Cohort Profile

Cohort Profile: The Hazelwood Health Study Adult Cohort

Jillian Ikin [ORCID] ,[1]* **Matthew TC Carroll,**[2] **Judi Walker,**[2] **Brigitte Borg,**[3]
David Brown,[1] **Martin Cope,**[4] **Anthony del Monaco,**[1]
Martine Dennekamp,[1] **Christina Dimitriadis,**[1] **Caroline X Gao,**[1]
Yuming Guo,[1] **Fay Johnston,**[5] **Danny Liew,**[1] **Darryl Maybery,**[2]
Bruce Thompson,[6] **Malcolm Sim**[1] **and Michael J Abramson**[1]

[1]Department of Epidemiology and Preventive Medicine, School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC, Australia, [2]Monash Rural Health, Monash University, Churchill, VIC, Australia, [3]Respiratory Medicine, The Alfred, Melbourne, VIC, Australia, [4]CSIRO Climate Science Centre, Oceans and Atmosphere, Aspendale, VIC, Australia, [5]Environmental Health Research Group, Menzies Institute of Medical Research, University of Tasmania, Hobart, Tasmania and [6]School of Health Sciences, Swinburne University of Technology, Hawthorn, VIC, Australia

*Corresponding author. Department of Epidemiology and Preventive Medicine, Monash University School of Public Health and Preventive Medicine, 553 St Kilda Rd, Melbourne, VIC 3004, Australia. E-mail: jill.ikin@monash.edu

Why was the cohort set up?

During a period of extreme weather conditions in February 2014, bushfire embers ignited a series of small fires in the Hazelwood open-cut brown coal mine located in the Latrobe Valley, a rural area containing small towns in the State of Victoria, Australia. These rapidly spread and the resulting coal fire burned for more than 6 weeks. Low buoyancy of the smoke plume led to dense smoke levels, particularly in the adjacent town of Morwell.[1] There was limited research on emission factors from open-cut coal mine fires,[1] and few precedents upon which to base public health protection messages or to assess adverse health effects.[2] There were gaps in the evidence available for the health impacts of poor air quality for time periods of weeks to months. Most evidence to date had been based upon short (days) or long-term smoke exposure (years to decades) but not medium term exposure (weeks to months).[2]

On 21 March 2014, the Victorian State Government appointed a Board of Inquiry into the Hazelwood Coal Mine Fire. The Inquiry heard that the Latrobe Valley community, particularly those in Morwell, reported a variety of physical symptoms including sore and stinging eyes, coughing, shortness of breath, headaches, chest pain, fatigue, mouth ulcers, blood in noses and rashes.[3]

The Victorian Department of Health and Human Services (DHHS) determined that it was important to learn from the fire by monitoring long-term health effects. The Board of Inquiry affirmed the proposed long-term health study as a useful predictive tool to assist with understanding future risks, and to prevent or reduce the chances of adverse health effects arising from similar situations in future.[3] In order to achieve these objectives, the DHHS commissioned the Hazelwood Health Study [www.hazelwoodhealthstudy.org.au], a programme of work comprising several research streams over at least a 10-year period. A multi-institutional team led by Monash University was the successful tenderer.

The Adult Survey is the largest stream of research in the programme and focuses on the health of adults who live in Morwell compared with Sale, a similar town outside the

Valley, which experienced minimal smoke exposure during the time of the mine fire. The Adult Survey aims to investigate whether people who were heavily exposed to smoke from the Hazelwood mine fire, compared with otherwise similar people who were minimally exposed, are more likely to have clinical or sub-clinical cardiovascular, respiratory or psychological conditions or to develop them in the future.

Who is in the cohort?

Participants recruited in to the Adult Survey formed the Hazelwood Health Study Adult Cohort. Eligible Adult Survey subjects were people aged 18 years or older on 31 March 2014, who lived in Morwell (exposed group) or in one of 16 selected statistical areas level 1 (SA1s) within Sale (comparison group). The selected SA1s had comparable median age, household size, socioeconomic indices and population stability to Morwell. Air pollution modelling undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Oceans & Atmosphere flagship had identified Sale as having minimal smoke exposure during the mine fire event.[4]

The Victorian Electoral Commission (VEC) electoral roll was assessed to be a near-to-complete sampling frame from which to identify eligible subjects. This was because, with few exceptions, electoral registration is compulsory for Australian citizens aged 18 years or older.[5] The VEC identified 9448 registered adults in Morwell and 4444 registered adults in the selected areas of Sale.

Recruitment in to the Adult Survey commenced in May 2016 and closed in February 2017. The initial invitation to participate was sent by mail. Follow-up with non-responders included telephone contact and reminder postcards followed by mailed reminder packs. Further promotional activities included letter box delivery of flyers, newspaper and radio advertising, free catered events, posters and roadside banners.

Table 1 shows that 3037 Morwell residents (34%) and 957 Sale residents (23%) from the VEC electoral roll were recruited. An additional 59 Morwell residents and three Sale residents who were not listed on the electoral roll responded to the study's promotional activities and participated. The final size of the adult cohort was 4056 participants, including 3096 from Morwell and 960 from Sale. At the time of participation, the cohort ranged in age from 20 to 102 years.

