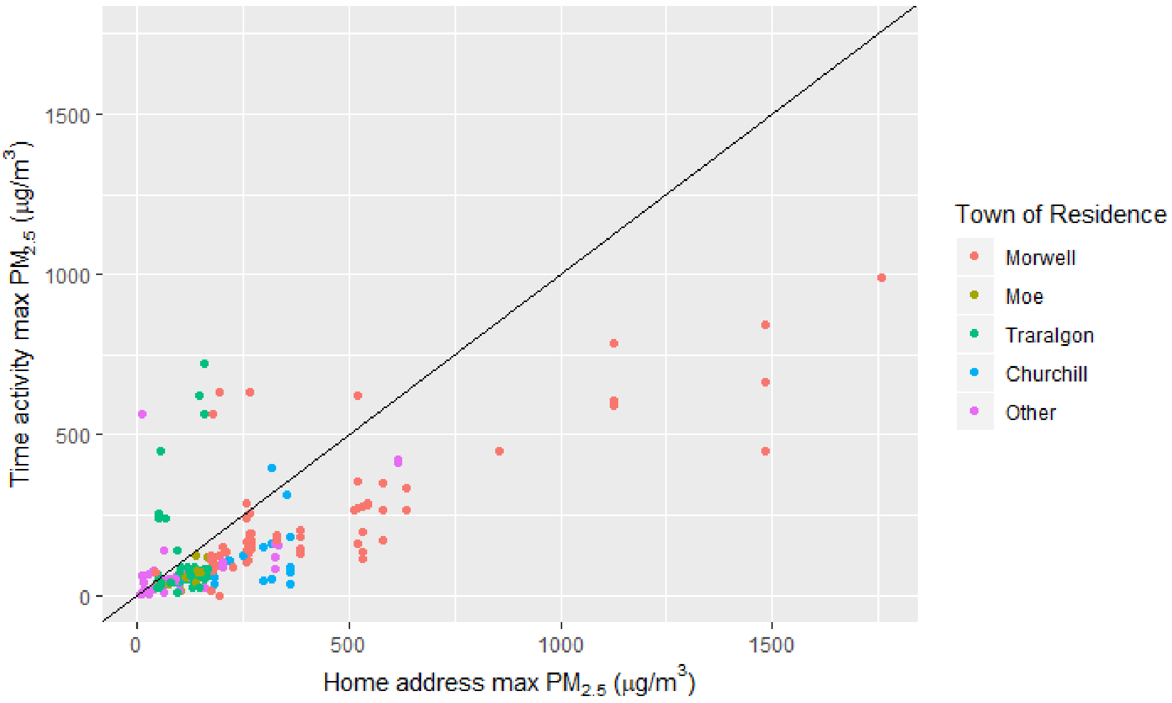
Logistic regression results indicated that the confidence of the respondent was positively associated with a change in the mean exposure allocation (β = 0.45, p = 0.09), although the association was not statistically significant. There was no association between confidence and the size of changes in maximum $PM_{2.5}$ exposure (β = -0.06, p = 0.78).

Figure 3. Mine fire smoke exposure derived using time activity locations versus home address locations. Points above the 45º line indicate that the individual exposures estimated from the time activity data were higher than at the home address. (a) mean and (b) maximum daily exposure estimates for each participant**.**

(a)



(b)



(2) Background air pollution in the Latrobe Valley

Routine air quality monitoring data

$PM_{2.5}$

Long term background air quality in the Latrobe Valley has been described in detail elsewhere [38, 39]. The annual average $PM_{2.5}$ measured at three Environment Protection Authority air monitoring stations during 2015, the year following the coal mine fire, were 7.7, 6.8, and 6.5 µg/m^3 for Traralgon, eastern Morwell and southern Morwell [38]. These concentrations are very similar to $PM_{2.5}$ concentrations measured in the Victorian capital city of Melbourne which ranged between 6.2 µg/m^3 to 7.6 µg/m^3 at different air monitoring stations during 2015 [40] (Table 1).

NO_2

In the Latrobe Valley the annual average of hourly NO_2 at the stations of Traralgon and eastern Morwell were 6.0 and 5.0 parts per billion (ppb). By comparison, the annual average of hourly NO_2 at the Melbourne stations of Alphington and Dandenong during 2015 of 10.0 ppb were almost double (Table 1). Both locations are well inside the national air quality standard for NO_2 of 30 ppb.

