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Health impacts of bushfire smoke exposure in Australia

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Abstract:

Smoke exposure from bushfires, such as those experienced in Australia 2019-2020, can reach levels up to 10 times those deemed hazardous. Short-term and extended exposure to high levels of air pollution can be associated with adverse health effects, although the most recent fires have brought into sharp focus that several important knowledge gaps remain. In this article, we briefly identify and discuss the existing Australian evidence base and make suggestions for future research.

Introduction

The disastrous Australian wildfire season in 2019-2020 has served to further propel the environmental and health impacts of climate change to the fore of public focus. As scientists and health professionals scramble to quantify and address the damage to affected communities and surrounding environments, it will be some time before the full health impacts of this current bushfire season are known. Over ten million people across three states have been intermittently covered by a blanket of thick smoke for months. In the past, the smoke from bushfires and controlled burns has generally been in the form of sporadic, short-term spikes in air pollutant concentrations. The current duration and scale of population exposure to bushfire pollution is unprecedented, but despite this, the existing literature can provide an indication of what important questions for public health agencies, emergency management authorities, and clinicians remain unresolved and are thus worthy of greater attention.

As part of a systematic review led by Walter et al. (Walter, 2020) a sub-set of epidemiological studies which identified the predominant pollution source as; vegetation fires, bushfires, forest fires and controlled burns, hereon referred to as landscape fire smoke (LFS) were identified. Given recent events, we sought to emphasise the main cardio-respiratory results identified in these Australian studies.

Respiratory impacts

All nine identified studies found significant associations between LFS and respiratory impacts, as measured by ambulance or hospital data, with the strongest effects observed on the day of exposure (Table 1).

A validated database used to distinguish days with high pollution resulting from LFS was used in two Sydney based studies to characterise the impacts of specific 'event' days rather than incremental pollutant increases (Johnston et al., 2014, Martin et al., 2013). Studies which compared impacts of background airborne particulate matter (PM) to that arising from fires (PM_{LFS}), found the latter to be associated with higher respiratory risk estimates (Salimi et al., 2017, Morgan et al., 2010, Chen et al., 2006), raising the potential for a differing or greater magnitude of cellular responses arising from the specific chemical composition unique to the particles in LFS.

Table 1. Australian LFS pollutant associations with total respiratory outcomes

Chronic obstructive pulmonary disease (COPD)

Four of the six studies found significant positive associations between smoke event days or PM_{LFS} and COPD hospital admissions or ED attendances (Table 2). Effects were strongest on the day of exposure, although one study reported persistent raised risk effects for up to three days in the elderly (>65 years) (Morgan et al., 2010). Interestingly, one study found a greater magnitude of effect in the 15 – 65-year age group compared to > 65 years (Johnston et al., 2014) and another found negative associations at lagged intervals of one to three days (lag 1-3) post exposure (Hanigan et al., 2008). These findings may be due to increased protective behaviours (less time spent outdoors) or the small study numbers and an inability to account for emergency department (ED) presentations not requiring hospital admission, respectively.

Table 2. Australian LFS pollutant associations with COPD

Asthma

All seven studies found strong significant associations between PM_{LFS} or smoke event days and asthma hospital admissions or ED attendances (Table 3). Australia has the second highest total population asthma prevalence rate of the Organisation for Economic Cooperation and Development (OECD) countries (Deloitte., 2015), which is likely to influence the strong associations observed between LFS and asthma impacts. As with other respiratory conditions, asthma impacts are greatest on the day of exposure; however lagged effects appear inconsistent, with three studies finding no associations at intervals of 2 – 3 days post-exposure (Haikerwal et al., 2016, Morgan et al., 2010, Hanigan et al., 2008) and the remaining studies reporting lagged associations (Johnston et al., 2014, Martin et al., 2013, Johnston et al., 2007, Johnston et al., 2002). The only study to examine beyond the 3-day interval found the highest risk estimates at five days post exposure (Johnston et al., 2002).