This recruitment rate rendered the cohort potentially vulnerable to participation bias. However, there were some data sources available which could be used to assess the extent to which the cohort participants were representative of the source populations. These are shown in Tables 2–4.

Table 1. Recruitment outcomes for the Morwell and Sale residents registered with the Victorian Electoral Commission (VEC)

VEC electoral roll	Morwell $n=9013^a$	Sale $n=4206^a$		Study total $n=13\,219$
	n (%)	n (%)	χ^2 p-value	n (%)
Participants	3037 (34%)	957 (23%)	<0.001	3994 (30%)
Refusers	1170 (13%)	829 (20%)		1999 (15%)
Non-responders	4806 (53%)	2420 (58%)		7226 (55%)

[a]From 9448 adults registered in Morwell, 435 were excluded because they were deceased ($n=326$) or ineligible. From 4444 adults registered in Sale, 238 were excluded because they were deceased ($n=174$) or ineligible.

Table 2 shows that participants in both Morwell and Sale were more likely to be female and aged 50 years or above, compared with the 2011 Australian Bureau of Statistics (ABS) Census[6] estimates for the two towns. Based on these data, post-stratification weighting of participant results by gender and five-year age band were applied. This weighting aimed to minimize any bias in health outcomes which may have been caused by over-representation of women and older people.

As tobacco smoking is a major risk factor for cardiovascular and respiratory diseases,[7] it was also important to know whether smokers were evenly represented among the participants. The breakdown of adult cohort participants by smoking status is shown in Table 3 alongside Victorian Population Health Survey 2011–12 data[8] for Latrobe City (which includes Morwell) and the Shire of Wellington (which includes Sale). A slight over-representation of former smokers among Morwell participants, and under representation of current smokers among Sale participants, highlighted the importance of adjusting for this risk factor in analyses.

A brief refuser questionnaire, including self-reported health status, was completed by 20% of the refusers from Morwell and 15% from Sale. Table 4 indicates that within each town, participants reported a similar health status to refusers. This finding reduces the likelihood that participation bias was affecting the observed differences in health between the two groups.

How often have they been followed up?

The Hazelwood Health Study Adult Cohort, comprising the 4056 Adult Survey participants, has formed the basis for further recruitment into a number of follow-up research streams. The recruitment results for these streams are detailed in Figure 1.

Eligibility has varied for each stream. Upon completion of the Adult Survey, 2223 Morwell participants and 649

Table 2. Australian Bureau of Statistics 2011 Census estimated adult resident population by age and gender for Morwell and Sale compared with adult cohort participants

	Morwell			Sale		
	Participants $n=3096$ n (%)	Census[a] $n=10429$ n (%)	χ^2 p-value	Participants $n=960$ n (%)	Census[a] $n=4816$ n (%)	χ^2 p-value
Gender			0.002			0.136
Male	45%	48%		43%	45%	
Female	55%	52%		57%	55%	
Age category			<0.001			<0.001
18–29	8%	25%		9%	28%	
30–39	9%	16%		10%	14%	
40–49	14%	17%		13%	17%	
50–59	20%	16%		20%	16%	
60–69	24%	13%		22%	11%	
70+	25%	13%		27%	14%	

[a]Data source: Population Estimates by Age and Sex, Victoria, by Statistical Geography [ASGS 2011], 2011, Australian Bureau of Statistics. [http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3235.02011?].

Table 3. Self-reported smoking status in Latrobe City and Shire of Wellington compared with the adult cohort participants

	Morwell participants N=3096	Latrobe City[a] N=42 068	χ^2 p-value	Sale participants N=960	Shire of Wellington[a] N=73 788	χ^2 p-value
Smoking status			<0.001			<0.001
Current smoker	19%	20%		14%	19%	
Former smoker	32%	26%		33%	28%	
Never	49%	54%		52%	53%	

[a]Data source: Victorian Population Health survey 2011–12 Findings, [https://www2.health.vic.gov.au/Api/downloadmedia/%7B14305C13-A130-4AB1-A5E1-4E94370DBC78%7D].

Table 4. Comparison of participants with non-participants who completed a refuser questionnaire

	Morwell			Sale		
	Participants $n=3096$ n (%)	Refuser questionnaire $n=235$ n (%)	χ^2 p-value	Participants $n=960$ n (%)	Refuser questionnaire $n=123$ n (%)	χ^2 p-value
In general would you say your health is:			0.395			0.185
Excellent	263 (9%)	19 (9%)		144 (15%)	18 (15%)	
Very good	800 (26%)	54 (24%)		325 (34%)	39 (33%)	
Good	1087 (35%)	82 (37%)		289 (30%)	27 (23%)	
Fair	659 (21%)	41 (18%)		151 (16%)	24 (20%)	
Poor	266 (9%)	27 (12%)		45 (5%)	10 (8%)	

Sale participants consented to linkage with data from the Victorian Ambulance Clinical Information System (VACIS), the Victorian Ambulance Cardiac Arrest Registry (VACAR) and the Victorian Cancer Registry (VCR). In parallel, 2115 Morwell and 610 Sale participants consented to linkage with hospital admissions and emergency presentations data from the Victorian Admitted Episodes Dataset (VAED) and the Victorian Emergency Minimum Dataset (VEMD). The Hazelinks Stream undertook the first round of these linkages in 2018.