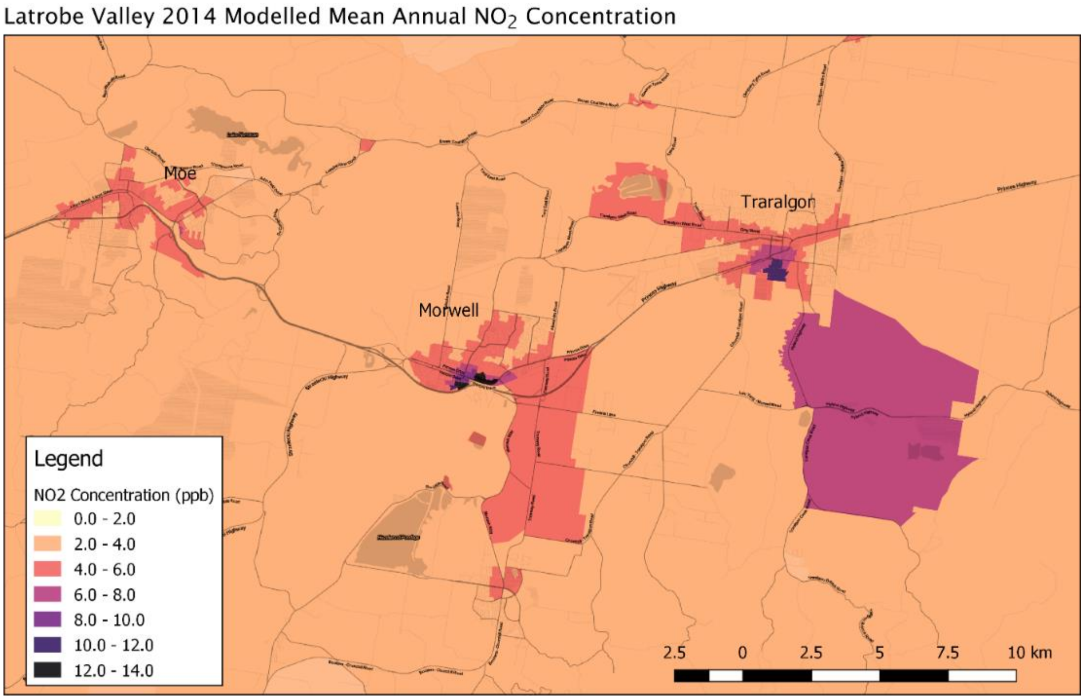
Table 1. Average annual NO_2 (ppb) and $PM_{2.5}$ (µg/m^3) in the Latrobe Valley, East Melbourne and West Melbourne, 2015, from EPA Victoria's air quality monitoring stations.

	Latrobe Valley	East Melbourne	West Melbourne
Ambient NO_2 (ppb)	6.0	10.0	10.0
Ambient $PM_{2.5}$ (µg/m^3)	6.7	7.6	6.9

Modelled air quality estimates

Figure 4 shows the modelled mean annual NO_2 concentration at various locations in the Latrobe Valley in 2014. The highest modelled concentrations of NO_2 were in the vicinity of power stations and town centres.

Figure 4. Modelled mean annual NO_2 concentration in the Latrobe Valley.



(3) Exposure to sources of combustion-related air pollution inside participant's homes

Using data collected from the baseline survey administered to all ELF study participants we analysed the results to understand important sources of combustion-related air pollution sources within the participant homes.

3.3.1 Exposure to Environmental Tobacco Smoke (ETS)

Table 2. Number (%) of children exposed to mother's cigarette smoking in utero and/or an adult smoker living in their current house at the time of survey (any exposure vs none).

Exposed to ETS in current house	**Mother smoked during pregnancy**			**Total n (%)**
	No n (%)	Yes n (%)	Don't know n (%)	
No	390 (86)	21 (21)	6 (75)	417 (74)
Yes	66 (14)	81 (79)	2 (25)	149 (26)
Total	456 (100)	102 (100)	8 (100)	566 (100)

Smoking by the child's mother during pregnancy was strongly correlated with presence of an adult smoker in the child's current house (any adult smoker, including the child's mother). Of the 558 ELF children for whom smoking exposure data was available, 102 children (18%) had a mother who smoked during pregnancy. Of these 102 children, 81 (79%) were living with a smoking adult at the time of the ELF survey. Of the 456 children whose mothers did not smoke during pregnancy, only 66 (14%) lived with a smoking adult at the time of the ELF survey. Overall, 147 children (26%) lived with a smoking adult at the time of the ELF survey, and 411 children (74% of all children) did not live with a smoking adult at the time of the ELF survey. Note that we do not have a measure of the length of time the child was exposed to tobacco smoke in early life, just the presence or absence of a smoker in their *current* house. Similarly, "mother smoked in pregnancy" encompasses any report of smoking in pregnancy (versus none).

