An exploration of the trajectory of psychological distress associated with exposure to smoke during the 2014 Hazelwood coal mine fire

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Abstract

Due to climate change, catastrophic events such as landscape fires are increasing in frequency and severity. However, relatively little is known about the longer-term mental health outcomes of such events. Follow-up was conducted of 709 adults exposed to smoke from the 2014 Hazelwood mine fire in Morwell, Victoria, Australia. Participants completed two surveys evaluating posttraumatic distress, measured using the Impact of Events Scale-Revised (IES-R), three and six years after the mine fire. Mixed-effects regression models were used to evaluate longitudinal changes in distress. IES-R total scores increased on average by 2.6 points (95%CI: 1.2 to 3.9 points) between the two survey rounds, with increases across all three posttraumatic distress symptom clusters, particularly intrusive symptoms. This increase in distress was evident across all levels of fine particulate matter (PM_{2.5}) exposure to the mine fire smoke. Age was an effect modifier between mine fire PM_{2.5} exposure and posttraumatic distress, with younger adults impacted more by exposure to the mine fire. Greater exposure to PM_{2.5} from the mine fire was still associated with increased psychological distress some six years later, with the overall level of distress increasing between the two survey rounds. The follow-up survey coincided with the Black Summer bushfire season in south-eastern Australia and exposure to this new smoke event may have triggered distress sensitivities stemming from exposure to the earlier mine fire. Public health responses to disaster events should take into consideration prior exposures and vulnerable groups, particularly younger adults.

Keywords: posttraumatic distress; mine fire; air pollution; PM_{2.5} exposure, environmental disasters

Highlights:

- PM_{2.5} exposure during the Hazelwood mine fire resulted in posttraumatic distress
- The exposure-distress relationship persists in the impacted community 6 years on
- Intrusive thoughts were the most prominent longer-term symptoms of distress
- A subsequent smoke event may have activated distress sensitivity that has developed
- Recurrent exposure to disaster adds to the complexity of distress trajectories

Introduction

Given that climate change has accelerated the rate of catastrophic events occurring across the globe, understanding the longer-term trajectory of posttraumatic distress after exposure to environmental disasters has become increasingly important (Hughes et al., 2016; Leaning & Guha-Sapir, 2013). Although a range of studies have evaluated longer-term mental health and wellbeing in the aftermath of disasters, such as earthquakes and hurricanes, there was little evidence on the impact of repeated exposures, threats of landscape fires, and protracted air pollution events on mental health outcomes.

In previous research, Norris et al. (2002) concluded that levels of psychological distress and rates of posttraumatic stress disorder (PTSD) peaked within the first year post-event and then declined over time. However, other longitudinal studies such as McFarlane (1988) have found a persistent effect of exposure to fire events on the presentation of PTSD symptoms. Bryant (2019) observed that as many as 25% of cases of PTSD may not become apparent until several years after exposure to a disaster event. Other studies found that levels of distress and PTSD had not returned to pre-disaster levels 4-7 years afterwards (Bryant et al., 2018; North et al., 2011; Paxson et al., 2012).

The Latrobe Valley region in south-eastern Australia is prone to bushfire events (Teague et al., 2014). The Hazelwood mine fire occurred in February and March 2014. Wildfires spotted into the Morwell open-cut coal mine adjacent to the Hazelwood power station and resulted in a mine fire which burnt for a period of approximately six weeks, blanketing surrounding communities in smoke and ash. In Morwell, the nearest town to the mine, concentrations of fine particulate matter 2.5µm or less in diameter (PM_{2.5}) during the event reached as high as 3,700 µg/m³, greatly exceeding the estimated average background PM_{2.5} concentrations (6 µg/m³) and breaching national pollution standards 23 times during the 45 day mine fire (Luhar et al., 2020).

Early reports following the mine fire indicated that physical symptoms and psychological distress were evident within the local community, and residents held significant concerns about potential long-term health consequences (Wood et al., 2015). In response, the Victorian government

commissioned the Hazelwood Health Study (HHS; www.hazelwoodhealthstudy.org.au) to investigate the long-term impacts of the mine fire smoke on the health and wellbeing of people living in affected communities. Results from the HHS Adult Survey conducted approximately 2.5 years after the mine fire indicated a dose-response relationship between level of PM_{2.5} exposure during the mine fire and severity of subsequent psychological distress, with the relationship strongest for the youngest adults (Broder et al., 2020; Ikin et al., 2020). Additional risk factors identified in the survey included prior physical and mental health diagnoses, and prior exposures to trauma.

The current study followed-up HHS Adult Survey participants to investigate for the continued presence of, and changes in, the relationship between PM_{2.5} exposure during the Hazelwood mine fire and subsequent event-related psychological distress. Importantly, the data collection period for the follow-up survey overlapped with the 2019-20 Australian “Black Summer” bushfires. Significant fire activity elsewhere in the region caused periods of widespread smoke haze across the Latrobe Valley, particularly in January 2020 (Davey & Sarre, 2020; Vardoulakis et al., 2020). Accordingly, the findings presented in this study also provide an opportunity to consider how longer-term psychological impacts of exposure to a stressful event present within the context of a subsequent event with comparable characteristics.

Methods

Study Design

This study presents the analysis of longitudinal self-reported survey data, collected at two time points from a subset of the Adult Survey cohort (Ikin et al., 2020). The baseline Adult Survey, conducted between May 2016 and February 2017, represented round one (R1) of data collection. Round two (R2) data were collected in a Mental Health and Wellbeing Survey conducted three years later, between December 2019 and March 2020.

Participants

Eligibility

All Adult Survey participants who had been residents of Morwell and at least 18 years of age at the time of the mine fire ($n = 3,096$) were eligible for selection into the Mental Health and Wellbeing survey, with the exception of 17 known to have deceased and two who had previously withdrawn their consent to follow-up.

Sampling

From 3,077 eligible, a weighted random sample of 1,512 people, stratified by age at R1 (<35; 35-65; >65 years) and tertiles of mine fire-related PM_{2.5} exposure, were invited to participate in the R2 survey. Although females were over-represented in the Adult Survey, gender was not associated with IES-R scoring at R1, so was not included as a stratification variable for R2.

Recruitment Methods

A staggered approach was taken to inviting participation in R2, starting with email, then SMS, and finally postal approaches (depending on the contact information provided by participants at R1). Within each contact mode, a survey invitation and a reminder were delivered approximately one week apart. Approaches continued in turn until either a response was received or all attempts (i.e., two approaches in each of the three modes) had been made.

