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Evidence Review: Reducing time outdoors during wildfire smoke events: Advice to stay indoors, advice to reduce outdoor physical activity and cancelling outdoor events

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Key points

- Five air sampling studies that modeled residential building infiltration efficiencies suggest that staying indoors can be effective at reducing wildfire smoke exposure (using particulate matter as an indicator) when a building has little air infiltration from outdoors, wildfires are shorter rather than longer, when sources of indoor air pollution are minimal and effective indoor air cleaners are used (the effectiveness of different types of air filtration is beyond the scope of this review, and is described in the review *Clean Air Shelters*). Of the five studies, one was conducted during a wildfire smoke event and one during prescribed biomass burning activities.
- There are no studies that examined whether reducing outdoor physical activity is an effective way to reduce wildfire smoke exposure and associated ill health during a wildfire smoke event.
- Grey literature suggests that in advance of outdoor events, providing public information about real time air quality resources and associated health risks (e.g., internet-based visibility and air quality assessment tools) may help encourage event attendees to make informed decisions, and to be prepared for any day-of event changes or cancellations that may occur.
- Public service advisory (PSA) effectiveness during wildfire smoke events was examined in four retrospective cross-sectional surveys in California, USA and New South Wales, Australia. Among them:
 - Three studies examined PSA *recall* and between them found that:
 - The general public recalled simple and non-technical advisories more easily. “Stay indoors” and “reduce outdoor physical activity” were the most recalled among wildfire smoke public health messages.
 - Recall was higher among adults with full time employment, people with longer duration of exposure, and those with certain clinical conditions including asthma, and chronic obstructive pulmonary disease (COPD).
 - Some subpopulations have been shown to be less likely to hear PSAs: people with English as a second language, who are elderly and/or less educated, have low income and/or without a full time job.
 - Three studies examined PSA *compliance* and between them found that:
 - The general public tended to heed to messages that were simple and did not require the use of special equipment (e.g. air filters or air conditioners). “Stay indoors” and “reduce outdoor physical activity” were the most adhered to among wildfire smoke public health messages.
 - Compliance with PSAs was the highest among parents with children aged 16 or younger, females, adults aged 18-64 years, English-speakers, persons educated beyond high school with higher earning incomes and full-time employment, persons with depression, asthma, increased inhaler use or a visit to the doctor during wildfires, as well as persons who experienced longer exposures to smoky air. Asthmatics were more likely to remain indoors during a smoke event.
 - None of the studies reported whether any subpopulations were less likely to comply with PSAs.

Evidence gaps

- Evidence that staying indoors reduces smoke exposure would be strengthened by studies with improved personal exposure assessment and those that examine populations living in a wide range of housing types and geographical areas (outside of California, USA and New South Wales, Australia).
- There is only suggestive evidence on the effectiveness of reducing outdoor physical activity during wildfire smoke events at reducing exposure to smoke.
- There is no peer-reviewed evidence on the effectiveness of cancelling outdoor events in reducing exposures to and ill health effects of wildfire smoke. Effectiveness of alternative approaches such as an ‘informed participation’ approach, and offering options for reduced participation need to be evaluated.
- Among studies about PSA effectiveness during wildfire smoke events (in California, USA and Australia):
 - There is no clear evidence on how to ensure all segments of the population *hear or see PSAs*, particularly sensitive populations and those who may be more difficult to reach.
 - The effectiveness of communication via media such as text messaging, social media networks, and internet for public health advisories during wildfire smoke events has not been assessed.
 - Evidence about *PSA compliance* is limited to cross-sectional studies reliant on participant recall, therefore it is unclear whether people who stayed indoors did so because of advisories, or if they would have stayed inside anyway.
 - The evidence suggests that people comply with non-technical advisories more than technical advisories however, these studies do not take into account the relative frequency in broadcasting the advisories. Therefore it is not clear whether people are more likely to heed non-technical advice because they hear it more often, or for other reasons.

Considerations

- Access to clean indoor air, either at home or at a community clean air shelter, will impact the effectiveness of staying indoors to reduce exposure to wildfire smoke. The exposure reduction achieved by staying indoors is affected by indoor air pollution (e.g., smoking and other combustion sources), rate of infiltration of smoky outdoor air (the effectiveness of different types of air filtration is beyond the scope of this review, and is described in the review *Clean Air Shelters*).
- Potential risks of staying indoors include lost income, disruption of daily and community activities and increased risk of heat stress.
- Staying indoors may be less effective during longer duration fires.
- Advisories to reduce outdoor physical activity during wildfire smoke events may be more effective if paired with alternate physical activity options indoors.
- A number of options are available to modify outdoor events rather than cancel them – e.g. providing the option to participate in part of the event (e.g. switching from a marathon to a half-marathon) and encouraging informed participation (i.e., educate participants about potential risks of participating and allow them to decide whether to participate, and/or monitor their health during the event).
- Some populations who are less likely to hear PSAs (e.g. people with English as a second language, who are elderly and/or less educated, have low income and/or without a full time job) may require targeted communications.