The Cardiovascular Stream undertook Round 1 of clinical testing between October 2017 and May 2018. Eligible
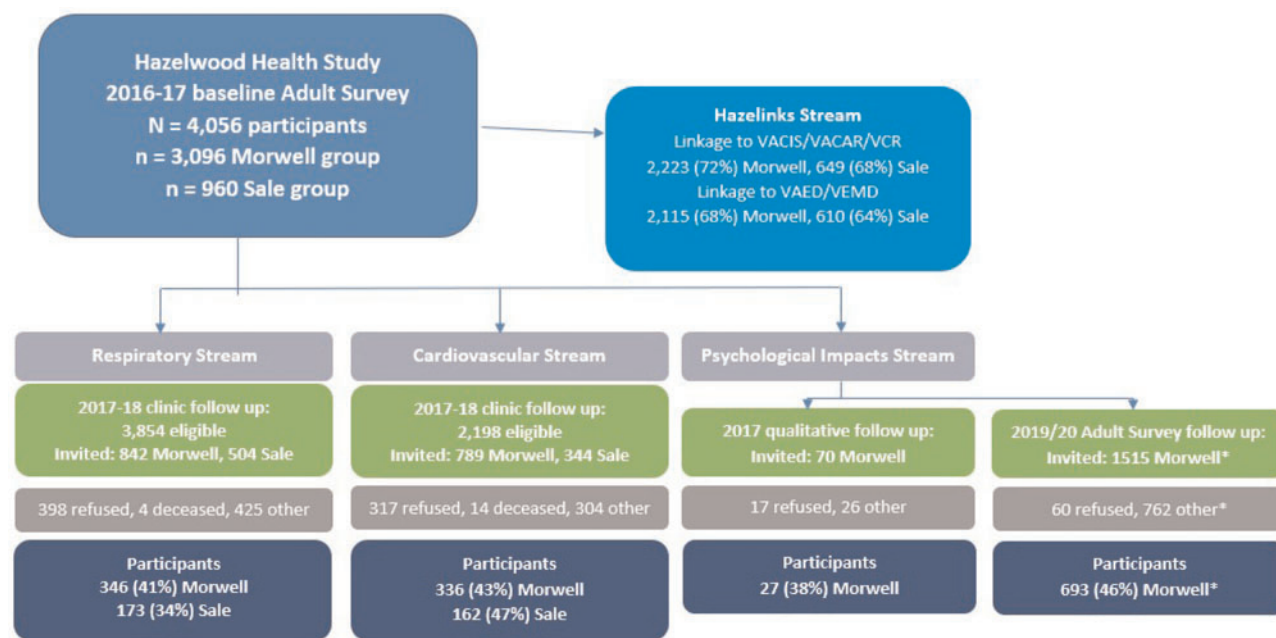
Figure 1 Hazelwood Health Study Adult Cohort baseline and follow-up recruitment *Recruitment numbers preliminary at the time of publication. VACIS, Victorian Ambulance Clinical Information System; VACAR, Victorian Ambulance Cardiac Arrest Registry; VCR, Victorian Cancer Registry; VAED, Victorian Admitted Episodes Dataset; VEMD, Victorian Emergency Minimum Dataset.

cohort members were men aged 55–89 years and women aged 60–89 years. Those who specified no further contact, had an unknown age or gender, no valid address or an address outside the study area were excluded. Those with any underlying cardiovascular condition were oversampled such that 50% of those invited had reported a diagnosis of angina, heart attack, heart failure, irregular heart rhythm/arrhythmia, stroke and/or other heart disease. A sample size of 330 Morwell and 165 Sale participants was required to observe a 33% difference in mean high-sensitivity C-reactive protein (hsCRP) level, assuming two-sample t test of logarithm transformed hsCRP values, a two-sided alpha value of 0.05 and 80% power. From a weighted random sample of 1333 Adult Survey participants who were invited, 336 from Morwell and 162 from Sale participated in the Cardiovascular Stream.

The Respiratory Stream undertook Round 1 of clinical testing between August 2017 and March 2018. Eligible cohort members were aged 18–89 years. Exclusion criteria were as per the Cardiovascular Stream and also contraindications to spirometry which included recent surgery, myocardial infarction, pneumothorax, pulmonary embolus, open pulmonary tuberculosis and known aneurysms. Those who had reported an asthma attack or taking asthma medication in the previous year were oversampled such that 40% met these criteria. A sample size of 339 Morwell and 170 Sale participants was required to observe a mean decline in forced expiratory volume (FEV_1) in the Sale group of 23.1 (±17.1) ml/year, assuming a

two-sample t test, a two-sided alpha value of 0.05 and 90% power. From a weighted random sample of 1333 Adult Survey participants who were invited, 346 from Morwell and 173 from Sale participated in the Respiratory Stream.