In sharp contrast to traffic association air pollution (TRAP) the asthma impacts of LFS were found to increase with age, with the lowest risk estimates for children, followed by adults and then elderly (Haikerwal et al., 2016, Morgan et al., 2010, Johnston et al., 2014). These counter-intuitive results are supported by a recent meta-analysis which found ED attendance increases with a 10 µg/m3 $PM2.5_{LFS}$ of fifteen per cent for elderly (95% CI, 1.1–1.2) compared to four per cent (95% CI, 1–1.08) for children (Borchers-Arriagada et al., 2019). The reasons for this remain unknown; however, it is likely that the high visibility of bushfire smoke compels protective behaviours of parents reducing children's exposure.

It is noteworthy that stratifying for gender revealed higher risks for adult females (Haikerwal et al., 2016). Additional differences may also present for atopy; a condition which also confers heightened vulnerability to TRAP, yet the $PM10_{LFS}$ associated reductions observed in peak expiratory flow in a small cohort of school children were only present in those without bronchial hyperactivity (Jalaludin et al., 2000).

Table 3. Australian LFS pollutant associations with asthma

Cardiovascular

The evidence across the ten included studies is mixed (Table 4). Cardiac arrests impacts appear to occur in the first 48 hours of exposure with greater effects seen in males (Dennekamp et al., 2015, Haikerwal et al., 2015), whereas ischaemic heart disease (IHD) impacts were observed at lagged exposure intervals of 2 – 3 days and were stronger in females (Haikerwal et al., 2015) and Indigenous Australians (Hanigan et al., 2008, Johnston et al., 2007).

Of the eight studies considering mortality, hospital admissions and ED attendances; five found no significant associations (Martin et al., 2013, Crabbe, 2012, Morgan et al., 2010, Hanigan et al., 2008), two found significant Ischaemic Heart Disease (IHD) associations at two days post exposure (Haikerwal et al., 2015, Johnston et al., 2014), and one found a significant IHD association three days post exposure, but only in the Indigenous study population (Johnston et al., 2007). Victorian ambulance data showed a strong association for Out of Hospital Cardiac Arrests (OHCA) in men (Haikerwal et al., 2015, Dennekamp et al., 2015), yet a Sydney-based study not separating for gender, found no significant increase in same day ambulance call outs for cardiac arrest (Salimi et al., 2017). There are similarities between these gender specific results and a Tasmanian study which found associations between reductions in wood heater smoke exposure and reduced cardio-vascular mortality only reached significance when restricting results to the male study population (Johnston et al., 2013). The high number of OHCAs that do not survive to the point of hospital admission (78.4% during the study period of Dennekamp et al, 2015) offer a potential explanation for the comparatively smaller and less consistent associations found in hospital *vs* ambulance data. Most of the comparable international epidemiological evidence is produced in North America, which has a greater prevalence of heart disease and reveals generally more positive and consistent associations between PM_{LFS} and cardiovascular ED attendances and hospital admissions (Liu et al., 2015).

Table 4. Australian LFS associations with cardiovascular disease

Composition of bushfire emissions

All anthropogenic air pollution is a complex mix of multiple air pollutants and air toxics. To date, most epidemiological evidence is generated from investigating the link between health outcomes and particulate matter (PM), probably because PM is markedly elevated during fires and is widely monitored around Australia. The size and specific chemical composition of PM will differ according to the source (e.g bushfire or traffic related), and this remains an area where further research is needed to understand the potential for composition-specific differences in health outcomes.

Temperature impacts

Unplanned bushfires tend to occur on days of extreme heat. Both heat and air pollution exert effects and when combined the total effect may be larger than the sum of individual effects. A recent Perth based study found a 6.6% joint additive effect of $PM2.5_{all}$ and heat waves on emergency department admissions (Patel et al., 2019).