1. Introduction

Most wildfire smoke management guidelines encourage public health officials to recommend that people stay indoors or reduce outdoor physical activity, or to cancel outdoor events. However, the evidence to support such interventions as protective measures against wildfire smoke exposure has not been reviewed. Public health authorities responsible for managing potential health risks associated with fire smoke exposure need evidence about when and how best to encourage people to stay inside or reduce outdoor physical activity, and whether to cancel large outdoor events. Thus, a review was conducted focusing on the evidence for effectiveness of these three interventions in wildfire smoke-affected communities.

2. Methods

Studies that evaluated the interventions in wildfire-smoke affected communities were identified using a variety of databases. We conducted primary searches using the search engines Ebsco, PubMed, Google Scholar, and Web of Knowledge. Key words included: “wild/bush fire, smoke, intervention, staying indoors, cancel outdoor events, exercise, physical activity”. Keyword combinations for each search engine are summarized in Appendix A (Tables A–D).

Articles with relevant titles were saved and abstract reviews conducted to identify relevant evidence. A secondary literature search to ensure completeness included a citation review and examining articles that cited the relevant literature. Grey literature (e.g., case studies and media coverage of wildfires) was identified through online searches using Google (using keywords: “wildfire, smoke, marathon, cancel, physical activity”; see Appendix A, Tables E–F) and via conversations with content experts (Appendix A, Table G). We used a hierarchy of evidence approach when evidence was unavailable on a topic; evidence from other comparable exposure situations (e.g., research on exposure to wood smoke or air pollution) was applied.

3. Results

The literature search of Web of Knowledge, Ebsco, and PubMed combined identified 1646 potentially relevant articles. Twenty-five of these with relevant titles had their abstracts reviewed. In Google Scholar, 16 additional articles were found and reviewed for relevance. A Google search identified seven media reports of wildfire events where large outdoor public events were affected.

Results are summarized by type of intervention:

- *Advice to stay indoors*: Guidance to reduce time outdoors in order to protect health.
- *Advice to reduce outdoor physical activity*: Guidance to decrease physical exertion outdoors in order to protect health.
- *Canceling outdoor events*: Decision that group activities that occur outside will not take place. Such activities include school activities (e.g., recess, outdoor classes and events), sporting events (e.g., tournaments, practices) and outdoor events (e.g., arts and cultural events, athletic events). Cancelation may occur through a number of means including by event organizers and through health authorities and may be voluntary or mandatory.

We present evidence on smoke exposure, health outcomes, effectiveness (i.e., compliance with advisories), considerations for public health implementation, and factors that might warrant such implementation. Table H summarizes the available epidemiological studies evaluating these interventions during real wildfire smoke events and Table G summarizes individual case examples. Research, policy, and knowledge gaps are identified and preliminary conclusions based on the available information provided.

4. Advice to stay indoors

4.1. Exposure to wildfire smoke

Staying indoors during wildfire smoke events can be effective at reducing the public's exposure to the complex health-damaging mixture of particulate matter (PM) and gases that form as a result of incomplete combustion. The effectiveness of staying indoors at reducing exposures (and subsequent health effects) depends largely on the portion of outdoor air pollution that makes its way indoors (i.e., the pollution infiltration efficiency) and the air quality within the building. Evidence suggests that staying indoors can be effective when a building has a low infiltration efficiency, wildfires are shorter rather than longer, when indoor air PM emissions from behaviours of inhabitants (e.g., cooking or smoking) are minimal, and with effective indoor air quality control (e.g., use of high efficiency particulate air (HEPA) filters).