In August and September 2017, the Psychological Impacts Stream invited a random sample of 70 Morwell cohort members, stratified by age and gender, to undertake qualitative interviews, of whom 27 participated. In November 2019, the Psychological Impacts Stream invited 1515 Morwell cohort members into a follow-up Adult Survey. At the time of publication, recruitment had just closed with 693 participants.

What has been measured?

The diverse range of health and exposure measures included in the baseline Adult Survey and follow-up Cardiovascular, Respiratory, Psychological Impacts and Hazelinks Streams are summarized in Table 5.

The baseline Adult Survey comprised a self-report survey, which participants could complete online, by telephone interview or on paper. The survey included demographic indices, the stem question to the Short Form (SF) 12,[9] doctor-diagnosed medical conditions, a modified version of the European Community Respiratory Health Survey (ECRHS),[10,11] the Pekkanen asthma severity score,[12] the Impact of Events Scale-Revised (IES-R) which measured the three symptom clusters of posttraumatic

Table 5. Health and exposure measures included in the baseline Adult Survey and follow-up Cardiovascular, Respiratory, Psychological Impacts and Hazelinks Streams

Adult Survey

Data collected by self-report survey:
- demographics
- respiratory symptoms
- respiratory conditions
- asthma severity
- symptoms of traumatic stress
- psychological distress
- stressful life events
- mine-fire related smoke exposure
- time-location diary
- residence type
- occupational exposures
- cigarette smoke exposure
- alcohol use

Respiratory Stream

Data collected by respiratory scientists:
- respiratory symptoms and medications
- asthma history and control allergen exposure
- fraction of exhaled nitric oxide (FeNO)
- spirometry before and after bronchodilator: forced expiratory volume in 1 s (FEV1), forced vital capacity (FVC), FEV1/FVC
- respiratory system resistance and reactance by forced oscillation technique (FOT)
- small airways function via multi-breath washout (MBW)
- gas exchange by transfer factor for carbon monoxide (T_Lco)

Hazelinks

Identified linkage with Victorian Ambulance Clinical Information System; Victorian Ambulance Cardiac Arrest Registry; Victorian Cancer Registry; Victorian Admitted Episodes Dataset; and the Victorian Emergency Minimum Dataset from 1 January 2009 onwards

Cardiovascular Stream

Data collected by interview:
- previously diagnosed cardiovascular conditions
- family medical history
- cigarette smoke exposure
- alcohol use
- physical activity
- dietary habits
- medications

Data collected by sonographer:
- endothelial function

Data collected by research nurse:
- 12-lead electrocardiograph (ECG).
- biometrics
- blood pressure

Blood analysis:
- high sensitivity C-reactive protein (hsCRP)
- fibrinogen
- high sensitivity (hs) troponin
- N-terminal pro B-type Natriuretic Peptide (NT-pro-BNP)
- lipids
- glycosylated haemoglobin (HbA1c)
- creatinine
- estimated Glomerular Filtration Rate (eGFR)

Psychological Impacts Stream

Data collected by interview (2017):
- short- and long-term psychological impacts of the mine fire
- intrusive rumination, hyperarousal and avoidance behaviour

Data collected by followup survey (2019–20):
- symptoms of traumatic stress
- psychological distress
- stressful life events

stress (intrusive rumination, hyperarousal and avoidance behaviour) related to the mine fire,[13] the Kessler-10 item (K10) general distress scale,[14] occupational exposures to dust, fumes, smoke, gas, vapour or mist, employment or volunteer roles in the emergency services, the Alcohol Use Disorders Identification Test-C (AUDIT-C)[15,16] and pack-years of cigarette smoking. Each participant's home address SA1 was used to generate an Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) score.[17]

Spatially resolved hourly estimates of mine-fire related concentrations of airborne particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) were modelled using a chemical transport model that incorporated information on air monitoring, coal combustion and weather conditions.[1,4] Adult Survey participants completed time-location diaries with their home, work and any relocation addresses for each day and night of the mine fire period. In order to estimate each participant's mine-fire related $PM_{2.5}$ exposure level, their time-location diaries were blended with the modelled data.[18]

In the Cardiovascular Stream clinic, trained interviewers administered questions about cardiovascular conditions, smoking and physical activity levels, the AUDIT-C,[15,16] the Australian Eating Survey[19] and medications. Sonographers measured endothelial function by ultrasound assessment of flow mediated dilatation (FMD) of the brachial artery following occlusion.[20] A research nurse collected data on height, weight, body mass index and hip-waist ratio, undertook 12-lead electrocardiograph and blood pressure measurement and collected blood samples which were later analysed for cardiovascular biomarkers.

In the Respiratory Stream clinic, respiratory scientists administered the ECRHS questionnaire[10,11] modified to

measure respiratory symptoms, history of asthma and allergen exposure. Lung function tests were performed as listed in Table 5.

The Psychological Impacts Stream added data from the 2017 qualitative interviews designed to explore both short- and long-term psychological impacts of the mine fire. There was a particular focus on the three symptom clusters of posttraumatic stress, which had been assessed with the IES-R in the Adult Survey. The 2019–20 follow-up survey has repeated the IES-R and K10 to assess longitudinal change in these psychological measures.