Measures

Participants completed the survey online, by telephone interview, or by mail-out.

Assessment of PM_{2.5} Exposure during the Mine Fire Period

Retrospective modelling of high resolution, hourly mine fire-related PM_{2.5} concentrations was conducted using a chemical transport model that incorporated data on air monitoring, coal combustion and meteorological conditions (Luhar et al., 2020). The modelled PM_{2.5} distribution data were merged with time-location diaries for the 45-day mine fire period that were provided by participants as part of the R1 survey to generate an estimated mean level of PM_{2.5} exposure during the mine fire period for each participant (Ikin et al., 2020). Three categories of PM_{2.5} exposure were subsequently established based on tertiles of the mean daily PM_{2.5} exposure of all R1 Morwell participants: “Low Exposure”

(<8.56 $\mu\text{g}/\text{m}^3$), “Medium Exposure” (8.56 $\mu\text{g}/\text{m}^3$ to 14.15 $\mu\text{g}/\text{m}^3$), and “High Exposure” (>14.15 $\mu\text{g}/\text{m}^3$).

Assessment of Event-Related Psychological Distress

The Impact of Events Scale – Revised (IES-R) (Weiss & Marmar, 1997) was used to assess participants’ levels of psychological distress specifically in relation to the 2014 Hazelwood mine fire. The 22-item IES-R has three subscales relating to the PTSD symptom clusters of “intrusion”, “avoidance”, and “hyperarousal”. Respondents rated their experience of each of the 22 symptoms over the previous week with regards to the Hazelwood event on a four-point scale (0 = “Not at all”; 1 = “A little bit”; 2 = “Moderately”; 3 = “Quite a bit”; 4 = “Extremely”). The primary outcome was the IES-R total score, which is the sum of scores for all 22 items. The three subscales were secondary outcomes, with intrusion and avoidance the sum of eight items and hyperarousal the sum of six items. Hyperarousal scores were scaled up by a factor of 8/6 to enable direct comparison between subscale scores.

Risk Factors

Demographic factors included in the analysis were age (at the time of the mine fire), gender, education, and employment status. Health factors included were self-reported doctor diagnosed physical conditions (cardiac events, asthma or chronic obstructive pulmonary disease [COPD]) and self-reported doctor/psychologist diagnosed prior mental health conditions (anxiety, depression, PTSD, or other mental health conditions diagnosed prior to the 2014 mine fire), measured as a part of the R1 Survey. Previous exposures to traumatic life-events were categorised as: none, one, or multiple traumatic events. In the case of self-reported prior mental health diagnoses, this question was repeated in the R2 survey. As expected, there was variation in the mental health diagnosis histories reported by some participants between R1 and R2. Accordingly, participant responses to both R1 and R2 were combined to take into consideration all reported mental health diagnoses that preceded the mine fire.

Ethics Approval

The Monash University Human Research Ethics Committee granted approval to conduct the surveys in May 2015 and October 2019 (approval numbers CF15/872 and 21151 respectively).

Statistical Analysis

Inverse probability weighting (also known as response propensity weighting) was used to account for longitudinal attrition bias (Chen et al., 2012). Weights were estimated using a probit regression model to predict survey participation based on R1 risk factors. These response weights are incorporated into all analyses.

Descriptive statistics are given for baseline covariates and IES-R outcomes, categorised by PM_{2.5} exposure group (low; medium; high). Crude differences between the PM_{2.5} exposure groups were compared using Pearson chi-squared tests for categorical measures, and analysis of variance (ANOVA) for continuous outcomes, with continuous data log-transformed where heavily skewed.

Linear mixed-effects regression models were implemented to evaluate changes over time in IES-R outcomes and to assess whether IES-R and changes in IES-R were associated with PM_{2.5} exposure during the mine fire. An interaction between PM_{2.5} exposure and survey round was evaluated to assess whether the impact of PM_{2.5} exposure changed over time. As younger adults reported higher levels of distress in R1 associated with higher PM_{2.5} exposure (Broder et al., 2020), interactions between age, mean PM_{2.5} exposure, and survey round were evaluated using two and three-way models. Age was centred at the cohort mean age during the mine fire, and mean PM_{2.5} exposure was centred at 10 µg/m³.

All regression models were adjusted for baseline covariates. Missing data were imputed using multiple imputation (Rubin, 1996) with chained equations using the ICE package (Royston & White, 2011). The mixed-effects models were executed on 20 imputed datasets and the results combined using Rubin's rules (Rubin, 1996).

A sensitivity analysis was conducted of IES-R total scores using unimputed and unweighted mixed-effects regression models to evaluate the impact of multiple imputation and response weighting on estimated effects. As scores on the IES-R were right-skewed, mixed-effects modelling was carried

out on log-transformed IES-R total scores to assess whether similar conclusions would be drawn to the main results. Statistical analyses were performed using Stata version 16 (Stata Corporation, College Station, Texas, 2019).

Results

Recruitment and Participant Characteristics

In total, 709 participants were recruited into R2 from 1,512 invitations. After excluding a further 17 deceased or permanently cognitively impaired participants, this equated to an overall response rate of 47%. A flowchart of recruitment into the R2 survey is presented in Figure 1. A comparison of responders to non-responders pre and post weighting is given in Table S1. Responders were slightly younger, with better self-rated health, higher employment and education levels. The non-participation bias related to these covariates was largely corrected with response weighting used in all analyses (see Table S1).

Figure 1

2019-2020 Mental Health and Wellbeing Survey Recruitment Flowchart

Participant characteristics by PM_{2.5} exposure group are presented in Table 1. The mean age of the cohort during the mine fire was 48.7 years. At the time of the R1 survey, 49% had post-secondary school qualifications, which is comparable with the region's adult population statistics (Australian Bureau of Statistics, 2016). One third of the cohort reported a mental health diagnosis prior to the mine fire (pre-2014). The participant characteristics were generally comparable between the three exposure groups, except for lower education levels in the medium exposure group and a slightly higher proportion of high exposure participants having experienced multiple traumatic life-events.