Both heat and humidity can stimulate airway C-fibre nerves, triggering asthma symptoms and increasing airway resistance more rapidly than cold air (Bernstein and Rice, 2013). Each 1°C increase in the standard deviation of summertime temperatures is associated with a 5 – 7% increase in mortality for patients with COPD and other chronic diseases (Zanobetti et al., 2012). High temperatures and sunlight also catalyse the formation of ground level ozone from oxides of Nitrogen and volatile organic compounds (both also present in LFS). With climate forecasting increasing heatwaves and longer summers (Keywood, 2016), the impacts of ozone will increase accordingly.

Additional health and related economic impacts

The physical health impacts of LFS are likely to extend beyond the cardio-respiratory system. International evidence has revealed LFS associations with low birth weights (Holstius et al., 2012), and pro-inflammatory effects (Huttunen et al., 2012). A recent Australian study examining fire fighters' exposures during prescribed burns found that while the mercury concentrations were not high enough for mercury poisoning, the cumulative impacts remain largely unaccounted (MacSween et al., 2019).

The economic costs of bushfire health impacts are largely unaccounted for. An American study of the Reno/Sparks area of Nevada estimated the costs of the 2008 fire season to be $2.2 million (US) (95% CI; $1.1 – $3.4 million) (Moeltner et al., 2013). This cost estimate accounted only for a population of 350,000 it is reasonable to expect a much larger figure for the Australian bushfires in 2019-2020.

Suggestions for future research and public health strategies

Climate modelling demonstrates this devastating fire season may be a harbinger of future events. Measurable health impacts provide a focus that may avoid the conflated climate policy debate. Future research is required to ascertain the range and magnitude of health impacts associated with prolonged LFS exposure, sub-populations with heightened vulnerability and the patterns of disease presentation across various time intervals from exposure. This information would be useful in tailoring targeted messaging for preventative public health strategies and to assist in the preparedness of health services. Quantifying the economic burden associated with health impacts is a key element required to incentivise policy changes. Identifying which mitigation strategies are effective, such as an analysis on the commercially available air filters and other protective indoor ventilation measures would be useful. As controlled short-term burns are planned events which produce very high ground level pollutant concentrations, sensitive locations e.g. schools and childcare centres could receive prior warning that is useful in planning (e.g. limit sports outside on these days). Rest homes should be equipped with a 'smoke plan' that details appropriate preventative measures according to the concentration of smoke. The impacts of bushfire emissions are unique and differ to other sources of air pollution, therefore specific LFS risk co-efficients drawn from Australian literature would be useful for health impact analyses.

Finally, while the health impacts of LFS are significant and merit further research and implementation of mitigation strategies, it is important to acknowledge there are other large sources of outdoor air pollution in Australia including coal-fired power stations, vehicle emissions and wood heaters. The current bushfire season has raised the public awareness of LFS impacts, creating an opportunity for health and science experts to strongly advocate that reductions in all sources of air pollution will result in public health improvements.