Summary of children's exposure to environmental tobacco smoke:

- 15% (81/558) of all ELF children had both a smoking mother while *in utero* and a smoker in the current house.
- 12% (66/558) did not have a smoking mother while *in utero* but did have a smoker in the current house.
- 4% (21/558) had a smoking mother while *in utero* but did not have a smoker in the current house.
- 70% (390/558) had neither a smoking mother while *in utero* nor an adult smoker in their current house.

Complete smoking data was collected for the primary carer, the second parent/caregiver and other adults in the child's current house(s), and for any adults smoking indoors or in cars in the child's previous houses, but not for the presence or absence of other smoking adults in houses prior to the current house.

3.3.2 Exposure to other sources of indoor pollution

The heating types used in each house were chosen from six categories: electric, flued gas, un-flued gas, closed wood, open wood or 'other'. The 'other' heating type was described in text by the participant. Approximately 10% of heating types were marked as 'other'. On inspection, all of these were able to be included in one of the existing categories, and so were re-classified.

Exposure to gas inside the home was common, with more than a third of children exposed to un-flued gas heating in pregnancy and a similar proportion in early childhood (n=216 and n=199, respectively), and three quarters exposed to a gas stove top for cooking (n=440 and n=426 respectively). Open wood heating was rare (2%, n=12 and n=14).

Nearly half of the children were exposed to incense, candles or mosquito coils (n=264 and n= 255).

Table 3. Number (Percent) of children exposed to each source of combustion-related air pollution in utero and in their first year of life (any exposure vs none).

Housing characteristic	Present in a house during pregnancy n (%)	Present in a house in child's first year of life n (%)
Gas heating with flue	139 (25)	143 (25)
Gas heating without flue	216 (38)	199 (35)
Closed wood heating	93 (16)	90 (16)
Open wood heating	12 (2)	14 (2)
Gas stove top	440 (78)	426 (75)
Incense, candles, or mosquito coils	264 (47)	255 (45)
Garage connected to house	121 (21)	122 (22)

Note 1: 64/566 (11%) of children were aged between 6 months and one year at the time of survey. It is likely that a small proportion of these children moved to a new house after the survey was completed. Some may therefore be misclassified as 'not exposed' to a housing variable in their first year of life, when in fact they were later exposed.
Note 2: more than one heating type per house was possible. Also, as some families moved to a new house during pregnancy or the first year of a child's life, some children lived in two or more houses with different heating types. Therefore, the totals in these categories add up to more than 100%.

(4) Housing characteristics that affect infiltration of outdoor air pollution

Data from the baseline survey were used to identify any known housing characteristics that affect how easily outdoor air pollution can move or accumulate indoors.

Table 4. Age of house, main house building material, roof type and air conditioner use during the mine fire period, for the children in the in utero and postnatal mine fire exposure groups (n=399).

	Number (%)
Year house was built	
Before 1986	205 (51)
1986-2004	62 (16)
After 2004	60 (15)
Unknown	72 (18)
Building material of fire house	
Brick/concrete	209 (52)
Wood	124 (31)
Other	14 (4)
Unknown	52 (14)
Roof type of fire house	
Tile	197 (49)
Iron (Tin)	151 (38)
Other	3 (1)
Unknown	48 (12)
Air conditioner use during fire	
None	100 (18)
Rare/Occasional	123 (31)
Regular/Daily	118 (30)
Unknown	58 (15)

Half (51%, n= 205) of the houses lived in by ELF families during the fire period were built before 1986. One-sixth (16%, n = 62) were built between 1986 and 2004, and 15% (n = 60) were built after 2004. Nearly one-fifth (18%, n = 72) of respondents did not know when their house was built. The most common house building material was brick, with 52% (n = 209) of ELF children or their pregnant mothers living in a brick house during the fire period (Table 4). The second most common building material was wood (31%, n = 124). Tile roofs were slightly more common than iron (tin) roofs (49% vs 38%). Around three-quarters of children's homes in pregnancy and early childhood had air conditioners (n=433 and n=431 respectively), but many of these were not used, or were used only rarely. Less than one third (30%, n=118) of the ELF participants reported using air conditioners either regularly or daily during the fire period.

4. Discussion

(1) Mine fire pollution exposure estimates and the influence of reported travel during the fire period

There was a large gradient of exposure to smoke from the mine fire within the cohort, with town of residence and individual movements during the fire period influencing exposures. The use of residential address to assign exposure is a commonly cited limitation of many epidemiological studies on the health effects of air pollution [41-43]. Our results confirm previous findings that people's individual daily activities can influence their personal exposure [6-8].