Longitudinal Model of Event-Related Psychological Distress

As illustrated in Figure 2, IES-R total scores had increased at the R2 survey compared with corresponding scores from R1, with the upward change in scores evident across all exposure groups. The median IES-R total score increased by 2 points in the low exposure group, by 4 points in the medium exposure group, and by 6 points in the high exposure group (see Table S2 in the supplement). Similar patterns were observed for the IES-R subscales (see Figure 3 and Table S2).

Table 2 presents the results of the linear mixed-effects models for the IES-R total score, which included an interaction between age during the mine fire and fire-related PM_{2.5} exposure. Coefficients presented are the mean change in IES-R total scores. After adjusting for exposure level and other confounding factors, participants' IES-R total scores increased on average by 2.6 points (95% CI: 1.2 to 3.9 points) from R1 to R2.

For each 10 µg/m³ increase in mean PM_{2.5} exposure, there was an estimated 1.0-point increase in IES-R total score (95% CI: 0.0 to 1.9 points) at the cohort mean age during the mine fire, 48.7 years. This exposure—outcome relationship was not found to have attenuated or strengthened at the R2 survey (the interaction between PM_{2.5} exposure and survey round was not associated with the outcome, ($p = 0.48$) and not included in the final model).

The exposure—outcome relationship did vary by age (a strong interaction between PM_{2.5} exposure and age, $p = 0.05$). The effect of fire-related PM_{2.5} exposure was strongest for adults who

were younger at the time of the mine fire, moderate for those around the cohort average age during the mine fire, and least for those who were older. This is illustrated in Figure 4, which shows predicted IES-R total scores for people who were aged 25, 45, and 65 years at the time of the mine fire. For every 10 $\mu\text{g}/\text{m}^3$ increase in average daily $\text{PM}_{2.5}$ exposure, IES-R total scores increased by 2.2 points (95%CI: 0.6, 3.9) on average for participants aged 25 years, by 1.2 points (95%CI: 0.2, 2.2) for participants aged 45 years, compared with 0.1 points (95%CI: -1.1, 1.3) for participants aged 65 years.

Other covariates associated with a higher IES-R total score were self-reported diagnosis of asthma, self-reported COPD, having experienced multiple traumatic events, and being unemployed or unable to work. Having a certificate or tertiary qualification was observed to have a protective association with IES-R total score in comparison with having an education level of Year 10 or below. There was no evidence that IES-R total score was associated with past cardiovascular event(s) or mental illness diagnosed prior to the mine fire.

Longitudinal Model of Intrusion, Avoidance, and Hyperarousal Symptoms

Table 3 shows the results of the linear mixed-effects models for the three IES-R subscales. Mean scores increased from R1 to R2 for each subscale. The largest change found was for the intrusion subscale scores, which increased on average by 1.3 points (95%CI: 0.8 to 1.9 points) after accounting for exposure and other confounding factors. In line with the IES-R total score model, younger age was also found to be associated with higher levels of intrusion symptoms. For each 10-year step younger from the average participant age during the mine fire, the impact of mean mine fire-related $\text{PM}_{2.5}$ exposure on intrusion subscale scores increased on average by 0.3 points (95%CI: 0.1 to 0.5 points). The estimated exposure-outcome relationship for ages 25, 45, and 65 years is shown for each of the subscales in Figure 5. A similar pattern was observed for the avoidance and hyperarousal subscales, though to a lesser degree. Associations with the other covariates (asthma; COPD; prior traumatic events; employment status; education level) were also evident across each of the subscales.

Sensitivity Analyses

Table S3 presents sensitivity analyses for (1) imputed and unweighted mixed-effects regression model, (2) unimputed and unweighted mixed-effects regression model, and (3) unimputed and unweighted mixed-effects regression with log-transformed outcomes. The findings were consistent across all models, suggesting the robustness of the main results.

Table 1*Cohort Characteristics, Categorised by PM_{2.5} Exposure Group, at the R1 Survey¹*

Parameters ^{2, 3}	Low exposure N = 248	Medium exposure N = 236	High exposure N = 225	Total	p-value
Mean age during the mine fire (SD)	50.0 (17.7)	46.3 (18.4)	50.0 (17.2)	48.7 (17.9)	0.10
Male	104 (45%)	108 (48%)	107 (50%)	319 (47%)	0.53
Highest education level					
Secondary up to year 10	54 (27%)	62 (34%)	38 (20%)	154 (27%)	0.01
Secondary year 11-12	48 (21%)	59 (26%)	57 (27%)	164 (24%)	
Certificate, university or other tertiary degree	141 (53%)	108 (41%)	127 (53%)	376 (49%)	
Employment status					
Paid employment	136 (51%)	126 (49%)	129 (52%)	391 (51%)	0.29
Other: “student”; “volunteer”; “home-duties”; “retired”	86 (39%)	68 (34%)	67 (34%)	221 (36%)	
Unemployed or unable to work	23 (10%)	37 (17%)	29 (14%)	89 (13%)	
Asthma	76 (30%)	74 (31%)	60 (27%)	210 (30%)	0.66
COPD	9 (4%)	9 (6%)	12 (7%)	30 (5%)	0.53
Cardiovascular events⁴	41 (19%)	39 (19%)	43 (20%)	123 (20%)	0.98
Anxiety prior to 2014	60 (23%)	61 (27%)	57 (26%)	178 (26%)	0.69
Depression prior to 2014	57 (23%)	56 (24%)	64 (29%)	177 (26%)	0.32
PTSD prior to 2014	12 (5%)	11 (5%)	13 (5%)	36 (5%)	0.96
Any mental health diagnosis prior to 2014¹	78 (31%)	76 (33%)	81 (37%)	235 (34%)	0.48
Number of traumatic life-events					
None	83 (33%)	83 (35%)	63 (27%)	229 (32%)	0.06
One	60 (24%)	50 (20%)	36 (16%)	146 (20%)	
Multiple	105 (43%)	100 (45%)	125 (56%)	330 (48%)	

¹Prior mental health based on R1 survey responses with additional correction utilising R2 survey responses, where participants had entered further information about their mental health history.

²Missing data (%): education was missing for 15 participants (2.1%); employment was missing for 8 (1.1%); asthma was missing for 2 (0.3%); cardiac was missing for 8 (1.1%); anxiety was missing for 2 (0.3%); depression was missing for 2 (0.3%); PTSD was missing for 3 (0.4%); and traumatic life events was missing for 4 (0.6%).

³Statistics presented are number of participants (weighted %) and weighted mean (SD), with weighted chi-square tests performed for categorical variables and weighted ANOVA performed for continuous variables.