Hazelinks added routinely collected administrative health data including hospital admission, emergency presentation, ambulance attendance, cardiac arrest and cancer data.

What has it found? Key findings and publications

The Hazelwood Health Study Adult Survey and its follow-up streams have generated a substantial number of findings. Links to reports, fact sheets and publications can be found at [www.hazelwoodhealthstudy.org.au/study-find ings]. Key findings include the following.

Respiratory health

Figure 2 shows that 2.5 to 3 years after the mine fire, all self-reported respiratory symptoms were more common among Morwell compared with Sale participants, after adjusting for age, gender, employment, education and smoking.[21]
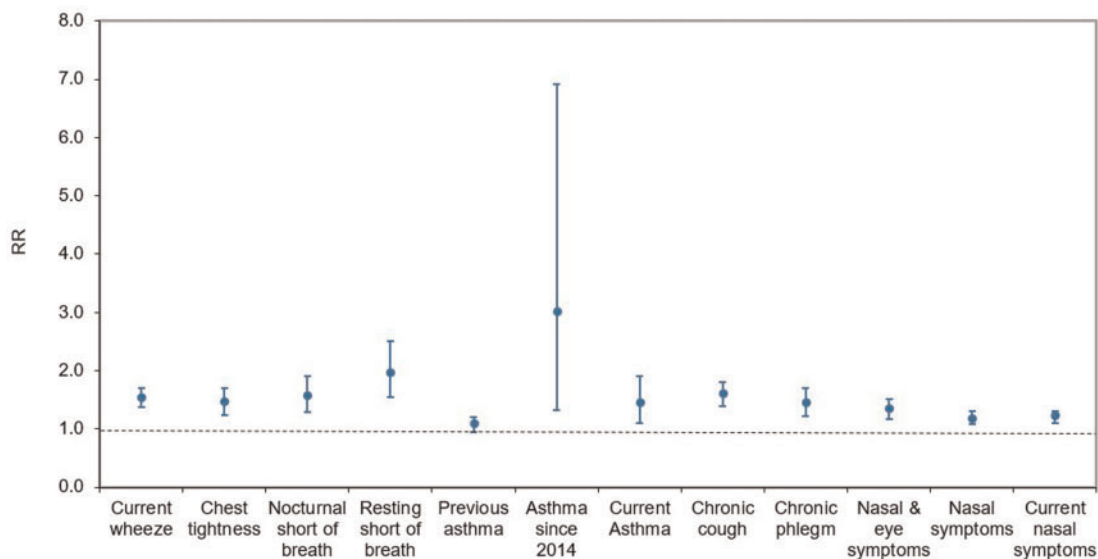
Figure 3 shows dose response relationships between chronic cough reported by Morwell participants, and both mean mine-fire related $PM_{2.5}$ exposure [odds ratio (OR) = 1.13, 95% confidence interval (CI): 1.03, 1.23 per 10 $\mu g/m^3$ increment in mean $PM_{2.5}$] and peak mine-fire related $PM_{2.5}$ exposure (OR = 1.07, 95% CI: 1.02, 1.12 per 100 $\mu g/m^3$ increment in peak $PM_{2.5}$).[18] A similar relationship was also shown between wheeze and peak mine-fire related $PM_{2.5}$ exposure (OR = 1.06, 95% CI: 1.02, 1.11 per 100 $\mu g/m^3$ increment in peak $PM_{2.5}$).[18]

Cardiovascular health

Cardiovascular testing suggested no association between Hazelwood mine-fire smoke exposure and cardiovascular disease evident 3.5 to 4 years after the fire. This included finding no difference between Morwell and Sale adults in terms of hsCRP, nor other cardiovascular markers listed in Table 5. There were also no differences between the Morwell and Sale participants in electrocardiograph, endothelial function and blood pressure findings.

Psychological health

More than 2 years after the mine fire, Table 6 shows that Morwell participants scored significantly higher than those from Sale on the IES-R (adjusted mean difference = 6.53; 95% CI: 5.72, 7.35, $p <0.001$). K10 general distress scores were also higher in the exposed group (adjusted mean difference = 1.69; 95% CI: 1.05, 2.33, $p <0.001$).[22,23]

These findings were supported by the qualitative interviews[24] where approximately a quarter of the 27