Building air pollutant infiltration occurs when an uncontrolled flow of air pollutant (e.g., PM) enters through gaps and cracks in a building's construction. Buildings have low infiltration efficiencies when only a small fraction of the total concentration of a select outdoor pollutant can make its way indoors and remains suspended in the air. Infiltration efficiencies vary by pollutant and by building characteristics. Typically, infiltration efficiencies for fine particulate matter¹ in industrialized countries range between approximately 0.2 (meaning 20% of PM_{2.5} concentration makes its way indoors) in a tightly sealed home using a portable air filter with windows closed (1, 2) to nearly 1.0 (100% infiltration) in a home with open windows(1-3). Gases such as carbon monoxide (CO) generally have higher infiltration efficiencies than does PM. When a building is sealed, even if improperly, wildfire smoke PM concentrations are generally lower indoors than outdoors (4), but the ratio between the two depends on building characteristics. Four residential air sampling studies suggested that infiltration efficiencies are influenced by various housing factors. Characteristics associated with increases in the ratio of PM in indoor to outdoor air include more frequent window opening (5, 6), use of air conditioning (6), older homes (2, 6), and lower home value (7). Factors associated with decreased PM indoor to outdoor ratios include use of forced air heat (5), central air conditioning (e.g., recirculating rather than drawing in outside air) (5), portable air cleaners (e.g., HEPA filter units or electrostatic precipitators) (5, 6), and presence of double glazed (double pane) windows (5). If household inhabitants purchase and use appropriately sized portable HEPA air cleaners, they can improve indoor air quality (2). Many standard air conditioning units also have filters inserted or can have them inserted. (Please refer to the evidence review on *Clean Air Shelters* for further information about filtration of wildfire smoke).

One residential air sampling study showed that duration and intensity of wildfire smoke events may influence the protectiveness of staying indoors. The longer the wildfire smoke event lasts, the more smoke infiltration may occur, which reduces the benefit of staying indoors. For example, during a short-lasting wildfire smoke event in Australia, indoor air quality was associated with indoor household activities (e.g., cooking, burning candles, use of indoor air cleaners, and air conditioning) more so than with ambient air quality levels (8). After the smoke had persisted for several days, indoor air quality was more closely associated with external conditions and ambient pollutant levels, as well as management of household ventilation rate (8); the reason for this was unclear. The intensity of outdoor pollutant levels is impacted by meteorological factors such as rainfall or wind speed and direction (6, 9).

¹ Fine PM defined as PM_{2.5}, particulate matter less than 2.5 µm in aerodynamic diameter. Coarse PM, on the other hand, is defined as PM₁₀, particulate matter less than 10 µm in aerodynamic diameter,

Resident indoor activities influence the effectiveness of staying indoors as an intervention to wildfire smoke exposure. Smoking indoors is a major contributor to indoor air pollution, especially in small confined spaces (10). Ambient PM accounts for the majority of the indoor PM concentration in non-smoking homes in industrialized nations (5, 11). Indoor air quality worsens if inhabitants burn candles, cook, or heat a space (especially if the stove or heater burns kerosene, gas, propane, or wood), likely reducing the protective effect of staying indoors.

4.2. Health outcomes

While it is reasonable to assume that the health consequences of wildfire smoke will be diminished if staying indoors is effective at reducing exposure, few studies have directly addressed this question. Preliminary evidence suggests that staying inside may be protective in a well-sealed building but the protection afforded may depend upon the duration of smoke exposure.

Two previous wildfire smoke studies in Southern California indicate that staying indoors may be protective. However, staying indoors may not be sufficient to protect vulnerable individuals with pre-existing conditions, especially when smoke exposure lasts more than five days. Rates of ill health were compared between people who recalled reducing their time spent outdoors during a wildfire and those who did not. Mott and colleagues interviewed 289 Hoopa Valley Indian Reservation residents, of whom nearly a third had pre-existing cardiopulmonary conditions (12). They found that 60% reported worsened respiratory symptoms during wildfires in 1999. Those who recalled hearing any public service advisories (PSAs) were less likely to report worsening respiratory symptoms ($OR=0.25$) compared to those who did not. Among all respondents, 65% heard advisories to stay indoors and 34% acted and stayed indoors. Mott and colleagues concluded that there is likely a protective effect of staying indoors on respiratory health.

Following Southern California wildfires in 2003, Kunzli and colleagues (13) found unclear results. Among over 6,000 English-speaking elementary and high school students surveyed by a mail-home questionnaire as part of larger health studies, the act of following advice to stay indoors was associated with a 1.2-to 1.6-fold increase in respiratory symptom rates compared to those who did not follow this advice. The higher rate of respiratory symptoms among those who stayed indoors may be explained by the finding that more asthmatic children than non-asthmatic children stayed indoors and reduced outdoor physical activity during the wildfire, and they were more likely to change their behaviour in general. Kunzli and colleagues also found that wildfire smoke exposures of more than five days were associated with a greater likelihood of reporting ill health, and duration of exposure was a larger predictor of respiratory symptoms than staying indoors. These findings would be strengthened by comparisons between health effects among asthmatic children who stayed inside and those who did not.

4.3. Effectiveness of messages

Although evidence is limited, four observational cross-sectional retrospective survey studies suggest that most members of the general public hear and comply with PSAs to stay indoors in particular. It is the most commonly heard and easiest to understand and perform of wildfire smoke intervention advisories. However, the strength of the causal relationship is difficult to ascertain due to challenges in study design.