⁴Self-reported heart attack, heart failure, angina, irregular heart rhythm, stroke or other heart disease collected in the R1 survey.

Figure 2

Distribution of IES-R Total Scores, Categorised by PM_{2.5} Exposure Group, at Each Survey Round

Figure 3

Distribution of IES-R Subscale Scores, Categorised by PM_{2.5} Exposure Group, at Each Survey Round

Note. Hyperarousal scores have been scaled (by multiplying 8/6) to enable direct comparison with scores for the other subscales.

Table 2*Linear Mixed-Effects Model for IES-R Total Scores*

Risk factors at R1	IES-R total score	
	Coefficient ⁴ (95% CI)	p-value
Mean exposure to mine fire-related PM_{2.5} (per 10 µg/m ³ ; at the mean age during the mine fire of 48.7 years) ¹	1.0 (0.0, 1.9)	0.048
Survey round (0 = R1; 1 = R2)	2.6 (1.3, 3.9)	<0.001
Age during the mine fire (per 10 years; at a PM_{2.5} exposure level of 10 µg/m³)²	0.3 (-0.6, 1.3)	0.49
Interaction between PM_{2.5} exposure and age³	-0.5 (-1.1, 0.0)	0.050
Mental health conditions prior to 2014	1.3 (-1.2, 3.7)	0.32
Male	0.3 (-1.8, 2.4)	0.80
Cardiovascular event	1.5 (-1.9, 4.9)	0.39
Asthma	2.6 (0.3, 5.0)	0.030
COPD	7.4 (0.7, 14.2)	0.031
Number of traumatic life-events		
None	Ref	
One	1.3 (-1.4, 4.1)	0.33
Multiple	4.1 (1.6, 6.6)	0.001
Education level		
Secondary up to Year 10	Ref	
Secondary Year 11-12	-3.3 (-7.0, 0.5)	0.09
Certificate, university, or other tertiary degree	-5.4 (-8.4, -2.3)	<0.001
Employment status		
Paid employment	Ref	
Other: “student”; “volunteer”; “home-duties”; “retired”	1.7 (-1.3, 4.8)	0.27
Unemployed or unable to work	5.4 (1.3, 9.4)	0.010

¹ Mean PM_{2.5} exposure was centred at 10 µg/m³ and divided by 10 to give exposure units per 10 µg/m³.² Age during the mine fire was centred at mean age, 48.7 years, and divided by 10 to give age in 10-year units.³ The increase in the exposure effect per each 10-year increase in age.⁴ Coefficients were estimated from multivariate weighted mixed-effects regression with missing data imputed (see methods).

Table 3

Linear Mixed-Effects Models for IES-R Subscale Scores

Risk factors at R1	Intrusion		Avoidance		Hyperarousal ⁵	
	Coefficient ⁴ (95% CI)	p-value	Coefficient ⁴ (95% CI)	p-value	Coefficient ⁴ (95% CI)	p-value
Mean exposure to mine fire-related PM_{2.5} (per 10 µg/m³; at the mean age during the mine fire of 48.7 years)¹	0.5 (0.1, 0.9)	0.012	0.4 (0.0, 0.7)	0.037	0.1 (-0.2, 0.5)	0.45
Survey round (0 = R1; 1 = R2)	1.3 (0.8, 1.9)	<0.001	0.8 (0.3, 1.3)	0.002	0.7 (0.1, 1.2)	0.014
Age during the mine fire (per 10 years; at a PM_{2.5} exposure level of 10 µg/m³)²	0.2 (-0.2, 0.5)	0.40	0.2 (-0.2, 0.5)	0.33	0.0 (-0.4, 0.4)	0.98
Interaction between PM_{2.5} exposure and age³	-0.3 (-0.5, -0.0)	0.018	-0.2 (-0.4, 0.0)	0.053	-0.1 (-0.3, 0.1)	0.28
Mental health conditions prior to 2014	0.6 (-0.3, 1.6)	0.19	0.3 (-0.6, 1.2)	0.56	0.5 (-0.5, 1.4)	0.32
Male	0.4 (-0.5, 1.2)	0.40	-0.2 (-1.0, 0.5)	0.53	0.2 (-0.6, 1.0)	0.65
Cardiac event	0.7 (-0.6, 1.9)	0.33	0.3 (-1.0, 1.5)	0.67	0.8 (-0.6, 2.1)	0.28
Asthma	1.0 (0.0, 1.9)	0.041	0.8 (-0.0, 1.7)	0.053	1.1 (0.2, 2.1)	0.022
COPD	2.1 (-0.4, 4.6)	0.104	2.4 (0.0, 4.8)	0.049	3.9 (1.1, 6.7)	0.006
Number of traumatic life-events						
None	Ref		Ref		Ref	
One	0.3 (-0.7, 1.4)	0.54	0.4 (-0.6, 1.4)	0.40	0.8 (-0.3, 1.9)	0.15
Multiple	1.6 (0.6, 2.5)	0.002	1.4 (0.5, 2.2)	0.003	1.6 (0.7, 2.6)	0.001
Education level						
Secondary up to Year 10	Ref		Ref		Ref	
Secondary Year 11-12	-1.2 (-2.7, 0.2)	0.10	-1.1 (-2.4, 0.2)	0.09	-1.3 (-2.8, 0.2)	0.10
Certificate, university, or other tertiary degree	-1.9 (-3.1, -0.7)	0.002	-1.7 (-2.7, -0.6)	0.002	-2.4 (-3.6, -1.2)	<0.001
Employment status						
Paid employment	Ref		Ref		Ref	
Other: “student”; “volunteer”; “home-duties”; “retired”	0.7 (-0.6, 1.9)	0.28	0.4 (-0.6, 1.5)	0.45	0.8 (-0.3, 2.0)	0.17
Unemployed or unable to work	2.1 (0.5, 3.6)	0.01	1.6 (0.2, 2.9)	0.025	2.3 (0.6, 4.0)	0.007

¹ Mean PM_{2.5} exposure was centred at 10 µg/m³ and divided by 10 to give exposure units per 10 µg/m³.

² Age during the mine fire was centred at mean age, 48.7 years, and divided by 10 to give age in 10-year units.

³ The increase in the exposure effect per each 10-year increase in age.

⁴ Coefficients were estimated from multivariate weighted mixed-effects regression with missing data imputed (see methods).