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Study Reference	Location	Exposure	Outcome	Study Design	Significant results
Salimi, 2016	Sydney	10µg/m3 increase in PM2.5	Emergency Ambulance Dispatches (EAD) for breathing problems	Time series	Same day increases of 4% (RR=1.04, 95% CI 1.02 - 1.05). Compared to 3% (95% CI 1.02 – 1.04) for background PM
Johnston, 2014	Sydney	LFS event days	ED attendances	Case cross over	Same day increases of 7% (OR 1.07, 95% CI 1.04 - 1.10)
Martin, 2013	Sydney, Wollongong, Newcastle	LFS event days	Hospital admissions	Case cross over	Same day increases of 6% in Sydney (OR=1.06, 95%CI 1.02-1.09)
Crabbe, 2012	Darwin	10µg/m3 increase PM10 and fine particulate matter (FPM)	Hospital emergency admissions	Time series	Lag 1 (day after exposure) increases of 2.5% for PM10: (RR = 1.025, 95 %CI 1.000–1.051, p<0.05) and 9.1% for fine particles: (RR = 1.091, 95% CI 1.023–1.163, p<0.01)
Morgan, 2010	Sydney	10µg/m3 increase in PM10	Hospital admissions	Time Series	Same day increases of 1.24% (95% CI: 0.22% to 2.27%). Background ambient PM10 associated with much smaller 4% increase (95% CI: 0.02 to 2.07)
Tham, 2009	Melbourne & Gippsland	increase from 25th percentile to 75th of PM10	ED attendances and hospital admissions	Time Series	Same day increases of 1.8% in Melbourne RR= 1.018, 95% CI: 1.004–1.033, p = 0.01
Hanigan, 2008	Darwin	10 µg/m3 increase of PM10	Hospital admissions	Time Series	Same-day increases of 4.81% (95%CI: -1.04% - 11.01%) Stratified results: Non-Indigenous 3.14% (95%CI -2.99 – 9.66) Indigenous: 9.4% (95%CI 1.04 – 18.46) Lag 3 (3 days post exposure) increase for respiratory infection: Non-Indigenous (0.67%; 95%CI: -7.55%, 9.61%) Indigenous Australians (15.02%; 95%CI: 3.73%, 27.54%)
Johnston, 2007	Darwin	10µg/m3 increase of PM10	ED admissions	Case cross over	Same day increases of 8% (OR 1.08 95%CI 0.98–1.18) and 17% (OR1.17 95% CI 0.98–1.40) for Indigenous subpopulation.
Chen, 2006	Brisbane	increases from low (< 15 µg/m3) to medium (15 - 20 µg/m3) to high (>20 µg/m3) of PM10	Hospital admissions	Ecological	Same day increase from low – medium and medium - high level associated with 9% (95% CI 1.01 – 1.18) and 19% (95% CI 1.09 – 1.30) increases respectively. Same increases on non-bushfire days were associated with 11% (95% CI 1.05 – 1.17) and 13% (95% CI 1.06 – 1.23)

Study reference	Location	Exposure	Outcome	Study Design	Significant Results
Haikerwal, 2016	VIC	IQR increase (8.6 µg/m3) of PM2.5	ED attendances	Case cross over	No association
Johnston, 2014	Sydney	LFS event days	ED attendances	Case cross over	Same day increase OR 1.12 (1.02-1.24). When stratified for age, stronger impact in 15 – 64yr age group OR 1.23 (1.01-1.50) compared to > 65yr OR 1.08 (0.96-1.21)
Martin, 2013	Sydney, Wollongong, Newcastle	LFS event days	Hospital admissions	Case cross over	Same day and lag 1 increases observed in Sydney. Lag 0 OR=1.13 (95%CI=1.05-1.22)
Morgan, 2010	Sydney	10µg/m increase in PM10	Hospital admissions	Time series	Same day and sustained (up to lag 3) increases ranging from highest 3.80% (1.40% to 6.26%) (lag2) to lowest 2.87% (0.51 – 5.28) (lag3).
Hanigan, 2008	Darwin	10 µg/m3 increase of PM10	Hospital admissions	Time series	Positive non-significant trend for same day admissions, and negative association at lagged intervals
Johnston, 2007	Darwin	10µg/m3 increase in PM10	ED admissions	Case cross over	Same day increases of 21% for general study population (OR 1.21 95% CI: 1.0 - 1.47) with much greater risk for Indigenous sub-population (OR 1.98 (95% CI: 1.10 - 3.59) Positive association remained at lag1.