The majority of wildfire smoke-affected individuals surveyed either on the Hoopa Valley Indian Reserve in California in 1999 or in the city of Albury, New South Wales, Australia in 2003 reported they had heard a PSA to stay indoors, and the majority of those who heard them responded. On the Hoopa Valley

Indian Reserve, Mott and colleagues (12) found that 65% of 289 Aboriginal individuals surveyed heard at least one advisory telling them to stay indoors, 20% heard advisories to close windows, 16% heard advisories to limit outdoor physical activity, and 18% did not hear any advisories; approximately 34% of all respondents stayed indoors (12). In Albury, New South Wales, bushfire smoke exposure lasted for 38 days in 2003. Kolbe and Gilchrist found that more than 74% of 389 residents surveyed were aware of a myriad of PSAs that had been given, including advice to stay indoors (14). The authors did not report compliance specifically for the advisory to stay indoors, but respondents who recalled PSAs were 2.74 times more likely (95% CI: 1.50, 5.02) to have either stayed indoors, reduced outdoor activity, and/or taken action to prevent smoke getting into their homes.

Advice to stay indoors tends to be the most commonly recalled intervention advisory following wildfire smoke events. The reason for this is unclear, as frequency of public broadcasts to stay indoors or reduce outdoor physical activity compared with other advisories was not assessed. Mott and colleagues (12) found that in Hoopa Valley Indian Reserve in 1999 the PSA to stay indoors was recalled by 65%, close windows (20%), limit outdoor activities (16%) and the most often acted upon compared to any other individual action. Kunzli and colleagues (13) found that among school-age children affected by smoke from a Southern California wildfire in 2003, reducing time spent outdoors was the most commonly reported preventative action performed compared to the two other intervention actions (use of masks and air conditioner use). They did not specify why this was. In Australia, Kolbe and Gilchrist (14) found that 53.5% of people surveyed were aware of the PSAs, and the main message heard was to stay indoors. Similarly, among 1,802 school children who were surveyed after a 3-month long Southern California wildfire in 2007, staying inside was recalled the most frequently among all PSAs given. Sugerman and colleagues (15) suggested that this is likely due to the simplicity of the messages and the ease of following the advice to stay indoors compared to the more technical and costly actions such as use air cleaners or masks.

All four of these studies used retrospective survey designs, making it difficult to attribute an individual's decision to stay indoors specifically to PSAs (i.e., none were able to disentangle whether people who complied did so because they heard a public service announcement or if they were going to stay indoors anyway). In the 2003 Southern Australia wildfires, most survey respondents reduced their time outdoors whether they had heard an advisory or not (14).

4.4. Considerations when advising people to stay indoors

Compliance with advice to stay indoors depends on population characteristics, including demographics, education, socioeconomic status, and particular medium of receiving advisories. PSA efficacy and effectiveness are not uniform across a population. Kolbe and Gilchrist (14) found that parents of children ≤16 years old were most likely to have acted in response to a PSA, and the elderly were least likely to have heard the PSAs in the first place. Similarly, in Southern California in 2007, Sugerman and colleagues (15) found that PSA recall and compliance was lower for certain subgroups of the population, especially for messages with technical language or involving purchasing of equipment (e.g., air cleaners and masks). Survey respondents were less likely to recall advisories if they did not speak English as a first language or if they were elderly, less educated, lower income, or did not have a full time job. Conversely, those most likely to have heard advisories were working adults with full time jobs, longer exposures, and those with certain clinical conditions including asthma and chronic obstructive pulmonary disease (COPD). Compliance with most to all messages was higher among persons who were females, adults aged 18-64 years, English-speakers, persons educated beyond high school with higher earning incomes and full-time employment, persons with depression, asthma, increased inhaler use or a visit to the doctor during wildfires, as well as persons who experienced longer exposures to smoky air (>2 days).

Information alerts occur through different mediums in different communities and how information is used changes over time. Mott and colleagues (12) found that Hoopa Valley Indian Reserve residents primarily heard advisories on the radio or scanner (*a device that detects and tunes radiofrequencies*), from a physician or clinic personnel, or by word of mouth from a friend or family member. In Southern California and Albury, Australia, wildfire smoke PSAs were heard primarily through television (14, 15). No studies after 2009 have examined current means by which people receive information. The studies did not assess the use of cellular communication devices, email, text messages, or social media networks such as Twitter and Facebook when they evaluated wildfire smoke PSA communication effectiveness. People who may receive news via internet alone and do not use cable television and/or radio would not have been included in these studies.