⁵ Hyperarousal scores have been scaled (multiplied by 8/6) to enable direct comparison with scores for the other subscales.

Figure 4

Age-Dependence of the Relationship between $PM_{2.5}$ Exposure and IES-R Total Scores

Figure 5

Age-Dependence of the Relationships between $PM_{2.5}$ Exposure and IES-R Subscale Scores

(A) Intrusion

(B) Avoidance

(C) Hyperarousal

Note. Hyperarousal scores have been scaled (by a factor of 8/6) to enable direct comparison with scores for the other subscales.

Discussion

This paper reported a longitudinal adult cohort study examining the impacts of the Hazelwood mine fire. The main finding was that a dose-response relationship between participants' level of exposure to PM_{2.5} during the 2014 Hazelwood mine fire and the psychological distress they attributed to that event is still evident six years later. In addition, the level of distress associated with the mine fire was found to have increased over the three years since the R1 survey. Once again, younger adults reported higher levels of ongoing distress in response to their exposure to the mine fire, now six years in the past. This interaction between exposure and age was stronger for the intrusion subscale. Also consistent with R1 results, greater event-related distress at R2 was associated with asthma, COPD, multiple prior traumatic events, and being unemployed or unable to work.

The overall increase in event-related distress between the two survey rounds contrasts with previous bushfire studies in Australia, which have reported decreasing levels of distress over time (Bryant et al., 2018; Bryant et al., 2014; McFarlane et al., 1997). The finding also contrasts with HHS qualitative research conducted prior to and in the year following the 2019-2020 Black Summer fires. In qualitative research by Maybery et al. (2020) in the year after the Adult Survey, the majority of participants (22/26) reported that they were not experiencing symptoms of intrusion, avoidance, and/or arousal as a result of the mine fire.

A potential explanation for why mine fire-related distress increased overall in the cohort at R2 is that it may be attributable to exposure to the Black Summer bushfire event which coincided with the data collection period. Previous research indicates that posttraumatic distress symptoms are most likely to present when situations reminiscent of the initial traumatising experience are encountered (Ehlers et al., 2004; Layne et al., 2006; Marks et al., 2018; McFarlane, 2010). Hence, because data collection period overlapped with a major smoke event and extensive media coverage about the fires, there was potential for mine fire-related distress to have been triggered at the time of the survey. In this light, it is interesting that the intrusive symptom domain was prominent amongst the results, both in terms of the increase of this symptom type between rounds and its continuing association with exposure to

PM_{2.5} from the Hazelwood mine fire. Exposure to a traumatic event may lead to the development of memories and fear-conditioning that render an impacted person sensitive to re-experiencing distress following additional events (McFarlane, 2010). In line with the sensitisation effect described by McFarlane (2010), it is plausible that the Black Summer bushfires triggered intrusive memories associated with the earlier Hazelwood mine fire event, in particular, among our cohort exposed to both events.

The increasing frequency at which environmental disasters such as bushfires are occurring means that people living in areas prone to these types of events are vulnerable to recurrent exposure, which adds to the complexity of measuring and understanding levels of event-related distress and trauma. While we did not set out to assess the impact of a subsequent smoke event on distress associated with an earlier event, our findings suggest that the new event activated a sensitivity that has developed within this community, associated with exposure to the Hazelwood mine fire. We are not aware of any research that has explicitly examined the impact of exposure to multiple smoke events, so there is a clear need for research to address this knowledge gap. Regardless, our findings emphasise the need for targeted mental health screening in disaster-prone communities that takes into consideration the potential impact of accumulated exposures. In addition, this research identifies other risk factors for increased distress, including younger people being more vulnerable.

Strengths and Limitations

This research has considerable strengths. Rather than relying on population-level pollution data, the current analysis utilised an individual-level PM_{2.5} exposure estimate. This was a much more precise estimate of exposure that is largely free from the influence of the individual's perception of the exposure (Glass & Sim, 2006). Additional strengths of this research include the large cohort recruited for R1, the strong recruitment rate for R2, and multivariate modelling that accounted for the impacts of other risk factors relevant to psychological distress, such as asthma, prior mental health diagnoses, and prior traumatic exposures.

However, there are also limitations to this research, including the potential for participant recall bias in the self-reported time-location information from the R1 survey, particularly given that this information was collected more than two years after the mine fire (Coughlin, 1990). Furthermore, there are well-recognised limitations to self-report data more generally (Althubaiti, 2016). It is possible that selection bias may persist even after the application of sample weighting in the research design and response weighting in the statistical analyses. However, sensitivity analyses showed consistency between results with or without response weighting and multiple imputation, suggesting our findings were fairly robust to potential bias.

While the coincidental timing of the R2 survey with the Black Summer bushfires provided insights into the possible impacts of a new event on the experience of distress arising from a previous event, we were unable to say what the ongoing distress levels would have been in the absence of this event; a further round of surveys is planned, which will shed further light on the longer-term trajectory of event-related distress. In addition, as the survey was designed and launched without foreknowledge of the impending local environmental conditions that would result from the Black Summer bushfires, we were not positioned to capture information on individual participants' exposure to PM_{2.5} during this event. Further research is planned to investigate the relationship between the Black Summer bushfire-related PM_{2.5} exposure and attribution of distress to the earlier mine fire event.

Conclusions

The key messages are that higher levels of exposure to PM_{2.5} during an extended mine fire were associated with greater psychological distress in relation to the event some six years later, and that the level of distress increased between the two survey rounds. Furthermore, it is plausible that this increase in distress was due in some part to the experience of a new smoke event at the time of the survey which triggered recall of the earlier mine fire in an already sensitised population. We recommend that public health agencies include warnings that people who have experienced similar events in the past may experience increased psychological distress in response to new events and that they should seek support if needed. This is particularly important given that the likelihood of residents in disaster-prone

communities experiencing multiple disaster events is increasing due to climate change. In addition, the finding that multiple risk factors were associated with greater event-related psychological distress suggests that a more nuanced approach could be taken to identifying and supporting vulnerable groups in the aftermath of disaster. This need was reinforced by finding that younger adults appeared to be at greater risk of psychological distress following disaster.