Figure 2 Adjusted rate ratios (RR) and 95% confidence intervals for self-reported asthma and current respiratory symptoms in Morwell participants compared with Sale participants. The dashed - - - - line indicates no difference in risk between the Morwell participants and the Sale participants.
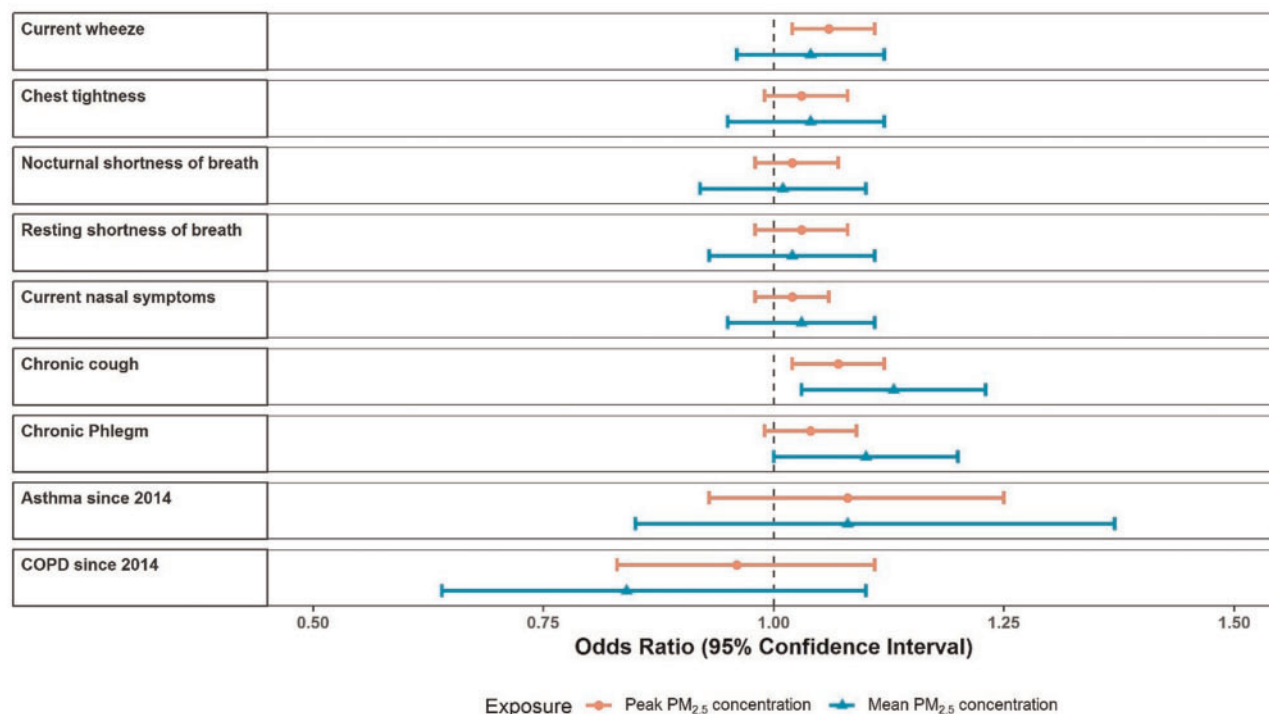
Figure 3 Dose-response associations between mine-fire related PM2.5 concentrations and respiratory outcomes in Morwell 2.5 to 3 years after the mine fire. Figure 3 reproduced from Johnson *et al.*[18] with permission. The dashed line indicates no dose-response association between PM2.5 and respiratory outcomes. PM2.5 is particulate matter less than 2.5 μm in diameter.

Table 6. IES-R and K10 scores for the Adult Survey cohort

Psychological measure	Morwell $n = 3091$ Weighted mean (SE)	Sale $n = 960$ Weighted mean (SE)	Mean diff	Adj mean diff[a] (95% CI)	*p*-value
IES-R					
Intrusion (scores 0–32)	3.94 (0.14)	0.63 (0.09)	3.31	2.68 (2.36, 3.00)	<0.001
Avoidance (scores 0–32)	3.47 (0.13)	0.71 (0.10)	2.76	2.22 (1.90, 2.53)	<0.001
Hyperarousal (scores 0–24)	2.50 (0.11)	0.30 (0.05)	2.20	1.69 (1.46, 1.92)	<0.001
Total score (scores 0–88)	9.87 (0.36)	1.66 (0.22)	8.20	6.53 (5.72, 7.35)	<0.001
K10	16.66 (0.19)	14.06 (0.27)	2.60	1.69 (1.05, 2.33)	<0.001

IES-R Impact of Events Scale-revised; K10 Kessler 10-item general distress scale; SE standard error.

[a]Adjusted for age, gender, education, marital status, Index of Relative Socioeconomic Advantage and Disadvantage score, drinking and smoking.

participants reported distress which had dissipated by the time of the interviews, with four interviewees reporting still being affected 3 years after the event. Intrusive thoughts were the most frequently reported symptom of posttraumatic stress. Notably, half of the interviewees reported no psychological distress at the time of interview. The interviews also highlighted the increased vulnerability of people with pre-existing mental health concerns.[22,24]

What are the main strengths and weaknesses?

The Hazelwood Health Study Adult Cohort data have a number of strengths which provide confidence in the findings, but also some limitations which affect interpretation. A modest response rate was achieved, and weightings were applied to best reflect the source population. An assessment of some refusers indicated that exposed people with ill health were not over-represented in the sample. The Adult Survey's sub-streams all achieved their required sample sizes.

Not reliant on self-report alone, individual exposures to $PM_{2.5}$ were estimated from a combination of detailed time-location diaries, including residential, relocation and work addresses, and spatially and temporally resolved modelled $PM_{2.5}$ concentrations, using a chemical transport model that incorporated information on air monitoring, coal combustion and weather conditions. It is possible that

some participants may have had difficulty recalling their precise locations and dates more than 2 years after the fire, and considerable effort was made to manually review any detected inconsistencies in participant's time-location diaries.