In fire-prone areas, public messaging needs periodic revamping to ensure that people still listen (16). It is also important to consider a community's baseline understanding of wildfire smoke threats and interventions. People living in fire-prone areas may increase their tolerance or indifference toward public health interventions due to repeat events, or alternatively, living in fire-prone areas may cause the public to be more informed and prepared. In 1998 in Florida, people with more experience with wildfires were less likely take action to decrease fire risk to their homes during a wildfire (17). No other studies have been conducted to confirm these findings. Overall, however, the general public needs to have easy to understand messages with easy to perform actions such as staying indoors.

4.5. When to advise the public to stay indoors

PSA effectiveness also depends on the characteristics of the advisories such as their timing, frequency, and strategic targeting (e.g., some messages may be targeted at specific vulnerable subgroups, while others are intended for the entire community). The “right time” to release a public service announcement to stay indoors has not been well established. In previous wildfire smoke events (described in section 4.3), the public have been alerted based on the following:

- The US Environmental Protection Agency (EPA) ambient daily PM₁₀ standard of 150µg/m³ was exceeded (12) for multiple days and there was concern over the health effects (12, 15).
- The US EPA ambient hourly PM₁₀ guidelines were exceeded (according to estimates of PM₁₀ levels based on a 1999 Pollution Standard Index (14) using visibility of known markers (18).
- Reasons for decision to release public health advisories were not provided, but ambient hourly PM₁₀ exceeded US EPA limits in some areas (PM₁₀ reached nearly 1,000 µg/m³) (13).

Real time, frequent measures of air quality during wildfire smoke events are not available everywhere. In industrialized nations, air quality indices such as the US EPA's Pollution Standard Index (1999) or Canada's Air Quality Health Index (AQHI) may exist². Air quality indices have the potential to help inform sensitive individuals to stay indoors and reduce strenuous activities, but approaches vary by province, state, and country. Furthermore, using PM_{2.5} fine particulate as an indicator may be more relevant as it is the size fraction most consistently associated with fire smoke and has the greatest evidence for adverse health impacts. (Air quality monitoring methods are described in the evidence review on *Smoke Surveillance*.)

² The main air quality messaging tool in approximately 60 Canadian cities and towns; provides air quality rating estimates based on 3-hour moving average of measured ozone, PM and NO₂ concentrations.

It is important to weigh the costs (e.g., possible diminished income to families from not being able to go to work, or to a community's tourism industry from cancelling a public event so that people stay indoors) with the benefits (e.g., potentially decreasing exposures and subsequent health effects of wildfire smoke) of the intervention. Mott and colleagues (12) observed that Aboriginal men with pre-existing respiratory conditions volunteered to suppress fires in their community to increase their household income, inadvertently increasing their exposure to smoke. These short and long term costs and benefits are not always apparent and need consideration as well.

Strategies used for rolling out public advice to stay indoors (in the four previous wildfire smoke scenarios described in section 4.3) tend to be systematic, targeting at-risk subgroups of the population first in order to ensure protection of the most vulnerable. As an example, in the 2003 Southern California wildfires, Kolbe and Gilchrist (14) summarized the general advisory release strategy. First, public health advisories targeted vulnerable subgroups of the population, including those with existing cardiovascular or respiratory diseases, the elderly (advising them to avoid strenuous outdoor physical activity, take their medications as prescribed, and follow established action plans such as seeking medical attention if they experience asthma, chest pain, or shortness of breath), and children. Later, once conditions worsened (smoke pollution reached very poor or hazardous levels), the whole community was then asked to reduce their levels of outdoor activity and stay indoors. In long-lasting wildfire smoke circumstances such the Southern California wildfires of 2007, where there were extended periods of concern over the health effects of the wildfire smoke, emergency PSA broadcasting through health departments and medical associations may continue for as long as is necessary (15).

4.6. Summary

Important considerations when advising the public to stay indoors include:

- Age and type of housing influence PM infiltration efficiencies (i.e., open housing, common in warmer climates, affords little protection due to rapid air change rates; the same is true for poorly sealed houses which are often older).
- Access to a home clean air shelter (indoor HEPA filtration or putting air conditioning on recirculate in a well-sealed home with clean indoor air and minimal indoor air pollution sources, or a community clean air shelter (e.g., shopping mall, community centre) (refer to evidence review on *Clean Air Shelters* for further detail).
- Severity and duration of the smoke (longer events may be associated with decreased protectiveness of staying indoors as the ratio of PM concentrations indoors compared to outdoors increases).
- Characteristics of the affected population, including underlying health status and the ability to hear and act on messages.