While the time activity exposure estimates were likely to be more accurate than those based on residential address, they did not result in substantially different estimates in the overall group but did highlight major differences for some individuals. For example, some participants who lived in less affected parts of the Latrobe Valley experienced substantially increased exposure through daily commuting to more smoke-impacted areas such as Morwell. Similarly, many were able to reduce their maximum exposure by moving away from severe smoke, however this did not substantially influence their mean exposure throughout the entire mine fire period.

A challenge with assigning exposures based on individual recall of locations over an extended period is gauging the accuracy of the individual's recall. This was considered in advance of developing the baseline questionnaire, and to attempt to place recall into context, participants were asked about how confident they were with their response. Previous studies have found that better recall was associated with higher confidence [44, 45]. Most participants in the ELF study were confident in their recall of their movements during the fire period, suggesting that the diaries accurately reflected their day-to-day locations.

Research implications **-** Exposure misclassification is less likely when using a method that takes individual daily movements into account, rather than relying on exposures estimated at the participant's residential address.

Health implications – We found that some people's smoke exposure was higher due to their daily activities than it would have been if they had stayed at their place of residence. This is likely to have health consequences for people at higher risk - e.g. pregnant women- who lived elsewhere but were employed in Morwell.

Policy implications **-** Individuals who are considered to be at risk from air pollution exposures should not be deployed to locations where air quality is poor, or they should be given leave during such incidents.

(2) Background air pollution in the Latrobe Valley

To understand the context of exposure to the mine fire emissions we described existing data on background air pollution in the Latrobe Valley and compared this with that of Melbourne. Available EPA air quality data from the three monitoring stations in the Latrobe Valley demonstrate that ambient $PM_{2.5}$ and NO_2 levels in the Latrobe Valley were comparable with other rural areas throughout Victoria, and that was notably lower than the levels recorded in large urban areas such as Melbourne [39]. Typical ambient $PM_{2.5}$ and NO_2 levels were well within Australian standards for ambient air quality [32]. As previous research has demonstrated, chronic exposure to air pollution can had greater adverse health impacts than short term exposure to similar concentrations [46]. It is therefore important to understand and adjust for these on-going exposures for the ELF study participants.

The LUR modelled data in Figure 4 highlighted the different spatial patterns of air pollutants in the towns compared with the mine fire emissions. As has been found in many other LUR studies, road traffic emissions and local industries typically contribute to reductions in air quality in urban locations [47-49]. By incorporating air quality data from all sources, it is now possible to separate the effects on children's health resulting from the mine fire emissions from those resulting from other sources.

Research implications – It is unlikely that the typical regional air pollution found in the Latrobe Valley is a confounder of the effect of the mine fire smoke on health, as the spatial distributions of background sources were different to that of the mine fire emissions. But, given the known impacts on health from urban air pollutants it is important to consider the potential influence of background air pollution.

Health implications – Given the relatively low concentrations of air pollution usually present in the Latrobe Valley, intermittent extreme exposures from events such as bushfires could be the more important risk to health associated with reduced air quality. Nevertheless, exposure to traffic related air pollutants, especially those from heavy vehicles, has been associated with adverse respiratory health outcomes. Holguin et al [50] reported that among 95 children with physician-diagnosed asthma, an interquartile increase in road length within a 200 m "home buffer" was associated with a 17% (95% CI: 2 to 40), P = 0.09 increase in exhaled nitric oxide but not with respiratory symptoms. A case–control study reported a proximity-related increased risk of wheezing in children living within 90 meters of major roadways (motorway or class A or B road) travelled by 10,000 to 100,000 vehicles daily [5]. These are important associations with known sources of air pollutants that need to be accounted for when considering the specific health outcomes associated with the mine fire emissions.

Policy implications – the evidence supporting no threshold of effect for air pollutants and health is increasingly being reported. As such, all efforts to reduce children, and vulnerable populations, from exposures to poor air quality are needed.

(3) Exposure to sources of combustion-related air pollution inside participant's homes

The majority of children enrolled in the ELF study had some form of combustion-related exposure within their homes. Understanding and accounting for this exposure when assessing health outcomes is needed so that we can separate exposures at home from exposures related to the mine fire emissions.