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References

- Althubaiti, A. (2016). Information bias in health research: Definition, pitfalls, and adjustment methods. *Journal of Multidisciplinary Healthcare*, 9, 211-217.
<https://doi.org/10.2147/JMDH.S104807>
- Australian Bureau of Statistics. (2016). *2016 Census QuickStats (Gippsland)*. Commonwealth of Australia.
[https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/CE215#:~:text=In%20the%202016%20Census%2C%20there,up%201.9%25%20of%20the%20population.&text=The%20median%20age%20of%20people,Electoral%20Divisions\)%20was%2044%20years](https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/CE215#:~:text=In%20the%202016%20Census%2C%20there,up%201.9%25%20of%20the%20population.&text=The%20median%20age%20of%20people,Electoral%20Divisions)%20was%2044%20years)
- Broder, J. C., Gao, C. X., Campbell, T. C. H., Berger, E., Maybery, D., McFarlane, A., Tsoutsoulis, J., Ikin, J. F., Abramson, M. J., Sim, M. R., Walker, J., A, L., & Carroll, M. (2020). The factors associated with distress following exposure to smoke from an extended coal mine fire. *Environmental Pollution*, 115131. <https://doi.org/10.1016/j.envpol.2020.115131>
- Bryant, R. A. (2019). Post-traumatic stress disorder: A state-of-the-art review of evidence and challenges. *World Psychiatry*, 18(3), 259-269. <https://doi.org/10.1002/wps.20656>
- Bryant, R. A., Gibbs, L., Gallagher, H. C., Pattison, P., Lusher, D., MacDougall, C., Harms, L., Block, K., Sinnott, V., & Ireton, G. (2018). Longitudinal study of changing psychological outcomes following the Victorian Black Saturday bushfires. *Australian & New Zealand Journal of Psychiatry*, 52(6), 542-551. <https://doi.org/10.1177%2F0004867417714337>
- Bryant, R. A., Waters, E., Gibbs, L., Gallagher, H. C., Pattison, P., Lusher, D., MacDougall, C., Harms, L., Block, K., & Snowdon, E. (2014). Psychological outcomes following the Victorian Black Saturday bushfires. *Australian & New Zealand Journal of Psychiatry*, 48(7), 634-643. <https://doi.org/10.1177/0004867414534476>
- Chen, Q., Gelman, A., Tracy, M., Norris, F. H., & Galea, S. (2012). *Weighting adjustments for panel nonresponse*. Columbia University.
<https://stat.columbia.edu/gelman/research/unpublished/weighting%20adjustments>
- Coughlin, S. S. (1990). Recall bias in epidemiologic studies. *Journal of Clinical Epidemiology* 43, 87-91. [https://doi.org/10.1016/0895-4356\(90\)90060-3](https://doi.org/10.1016/0895-4356(90)90060-3)
- Davey, S. M., & Sarre, A. (2020). Editorial: The 2019/20 Black Summer bushfires. *Australian Forestry*, 83(2), 47-51. <https://doi.org/10.1080/00049158.2020.1769899>

- Ehlers, A., Hackmann, A., & Michael, T. (2004). Intrusive re-experiencing in post-traumatic stress disorder: Phenomenology, theory, and therapy. *Memory*, 12(4), 403-415.
<https://doi.org/10.1080/09658210444000025>
- Glass, D. C., & Sim, M. R. (2006). The challenges of exposure assessment in health studies of Gulf War veterans. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 361(1468), 627-637. <https://doi.org/10.1098/rstb.2006.1822>
- Hughes, L., Rickards, L., Steffen, W., Stock, P., & Rice, M. (2016). *On the Frontline: Climate change and rural communities*. Climate Council of Australia.
<https://www.climatecouncil.org.au/resources/ruralreport/>
- Ikin, J., Carroll, M., Walker, J., Borg, B., Brown, D., Cope, M., Del Monaco, A., Dennekamp, M., Dimitriadis, C., Gao, C. X., Guo, Y., Johnston, F., Liew, D., Maybery, D., Thompson, B. R., Sim, M., & Abramson, M. J. (2020). Cohort Profile: The Hazelwood Health Study Adult Cohort. *International Journal of Epidemiology*, 49(6), 1777–1778.
<https://doi.org/10.1093/ije/dyaa083>
- Layne, C. M., Warren, J. S., Saltzman, W. R., Fulton, J. B., Steinberg, A. M., & Pynoos, R. S. (2006). Contextual influences on posttraumatic adjustment: Retraumatization and the roles of revictimization, posttraumatic adversities, and distressing reminders. In L. A. Schein, H. I. Spitz, G. M. Burlingame, P. R. Muskin, & S. Vargo (Eds.), *Psychological effects of catastrophic disasters* (1st ed., pp. 235-286). Routledge.
<https://doi.org/10.4324/9781315821306>
- Leaning, J., & Guha-Sapir, D. (2013). Natural disasters, armed conflict, and public health. *New England Journal of Medicine*, 369(19), 1836-1842. <https://doi.org/10.1056/NEJMc1315507>
- Luhar, A. K., Emmerson, K. M., Reisen, F., Williamson, G. J., & Cope, M. E. (2020). Modelling smoke distribution in the vicinity of a large and prolonged fire from an open-cut coal mine. *Atmospheric Environment*, 229, 117471. <https://doi.org/10.1016/j.atmosenv.2020.117471>
- Marks, E. H., Franklin, A. R., & Zoellner, L. A. (2018). Can't get it out of my mind: A systematic review of predictors of intrusive memories of distressing events. *Psychological Bulletin*, 144(6), 584-640. <https://doi.org/10.1037/bul0000132>
- Maybery, D., Jones, R., Dipnall, J. F., Berger, E., Campbell, T., McFarlane, A., & Carroll, M. (2020). 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*, 33(2), 216-230. <https://doi.org/10.1080/10615806.2019.1695523>