Combined, the Adult Survey and its sub-streams incorporate self-reported quantitative data, qualitative interview data, physical measurements, data from administrative health records and air pollution data. Whereas each data type has its own limitations, when combined these datasets provide a robust overview of the health impacts of smoke from the Hazelwood mine fire on the nearby community. In specific regard to self-reported quantitative data, validated and reliable questionnaires were used where available. Furthermore, for some health measures there were no differences reported between exposure groups, suggesting that exposed participants did not systematically over-report their symptoms. All statistical analysis allowed for known demographic and lifestyle confounders; however, we acknowledge that there may be some residual confounding from unmeasured risk factors.

Future follow-up data collections are planned that should provide more certainty around the long-term health impacts of exposure to the Hazelwood mine fire. Those follow-ups will include new information about long latency diseases such as cancer.

Can I get hold of the data? Where can I find out more?

The Hazelwood Health Study Adult Cohort data are held by the School of Public Health and Preventive Medicine and the School of Rural Health at Monash University. The researchers have a long-standing interest in environmental epidemiology and occupational health, with specific expertise in exposure assessment, respiratory, cardiovascular and psychological health, cancer, health in rural communities, cohort studies and biostatistics. In addition to the Adult Survey Cohort, other components of the broader Hazelwood Health Study include the Schools Study of psychological health in school-aged children,[25–27] the Early Life Follow-Up study of the health of exposed infants and pregnant mothers[28–31] and the Impact on Community Well-being study.[32,33] Researchers who are interested in collaborating on research relevant to the Hazelwood Health Study should contact the principal investigators, Professor Michael Abramson [Michael.Abramson@monash.edu] and Dr Matthew Carroll [Matthew.Carroll@monash.edu]. The Hazelwood Health Study is intended to continue until at least 2024. Study progress and updated findings can be found at [www.hazelwoodhealthstudy.org.au].

Profile in a nutshell

- The Hazelwood Health Study Adult Cohort was established to investigate the long-term respiratory, cardiovascular and psychological health impacts of smoke exposure from the February 2014 Hazelwood coal mine fire which burned for 6 weeks in the Latrobe Valley, Victoria, Australia.
- The cohort comprises 3096 adults from the town of Morwell which was heavily exposed to the smoke, and 960 adults from the comparison town of Sale which was minimally exposed.
- The baseline Hazelwood Health Study Adult Survey collected demographic, health and lifestyle risk factor data between May 2016 and February 2017.
- Participants provided time-locations diaries which were blended with spatially resolved, modelled hourly concentrations of mine-fire smoke-related particulate matter less than 2.5μm in diameter ($PM_{2.5}$) in order to estimate each participant's exposure level.
- Follow-up data collection has included respiratory symptoms, lung function testing, measurement of endothelial function, electrocardiograph, blood pressure, blood tests for cardiovascular biomarkers, medication use, psychological interviews focused on symptoms of posttraumatic stress, and linkage to State ambulance, hospital and cancer registry datasets.
- The Hazelwood Health Study is intended to continue until at least 2024. Study progress and updated findings can be found at [www.hazelwoodhealthstudy.org.au].

Conflict of interest

M.J.A. holds investigator-initiated grants from Pfizer and Boehringer-Ingelheim for unrelated research. He has also

undertaken an unrelated consultancy for Sanofi. D.L. has received research support and honoraria from Abbvie, Astellas, AstraZeneca, Bristol-Myers Squibb, Novartis, Pfizer, Sanofi and Shire for work unrelated to this study. Other authors have no potential competing interests to declare.