Thirty percent of ELF children were exposed to environmental tobacco smoke, either *in utero* or in early childhood or both. This is consistent with previous research showing that in 2013, 33% of all Australian households contained at least one adult smoker [51]. Smoking in Australia is more prevalent in rural households and in those experiencing greater socioeconomic disadvantage [52]. The proportion of Australian households with children who live with a smoker has decreased substantially in recent decades across all socioeconomic groups, although households in the lowest socioeconomic quintile are still most likely to contain an adult who smokes, with 50% of these families reporting at least one adult smoker in 2010 [52]. Smoking increases indoor $PM_{2.5}$ levels and the risk of respiratory illness for both the smoker and those exposed to environmental tobacco smoke, even when the smoker does not smoke indoors [19, 20]. Numerous studies have demonstrated the damaging effect of environmental tobacco smoke on children's respiratory and general health [53]. Because of its strong effect on health outcomes, environmental tobacco smoke is an important variable to adjust for when analysing for the effects of mine fire smoke exposure on the health of the ELF children.

A substantial proportion of ELF children's houses *in utero* and in early childhood had un-flued gas heating (35 and 38%, respectively) and/or gas cooktops (75 and 78%). Almost half of the children were exposed to incense, candles or mosquito coils *in utero* or in early life (45% and 47%, respectively). These exposures potentially increase the risk of respiratory symptoms and impaired lung development in children, especially for those with asthma. Australian data from Knibbs et al [54] showed that 38.2% of homes have natural gas as the main energy source for cooktop stoves, however this increased to 67% in Victoria, which was close to our findings. The authors calculated that exposure to gas cooking was related to a population attributable fraction estimate for childhood asthma of 12.3% (95% CI, 8.9-15.8%).

Research implications – Given that there are limited known impacts on health from indoor combustion-related sources of air pollutants it is important to consider any potential correlation and confounding by these other sources of air pollution.

Health implications – There are limited studies that have been able to separate out exposures to indoor combustion-related air pollutants and childhood asthma and reductions in respiratory health [21, 22, 23]. Those that have separated out exposures from indoor sources compared to outdoor sources suggest that it could be an important exposure route as children grow and develop [54].

Policy implications – Given the evidence supporting a no threshold effect for air pollutants and health, all efforts to reduce exposures to any sources of air pollution is recommended. Education and support for families, especially those who have or are expecting young children, about indoor sources, especially second-hand tobacco smoke and un-flued gas, should continue to be a high priority.

(4) Housing characteristics that affect infiltration and accumulation of outdoor air pollution

Internationally, there has been research conducted to understand which factors related to residences' building characteristics result in greater indoor concentrations of outdoor-related air pollutants [14, 24, 25]. This information was used by the ELF team to address and understand any potential differences in exposures during the mine fire.

Air conditioning was used at least occasionally in summer in 75% of ELF children's homes and was used during the mine fire at least some of the time in almost half the children's homes. This may have helped filter particulate matter from the air, potentially reducing mine fire smoke exposure for some participants. This is a typical recommendation made by regulatory agencies during smoke episodes [55].

Building materials, age of the home, air conditioning use and heating type can all impact pollution infiltration rates [14]. In a study of homes in Halifax, Canada a range of infiltration predictors were identified and included home age, income, presence of an air exchanger, use of a premium filter on the furnace, and the absolute temperature difference between indoors and outdoors. With homes that were built prior to 1945 having the highest infiltration rates [14].

Research implications – In locations with a mix of housing types, housing ages and building characteristics it may be that personal and indoor exposures to outdoor pollutants from a single source may be variable as a result of different infiltration rates. Investigation of home filtration through air conditioning units or portable air filters to reduce personal exposure to air pollution is warranted.

Health implications – While there is evidence about home heating, insulation and health outcomes, there is insufficient evidence to comment on the impact of leaky homes, air quality and health.

Policy implications – During periods of extreme air pollution it may be that homes with high infiltration rates are not suitable safe havens to protect individuals from exposure. Simple home-based interventions using air filters could be useful for health protection, but more research is needed.

5. Conclusion

In summary, children in the ELF study, or their pregnant mothers, were exposed to varying amounts of smoke from the Hazelwood mine fire. Those living in Morwell and other locations close to the mine fire were exposed to greater concentrations of smoke than those living further from the fire. Many residents moved temporarily away from their homes on some days to avoid the worst of the smoke. However, a small number of ELF children, or their pregnant mothers, were exposed to greater concentrations of smoke during their daily activities than they would have been at their home address, most likely because of work or childcare requirements.

Typical background air pollution concentrations for the area demonstrate that the Latrobe Valley generally has good air quality in comparison to Melbourne and the rest of Victoria.

A third of the ELF children had a tobacco-smoking mother and/or lived with a tobacco smoker, either while *in utero* or during early childhood or both, and a large proportion of the ELF children were exposed to un-flued gas heating, gas cooking, and/or other sources of indoor pollution.

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