5. Advice to reduce outdoor physical activity

5.1. Exposure to wildfire smoke

Outdoor physical activities involve spending time outdoors breathing more smoky air than one would otherwise. Physiological responses to physical activity in air pollution have been well described, including increasing ventilation and increasing mouth breathing and by-passing air filtration in the nasal passages, both of which increase personal exposure to the constituents of smoke (19). During physical activity, the volume of air intake increases up to tenfold. It follows that if one reduces outdoor physical activity during wildfire smoke events one also reduces exposure to wildfire smoke. However, no studies have been conducted during wildfires to examine the impact of physical activity on level of smoke exposure.

5.2. Health outcomes

There are no studies examining how health effects among the general public may change when one reduces outdoor physical activity in wildfire smoke situations. In absence of other studies, the next most relevant available information is occupational and diesel exhaust air pollution research. Diesel exhaust and wildfire smoke contain different mixtures of gases and particles. PM exposure is associated with adverse health effects (see evidence review on *Health Effects*). If, instead of being physically active outdoors, the public stayed indoors in a well-sealed, clean air environment with minimal indoor air pollution sources, this intervention would likely be health protective.

It is unclear whether it is worse to rest outdoors (e.g., to attend an outdoor theatre performance sitting in a park), or to engage in physical activity (e.g., to participate in an athletic sports game) on smoky days. A few firefighter studies (20-22) and one study of healthy volunteers (23) examined smoke exposures before, during, and after physical work but they did not directly examine the influence of physical activity or intensity of physical activity on smoke-related health impacts. No studies of low ambient level diesel exhaust or urban air pollution exposures have attempted to separate out whether level of physical activity matters (24). Preliminary evidence suggests that during high diesel exhaust exposure, the intensity of physical activity matters. Giles and Koehle (24) asked 18 healthy male volunteers to bike for six 30-minute trials of differing intensity or rest in a laboratory chamber with clean, filtered air or high diesel exhaust at PM_{2.5} concentrations comparable to those measured during wildfires (300 µg/m³) (25). They found that, following low- and high-intensity exercise in diesel exhaust, plasma oxides of nitrogen (NOx; a marker in the blood, which in the presence of diesel exhaust may combine with free radicals to produce powerful oxidants, resulting in oxidative stress) increased. Plasma NOx levels did not change following exercise and rest in clean air, and were not different between low- and high-intensity exercise in diesel exhaust. Further to this, these researchers found that there were no acute effects of exercising in diesel exhaust on pulmonary function, pulmonary inflammation, blood pressure, and autonomic control of the heart, and that exercise intensity did not exacerbate any physiological responses. These data suggest that advising individuals to reduce physical activity during bouts of high air pollution may not have additional benefit. However, it is important to note that for this study the acute effects were only studied up to 2 hours following exercise and we cannot conclude how these end points would change if monitored over a longer period of time or tested among less healthy individuals. Furthermore, other studies have not been conducted to confirm these results, and the results need to be interpreted with caution as diesel exhaust and wildfire smoke are different mixtures containing different pollutants.

5.3. Effectiveness of messages

Following wildfire smoke events when the public receives an abundance of health messaging, including the advice to reduce outdoor physical activity, at least one in five people who hear public health advisories is likely to remember the message. Among the respondents who heard PSAs in Sugerman (15) and Mott's (12) studies, advice to reduce outdoor physical activities was recalled by 88% and 19.4% of respondents, respectively. When paired with messaging to stay indoors and prevent smoke infiltration, the advisory to reduce outdoor physical activity can be very effective. According to Kolbe and Gilchrist (14), people who heard a PSA study were 2.74 times more likely (95% CI: 1.50, 5.02) to reduce their outdoor activity, stay indoors, or take measures to prevent smoke infiltration to their homes.

5.4. Considerations when advising people to reduce outdoor physical activity

Some individuals are less likely than others to hear advisories in general and others more or less likely to act on the advisory they hear (as outlined in section 4.4). Those with pre-existing respiratory conditions may be more likely to act on advisories, including reducing outdoor physical activity (as shown among schoolchildren in Southern California) (13).

5.5. When to advise the public to reduce outdoor physical activity

There are few guidelines with specific recommendations for when to issue advice about reducing outdoor physical activity. Public Health Departments in Oregon and Montana, USA have published wildfire smoke public health response guidelines using the AQI and associated visibility scales to assist with decisions about outdoor sporting events specifically (26, 27).

5.6. Summary

Overall, more research is needed to understand the effectiveness of advising the public to reduce outdoor physical activity during wildfire events at preventing ill health.

6. Cancelling outdoor events

6.1. Exposure to wildfire smoke

Although there have been no evaluations of the effectiveness of cancelling outdoor events for reducing exposure to wildfire smoke, an effect likely exists *if* participants have access to an alternative location with cleaner air. Many events are physically demanding, and cancellation is sometime advised to prevent the increased exposure associated with physical activity induced increases in ventilation.