- McFarlane, A. C. (1988). The longitudinal course of posttraumatic morbidity: The range of outcomes and their predictors. *Journal of Nervous and Mental Disease*, 176, 30-39.
<https://doi.org/10.1097/00005053-198801000-00004>
- McFarlane, A. C. (2010). The long-term costs of traumatic stress: intertwined physical and psychological consequences. *World Psychiatry*, 9, 3-10.
<https://doi.org/10.1002/j.2051-5545.2010.tb00254.x>
- McFarlane, A. C., Clayer, J., & Bookless, C. (1997). Psychiatric morbidity following a natural disaster: An Australian bushfire. *Social Psychiatry and Psychiatric Epidemiology*, 32(5), 261-268. <https://doi.org/10.1007/BF00789038>
- Norris, F. H., Friedman, M. J., & Watson, P. J. (2002). 60,000 disaster victims speak: Part II. Summary and implications of the disaster mental health research. *Psychiatry: Interpersonal and Biological Processes*, 65(3), 240-260. <https://doi.org/10.1521/psyc.65.3.240.20169>
- North, C. S., Pfefferbaum, B., Kawasaki, A., Lee, S., & Spitznagel, E. L. (2011). Psychosocial adjustment of directly exposed survivors 7 years after the Oklahoma City bombing. *Comprehensive Psychiatry*, 52, 1-8. <https://doi.org/10.1016/j.comppsy.2010.04.003>
- Paxson, C., Fussell, E., Rhodes, J., & Waters, M. (2012). Five years later: Recovery from post traumatic stress and psychological distress among low-income mothers affected by Hurricane Katrina. *Social Science & Medicine*, 74(2), 150-157.
<https://doi.org/10.1016/j.socscimed.2011.10.004>
- Royston, P., & White, I. R. (2011). Multiple imputation by chained equations (MICE): Implementation in Stata. *Journal of Statistical Software*, 45(4), 1-20.
<https://doi.org/10.18637/jss.v045.i04>
- Rubin, D. B. (1996). Multiple Imputation After 18+ Years. *Journal of the American Statistical Association*, 91(434), 473-489. <https://doi.org/10.2307/2291635>
- Teague, B., Catford, E. J., & Petering, S. (2014). *The Hazelwood Mine Fire Inquiry Report (parliamentary paper No. 342)*. Victorian Government Printer.
https://www.parliament.vic.gov.au/file_uploads/8101_HAZ_Hazelwood_Mine_Inquiry_Report_BOOK_LR_f5Bp6wNh.pdf
- Vardoulakis, S., Marks, G., & Abramson, M. J. (2020). Lessons learned from the Australian bushfires: Climate change, air pollution, and public health. *JAMA Internal Medicine*, 180(5), 635-636. <https://doi.org/10.1001/jamainternmed.2020.0703>

- Weiss, D. S., & Marmar, C. R. (1997). The Impact of Event Scale-Revised. In J. P. Wilson & T. M. Keane (Eds.), *Assessing psychological trauma and PTSD* (pp. 399-411). Guilford Press.
- Wood, P. J., Duffy, M., Yell, S., Morrissey, B., Whyte, S., Walker, L., Carroll, M., & Maybery, D. (2015). *Coal mine fire initial impact on community health and wellbeing summary report*. Federation University Australia.

Supplement

Table S1

Comparison of Responders to Non-responders

	Unweighted comparison			Weighted comparison using derived response weights		
	Non-responders	Responders		Non-responders	Responders	
Risk factors at R1	N=803	N=709	<i>p-value</i>	N=803	N=709	<i>p-value</i>
Age during mine fire, weighted mean (SD)	50.9 (19.0)	46.9 (17.0)	<0.001	50.9 (19.0)	48.7 (17.9)	0.035
Male	387 (48%)	319 (45%)	0.20	387 (48%)	319 (47%)	0.74
Mean exposure to PM2.5, weighted mean (SD)	15.0 (11.0)	14.8 (10.9)	0.69	15.0 (11.0)	14.9 (11.0)	0.88
Married/De facto	463 (58%)	429 (61%)	0.28	463 (58%)	429 (59%)	0.68
Employment at each survey, n (%)						
Paid employment (FT, PT, self-employed)	373 (47%)	391 (56%)	0.005	373 (47%)	391 (51%)	0.45
Other (student/volunteer/home-duties/retired)	305 (39%)	221 (32%)		305 (39%)	221 (36%)	
Unemployed/unable to work	110 (14%)	89 (13%)		110 (14%)	89 (13%)	
Education level at each survey, n (%)						
Secondary up to year 10	245 (31%)	154 (22%)	<0.001	245 (31%)	154 (27%)	0.10
Secondary year 11-12	207 (26%)	164 (24%)		207 (26%)	164 (24%)	
Certificate, University or other Tertiary Institute degree	339 (43%)	376 (54%)		339 (43%)	376 (49%)	
General health, n (%)						
Excellent/Very good	298 (37%)	303 (43%)	0.053	298 (37%)	303 (40%)	0.60
Good	276 (35%)	239 (34%)		276 (35%)	239 (34%)	
Fair/Poor	224 (28%)	166 (23%)		224 (28%)	166 (26%)	
Smoking status, n (%)						
Current smoker	161 (20%)	107 (15%)	0.011	161 (20%)	107 (18%)	0.52
Former smoker	226 (29%)	183 (26%)		226 (29%)	183 (27%)	
Occasional	18 (2%)	17 (2%)		18 (2%)	17 (2%)	
Never	381 (48%)	399 (57%)		381 (48%)	399 (52%)	
Drinking risk based on AUDIT-C score for all participants, n (%)						
Non-drinker	204 (27%)	158 (23%)	0.010	204 (27%)	158 (25%)	0.38
Low Risk	254 (33%)	286 (41%)		254 (33%)	286 (37%)	
High Risk	301 (40%)	249 (36%)		301 (40%)	249 (38%)	
Index of Relative Socio-economic Advantage & Disadvantage - Score, mean (SD)	860.4 (91.8)	867.2 (97.2)	0.19	860.4 (91.8)	862.9 (98.3)	0.63

Table S2

Distribution of IES-R Scores and IES-R Subscale Scores, Categorised by PM_{2.5} Exposure Group, at Each Study Round