References

1. Reisen F, Gillett R, Choi J, Fisher G, Torre P. Characteristics of an open-cut coal mine fire pollution event. *Atmos Environ* 2017; **151**:140–51.
2. Melody SM, Johnston FH. Coal mine fires and human health: What do we know? *Int J Coal Geol* 2015;**152**:1–14.
3. Hazelwood Mine Fire Inquiry. *Hazelwood Mine Fire Inquiry*. Melbourne, VIC: Australia Parliament of Victoria, 2014.
4. Luhar AK, Emmerson KM, Reisen F, Williamson GJ, Cope ME. Modelling smoke distribution in the vicinity of a large and prolonged fire from an open-cut coal mine. *Atmos Environ* 2020; **229**:117471.
5. Victorian Electoral Commission. *Do I Have to Enrol*? Melboune, VIC: VEC, 2020.
6. Australian Bureau of Statistics. 2011.0.55.001 Information paper. *Census of* Population and Housing—Products and Services, *2011-2012*. Canberra: ABS, 2012.
7. Australian Institute of Health and Welfare. *Australia's Health 2012*. Canberra: AIHW, 2012.
8. Department of Health. *Victorian Population Health Survey 2011–12: Survey Findings*. Melbourne, VIC: State Government of Victoria, 2014.
9. Ware JJ, Kosinski M, Keller S. A 12-Item short-form health survey: Construction of scales and preliminary tests of reliability and validity. *Med Care* 1996;**34**:220–33.
10. Abramson M, Kutin J, Raven J, Lanigan A, Czarny D, Walters E. Risk factors for asthma among young adults in Melbourne, Australia. *Respirology* 1996;**1**:291–97.
11. Burney P, Luczynska C, Chinn S, Jarvis D. The European Community Respiratory Health Survey. *Eur Respir J* 1994;**7**: 954–60.
12. Pekkanen J, Sunyer J, Anto JM, Burney P. Operational definitions of asthma in studies on its aetiology. *Eur Respir J* 2005;**26**: 28–35.
13. Horowitz MJ, Wilner N, Alvarez W. Impact of event scale: a measure of subjective stress. *Psychosom Med* 1979;**41**:209–18.
14. Kessler RC, Barker PR, Colpe LJ, Epstein JF *et al*. Screening for serious mental illness in the general population. *Arch Gen Psychiatry* 2003;**60**:184–89.
15. de Meneses-Gaya C, Zuardi AW, Loureiro SR, Crippa J. Alcohol use disorders identification test (AUDIT): an updated systematic review of psychometric properties. *Psychol Neurosci* 2009;**2**: 83–97.
16. Frank D, DeBenedetti AF, Volk RJ, Williams EC, Kivlahan DR, Bradley KA. Effectiveness of the AUDIT-C as a screening test for alcohol misuse in three race/ethnic groups. *J Gen Int Med* 2008; **23**:781–87.
17. Australian Bureau of Statistics. *Technical Paper Socio-Economic Indexes for Areas (SEIFA) 2016, 2018*. Canberra: ABS, 2012.
18. Johnson AL, Gao CX, Dennekamp M *et al*. Associations between respiratory health outcomes and coal mine fire $PM_{2.5}$ smoke exposure: a cross-sectional study. *Int J Environ Res Public Health* 2019;**16**:4262.
19. Collins C, Watson J, Guest M *et al*. Reproducibility and comparative validity of a food frequency questionnaire for adults. *Clin Nutr* 2014;**33**:906–14.
20. Thijssen D, Bruno R, van Mil A *et al*. Expert consensus and evidence-based recommendations for the assessment of flow-mediated dilation in humans. *Eur Heart J* 2019;**40**:2534–47.
21. Abramson MJ, Blackman J, Carroll M *et al*. *Hazelwood Health Study Adult Survey Report: Volume 1, Comparison of Morwell and Sale; 2017*. Monash University, Melbourne, VIC: HHS, 2017.
22. Maybery D, Jones R, Dipnall JF *et al*. A mixed-methods study of psychological distress following an environmental catastrophe: the case of the Hazelwood open-cut coalmine fire in Australia. *Anxiety Stress Coping* 2020;**33**:216–30.
23. Maybery D, Jones R, Carroll M, *et al*. Psychological outcomes following the Hazelwood mine fire: a mixed methods study. *PsyArXiv* 2019. doi: 10.31234/osf.io/euj96.
24. Jones R, Lee S, Maybery D, McFarlane A. Experiences of a prolonged coal-mine fire. *Disaster Prev Manag* 2018;**27**:534–45.
25. Maybery D, Carroll M, Berger E, Dipnall J, Lee S. The psychological impact and experiences of children following the Hazelwood mine fire and subsequent smoke event. *PsyArXivv* 2019. doi:10.31234/osf.io/rw657.
26. Berger E, Carroll M, Maybery D, Harrison D. Disaster impacts on students and staff from a specialist, trauma-informed Australian School. *J Child Adol Trauma* 2018;**11**:521–30.
27. Berger E, Carroll M, Maybery D. Children's perspectives on the impact of the Hazelwood mine fire and subsequent smoke event. *PsyArXiv* 2018. doi:10.31234/osf.io/8mhxf.
28. Shao J, Zosky GR, Hall GL *et al*. Early life exposure to coal mine fire smoke emissions and altered lung function in young children. *Respirology* 2020;**25**:198–205.
29. Melody SM, Ford J, Wills K, Venn A, Johnston FH. Maternal exposure to fine particulate matter from a coal mine fire and birth outcomes in Victoria, Australia. *Environ Int* 2019;**127**:233–42.
30. Melody SM, Ford JB, Wills K, Venn A, Johnston FH. Maternal exposure to fine particulate matter from a large coal mine fire is associated with gestational diabetes mellitus: A prospective cohort study. *Environ Res* 2020;**183**:108956.
31. Zhao B, Johnston FH, O'Sullivan T *et al*. Early life exposure to coal mine fire and tobacco smoke affect subclinical vascular function. *Arch Dis Child* 2019, Dec 20. doi: 10.1136/archdischild-2019-317528. [Epub ahead of print.]
32. Yell S, Duffy M. Community empowerment and trust: social media use during the Hazelwood mine fire. *Aust J Emerg Manag* 2018;**33**:66–70.
33. Duffy M, Whyte S. The Latrobe Valley: The politics of loss and hope in a region of transition. *Aust J Reg Stud* 2017;**23**:421–46.