6.2. Health outcomes

The impact of cancelling outdoor events on public health during wildfire smoke events has not been directly studied. Its value depends on how much of a reduction in smoke exposure results from not attending the event. This, in turn, depends on alternative access to cleaner indoor air (e.g., home or community air shelters) and whether people go there. Physically demanding events might also be cancelled in keeping with conventional advice to avoid vigorous physical activity. Public athletic events are usually attended by spectators, so cancelling such events relates to a wider range of physical fitness and exertion levels than would be reflected among direct participants or competitors.

6.3. Considerations when cancelling outdoor events

There are many factors to consider when assessing public health risks of wildfire smoke pollution and outdoor events. If an outdoor event involves individuals (participants and spectators) at higher risk of harm from exposure to air pollutants, the likelihood of potential adverse health effects is greater. The type of activity will vary by type of event, e.g., athletic games and competitions versus festivals and concerts. For some people, events mean extended time outside (e.g., weekend festivals). Providing real time air quality monitoring and clear risk communication in the weeks leading up to an event were found to be particular helpful by organizers of the Cadbury marathon in Hobart, Tasmania (28) (see Appendix, Table G).

6.4. When to cancel outdoor events

American guidelines provide thresholds for when to cancel outdoor events due to poor air quality conditions. Thresholds are based on the AQI and extrapolated for measurement over short time periods: PM_{2.5} or PM₁₀ 1- to 3-hour average over 351 µg/m³, 8-hour average over 200 µg/m³, and 24-hour average over 150 µg/m³ with visibility less than 1 mile (under arid conditions) (29). Air quality indices and thresholds used in certain states and in other countries have the same general approach but different degrees of precaution (27, 30).

A few large outdoor events identified by experts and through a grey literature search are shown in the Appendix (Table G). They highlight the diversity in approaches used by public health authorities. On January 13, 2013 the Cadbury Marathon in Hobart, Tasmania (an international high profile race) was threatened by smoke from several nearby bushfires. Careful consideration of whether to cancel the event was needed because approximately 2000 racers were registered, with some travelling long distances, and many spectators were expected to attend. Organizers, in consultation with local health authorities, decided to provide advance information to registrants about the air quality and health risks associated with particulate levels, and wait until race day to decide whether to cancel or not given air particulate levels. People were told that if hourly average PM_{2.5} exceeded 25 µg/m³ on the day of the marathon, participants would be advised that: 1) air quality is reduced due to bushfire smoke; 2) exposure to bushfire smoke can be associated with serious health problems; 3) physical activity will increase exposure to the air pollution; 4) people in higher risk groups must review their decision to participate in light of their personal health status and are reminded that they participate at their own risk. If the 1-hour PM_{2.5} exceeded 50 µg/m³, participants would have been advised to review their participation and only run at their own risk, with people in higher risk groups advised not to participate. If hourly PM_{2.5} levels exceeded 100 µg/m³ or if prevailing winds and other meteorological conditions indicated they were likely to increase to that concentration, organizers would consider cancelling the race. Ultimately, air quality on event day was clear and the marathon went ahead as planned. The public health authorities involved in this process noted that the availability of real time air quality measures, as well as the provision of advance information to competitors so that they could provide informed consent, was very helpful.

Providing alternatives to outdoor events, such as moving an event indoors, altering the duration, or postponing to a date when the smoke has cleared (rather than cancelling), may be appropriate alternatives. In August, 2010, a marathon in Edmonton, Alberta, Canada was threatened by wildfire smoke from wildfires in the neighbouring province of British Columbia. Organizers decided not to cancel the event. Instead, they provided information and gave registered racers the option of switching from the full to the half-marathon distance if they were concerned about their health. Informing people of potential risks and giving alternative options is another approach to consider.

In each of these cases (as well as the other events listed in Table G), no ill health was reported in the event coverage, although comprehensive reviews of event first aid records were not done. The generalizability of these cases to events involving the general public is limited because elite athletes represent a small minority in excellent health. Overall, more case reviews of general public outdoor events like outdoor concerts, festivals and street parades during wildfires are needed to better inform public health decision-making about cancelling large public outdoor events during wildfires.

7. Evidence gaps

This evidence review highlights some key research challenges and information gaps. Establishing a causal relationship between advising the public to stay indoors or cancelling outdoor events and health outcomes from wildfire smoke is challenging. Relevant epidemiological studies (outlined in section 4.3) that examined staying indoors during wildfire events were all retrospective surveys (and thus prone to recall and selection bias). It is difficult to determine whether people who stayed indoors did so because of advisories, or if they would have stayed indoors anyway. Existing guidance uses air quality indices as thresholds for when to take action, however there is variation in how precautionary these are.