Study reference	Location	Exposure	Outcome	Study Design	Significant Results
Haikerwal, 2016	VIC	IQR increase (8.6 μg/m3) of PM2.5	ED attendances	Case cross over	Same day increases of 1.96% (95%CI: 0.02, 3.94), with highest risks in women ≥ 20 years (5.08%; 95%CI: 1.76, 8.51).
Johnston, 2014	Sydney	LFS event days	ED attendances	Case cross over	Same day increases of 23% (OR 1.23, 95% CI 1.15, 1.30)
Martin, 2013	Sydney, Wollongong, Newcastle	LFS event days	Hospital admissions	Case cross over	Same day increase of 12% (OR=1.12, 95%CI=1.05-1.19)
Morgan, 2010	Sydney	10 μg/m increase of PM10	Hospital admissions	Time series	Same day increases of 5.02% (1.77% to 8.37%) for adults.
Hanigan, 2008	Darwin	10 μg/m3 increase of PM10	Hospital admissions	Time series	Non-significant association at lag 0 – 1. lag1 Non-Indigenous 8.54% (95% CI -5.60 – 24.80) lag 1 Indigenous Australians 16.27% (95% CI 3.55 – 40.17%)
Johnston, 2007	Darwin	10μg/m increase in PM10	ED admissions	Case cross over	Increases of 14% OR 1.14 95% CI: 0.9 - 1.44
Johnston, 2002	Darwin	10μg/m increase in PM10	ED admissions	Times series	Increases of 20% (RR 1.20; 95% CI, 1.09–1.34; P < 0.001) with strongest effect on days PM10 > 40μg/m3 (RR 2.39; 95% CI, 1.46–3.90), compared with days when PM10 levels were less than 10μg/m3.

Study reference	Location	Exposure	Outcome	Study Design	Significant Results
Salimi, 2016	Sydney	10µg/m increase of PM2.5	Emergency Ambulance Dispatch	Time series	Lag 2 increases in 'other' heart problems (RR=1.05, 95% CI 1.01 to 1.09). No association with same day arrest.
Haikerwal, 2015	VIC	IQR increase (9.04 µg/m3) of PM2.5	OHCA and ED attendances	Case cross over	Lag 0 -1 increases in OHCA of 6.98% (95% CI 1.03% to 13.29%). Lag 2 increases of IHD ED admissions of 2.07% (95% CI 0.09% to 4.09%) and hospital admissions of 1.86% (95% CI 0.35% to 3.44%). Lag 2 increase in AMI hospital admissions of 2.34% (95% CI 0.06% to 4.67%)
Dennekamp, 2015	Melbourne	IQR increases of PM2.5 (6.1 µg/m3), PM10 (13.7µg/m3), CO (0.3ppm) and number of study "fire hours".	OHCA	Case cross over	Increases of 8.05% (95% CI; 2.30 - 14.13) for PM2.5 , 11.1% (95%CI; 1.55 - 21.48) for PM10 and 35.7% (95%CI; 8.98 - 68.92) for CO. 174 "fire hours" were associated with an excess 23.9 (95% CI; 3.1 - 40.2) OHCAs due to elevations in PM2.5
Johnston, 2014	Sydney	LFS event days	ED attendances	Case cross over	Lag 2 increases in IHD (OR 1.07, 95% CI 1.01, 1.15) and inverse association for arrthymias (OR 0.91, 95% CI 0.83, 0.99).
Martin, 2013	Sydney, Wollongong, Newcastle	LFS event days	Hospital admissions	Case cross over	No associations
Crabbe, 2012	Darwin	10µg/m3 increases of PM and fine particles (FPM)	Hospital admissions	Time series	Strongest associations for CV hospital admissions; same day FPM (RR = 1.044, 95 % CI 0.989–1.102)
Johnston, 2011	Sydney	LFS event days	Mortality	Case cross over	Same day associations only noted when temperature removed from the model; cardiovascular mortality OR 1.10 (1.00 - 1.20).
Morgan, 2010	Sydney	10 µg/m3 increase of PM10	Mortality and hospital admissions	Times series	No associations
Hanigan, 2008	Darwin	10 µg/m3 increase of PM10	ED admissions	Time series	No significant associations. Weak trend at Lag 2 and 3 for circulatory and IHD admissions in Indigenous sub-population only.
Johnston, 2007	Darwin	10µg/m increase of PM10	ED admissions	Case cross over	Lag 3 association of IHD in sub-population of Indigenous Australians (OR 1.71 95%CI 1.14–2.55).