Psychological distress measures	Round 1 (2016-2017 Adult Survey)					Round 2 (2019-2020 Mental Health and Wellbeing Survey)				
	Low exposure	Medium exposure	High exposure	Total	p-value	Low exposure	Medium exposure	High exposure	Total	p-value
	N = 248	N = 236	N = 225			N = 248	N = 236	N = 225		
	Mean (SD) ²	Mean (SD)	Mean (SD)	Mean (SD)		Mean (SD) ²	Mean (SD)	Mean (SD)	Mean (SD)	
IES-R total score	7.7 (13.3)	10.1 (15.8)	11.2 (15.7)	9.7 (15.1)	0.05	10.6 (15.8)	14.0 (18.6)	13.6 (14.8)	12.7 (16.6)	0.08
Intrusion	3.0 (5.1)	4.0 (6.1)	4.7 (6.3)	3.9 (5.9)	0.009	4.4 (6.3)	5.9 (7.4)	5.8 (6.1)	5.3 (6.7)	0.040
Avoidance	2.7 (4.8)	3.6 (6.0)	3.9 (5.8)	3.4 (5.6)	0.07	3.6 (5.5)	4.7 (6.5)	4.9 (5.3)	4.4 (5.8)	0.043
Hyperarousal ³	3.1 (6.1)	3.6 (6.2)	3.9 (6.4)	3.5 (6.2)	0.55	3.7 (6.3)	4.7 (7.4)	4.1 (6.0)	4.2 (6.6)	0.34
	Median (IOR) ²	Median (IQR)	Median (IQR)	Median (IQR)		Median (IOR) ²	Median (IQR)	Median (IQR)	Median (IQR)	
IES-R total score	1 (0-9)	2 (0-13)	3 (0-16)	2 (0-13)	0.024	3 (0-16)	6 (1-20)	9 (1-22)	6 (0-19)	0.007
Intrusion	1 (0-4)	1 (0-7)	2 (0-7)	1 (0-6)	0.007	1 (0-6)	3 (0-8)	4 (0-10)	3 (0-8)	0.008
Avoidance	0 (0-4)	0 (0-5)	1 (0-6)	0 (0-5)	0.06	1 (0-5)	1 (0-7)	3 (0-8)	2 (0-7)	0.008
Hyperarousal ³	0 (0-3)	0 (0-4)	0 (0-5)	0 (0-4)	0.30	0 (0-5)	1 (0-7)	1 (0-7)	0 (0-7)	0.23

¹Missing data (%) were as follows: for each IES-R item missing observations ranged from 0.6% to 1.7% of the study sample (709) in R1 and 0% to 1.1% in R2; IES-R total was missing values for 32 participants (4.5%) in R1 and 22 (3.1%) in R2; Intrusion was missing for 21 (3.0%) in R1 and 10 (1.4%) in R2; Avoidance was missing for 26 (3.7%) in R1 and 18 (2.5%) in R2; Hyperarousal was missing for 13 (1.8%) in R1 and 9 (1.3%) in R2.

²Statistics presented are weighted mean (SD) and weighted median (IQR). Statistical tests performed: weighted ANOVA when mean (SD) is reported; and weighted ANOVA with log-transformed outcome when median (IQR) is reported.

³Hyperarousal scores have been scaled (by multiplying 8/6) to enable direct comparison with scores for the other subscales.

Table S3

Sensitivity Analysis of Linear Mixed-Effects Model Results for IES-R Total Scores

Risk factors at R1	Imputed & unweighted		Unimputed & unweighted		Log-transformed	
	Coefficient ⁴ (95% CI)	<i>p</i> -value	Coefficient ⁴ (95% CI)	<i>p</i> -value	Coefficient ⁴ (95% CI)	<i>p</i> -value
Mean exposure to mine fire-related PM_{2.5} (per 10 µg/m³; at the mean age during the mine fire of 48.7 years)¹	1.1 (0.2, 2.0)	0.022	1.0 (0.1, 1.9)	0.033	0.14 (0.05, 0.23)	0.002
Survey round (0 = R1; 1 = R2)	2.7 (1.6, 3.9)	<0.001	2.8 (1.6, 4.0)	<0.001	0.34 (0.24, 0.44)	<0.001
Age during the mine fire (per 10 years; at a PM_{2.5} exposure level of 10 µg/m³)²	0.5 (-0.4, 1.3)	0.30	0.4 (-0.5, 1.3)	0.34	0.07 (-0.01, 0.14)	0.09
Interaction between PM_{2.5} exposure and age³	-0.5 (-1.0, 0.0)	0.06	-0.5 (-1.0, 0.0)	0.053	-0.06 (-0.11, -0.00)	0.044
Mental health conditions prior to 2014	1.5 (-0.8, 3.8)	0.19	1.9 (-0.3, 4.2)	0.09	0.18 (-0.02, 0.38)	0.08
Male	0.0 (-1.9, 2.0)	0.97	0.1 (-1.8, 2.1)	0.89	-0.03 (-0.20, 0.15)	0.76
Cardiac event	1.0 (-2.0, 4.1)	0.52	0.5 (-2.5, 3.4)	0.74	-0.03 (-0.29, 0.22)	0.79
Asthma	2.0 (-0.2, 4.2)	0.08	1.5 (-0.7, 3.6)	0.19	0.19 (-0.00, 0.39)	0.06
COPD	8.0 (1.3, 14.7)	0.02	10.3 (3.0, 17.5)	0.005	0.59 (0.09, 1.10)	0.021
Number of traumatic life-events						
None	Ref		Ref		Ref	
One	1.0 (-1.5, 3.6)	0.42	0.7 (-1.9, 3.3)	0.59	0.11 (-0.14, 0.36)	0.37
Multiple	3.7 (1.3, 6.0)	0.002	3.0 (0.6, 5.3)	0.013	0.38 (0.17, 0.60)	<0.001
Education level						
Secondary up to Year 10	Ref		Ref		Ref	
Secondary Year 11-12	-3.1 (-6.8, 0.5)	0.09	-2.3 (-5.9, 1.4)	0.23	-0.19 (-0.49, 0.11)	0.21
Certificate, university, or other tertiary degree	-5.1 (-8.2, -2.0)	0.001	-4.3 (-7.4, -1.2)	0.006	-0.31 (-0.57, -0.06)	0.015
Employment status						
Paid employment	Ref		Ref		Ref	
Other: “student”; “volunteer”; “home-duties”; “retired”	1.4 (-1.5, 4.3)	0.34	1.6 (-1.3, 4.4)	0.28	0.11 (-0.14, 0.35)	0.39
Unemployed or unable to work	5.6 (1.7, 9.5)	0.005	5.8 (2.0, 9.6)	0.003	0.40 (0.09, 0.71)	0.012

¹ Mean PM_{2.5} exposure was centred at 10 µg/m³ and divided by 10 to give exposure units per 10 µg/m³.² Age during the mine fire was centred at mean age, 48.7 years, and divided by 10 to give age in 10-year units.³ The increase in the exposure effect per each 10-year increase in age.⁴ Coefficients were estimated from multivariate weighted mixed-effects regression with missing data imputed using chained equations.⁵ Hyperarousal scores have been scaled (by multiplying 8/6) to enable direct comparison with scores for the other subscales.