Studies assessing wildfire smoke exposures would be strengthened by improved personal exposure assessment and a wider range of locations. Personal exposures to wildfire smoke were not measured (e.g., using personal monitors) in any relevant studies. Exposure characterization was limited to ambient PM measures, and considered home locations as opposed to other indoor environments that may also have been used (e.g., malls, workplaces). For the infiltration efficiency studies, stationary indoor residential air pollutant monitors (e.g., for PM_{2.5} and ultrafine particles) were used, which is not representative of an individual's personal exposure level due to their activities and spatial variation within a building (31).

Generalizability of the evidence is also limited. Previous wildfire smoke studies evaluating these interventions were conducted between 1999 and 2007 in either: a) a low income Indian Reservation in California; or b) large urban cities with surrounding suburbs (in California, USA and New South Wales, Australia). More research focusing on different climates and a wider range of community or population characteristics is needed in order to better inform public health response to wildfire smoke events. Indoor behaviours (e.g., smoking) vary. In tropical regions, homes with open air structures (without walls or windows without glass) have infiltration efficiencies reaching 100%. Instead of staying indoors in these types of homes, the public may be better advised to go to community clean air shelters. Overall, indoor environments are so variable that it is hard to generalize personal exposure levels using the available household infiltration efficiency studies.

Understanding how behaviours of individuals and mediums of communication change under different wildfire scenarios is unpredictable when releasing public health advisories. It may be important to consider how different advisories may interact. For example, advice to stay home and wet hot ash before cleaning it off homes may conflict with advice to stay indoors or reduce outdoor physical activity. Moreover, existing studies of advisories have not assessed the full range of communication technologies no commonly available (e.g., cell phones, text messages, emails, social media networks, radio, internet, and television). It is important to understand how people access and receive information.

8. Summary and conclusions

The evidence presented here about the effectiveness and efficacy of advising the public to stay indoors and reduce outdoor physical activity or to cancel outdoor events is suggestive but limited. Key evidence gaps were identified, including the need for an evaluation of the effectiveness of these interventions at reducing wildfire smoke exposures and associated health outcomes. Effective delivery of free, easy to understand advisories in mainstream media outlets by a trusted information source will help with compliance. Advice to stay indoors seems to be readily received, understood, remembered and acted upon. However, staying indoors is only suitable if well-sealed buildings with minimal indoor air pollution sources are accessible. Staying indoors may not be advisable when smoke threat is combined with encroachment of the wildfire itself or when the risk of heat stress outweighs the protective effect of

staying indoors with windows closed. Reducing outdoor physical activity and cancelling outdoor events may decrease wildfire smoke exposure if people stay inside in clean air environments instead. The protectiveness of this intervention may depend on the duration of the wildfire smoke event.

A standardized solution for when to use each of these interventions is unrealistic, as context affects both feasibility and effectiveness. Advisories to stay indoors may need to be locally-driven, focused on an affected population and their behaviours and living conditions. Evidence suggests that in California asthmatics may be more likely to stay indoors during wildfire smoke events and certain subgroups of the population are more likely to comply with PSAs in general (e.g. females, adults aged 18-64 years, English-speakers, persons educated beyond high school with higher earning incomes and full-time employment, persons with depression, asthma, increased inhaler use or a visit to the doctor during wildfires, as well as persons who experienced longer exposures to smoky air. In Australia, parents of children aged ≤16-years are most likely to comply with PSAs in general. Knowledge of local geography, culture, housing characteristics (e.g., prevalence of air conditioning), public preparedness (i.e., education), and location of vulnerable populations in the smoke-affected communities is crucial. For public health protection, it may be important to weigh the costs and benefits of different scenarios for the timing and type of advisories to stay indoors, reduce outdoor physical activity, or cancel outdoor events.

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Appendix

Table A: Ebsco¹ – Key Search Statements and Results (Primary Search)

Key Search Statements	
Search #1:	
Wildfire AND intervention	
Limits: scholarly (peer reviewed) journals; not limited by date or language ²	Results (89 total); 7 saved for consideration (1 useful article; Collins, 2008)
Search #2:	
Bushfire AND intervention	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (49 total) saved for consideration
Search #3:	
Fire AND smoke AND shelter	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (22 total); 0 saved for consideration
Search #4:	
Fire AND smoke AND forest AND indoors AND outdoors	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (4 total); 2 saved for consideration
Search #5:	
Fire AND forest AND intervention AND smoke	
Limits: scholarly (peer reviewed) journals; human-specific findings but not limited by date or language ²	Results (8 total); 0 saved for consideration
Search #6:	
Fire AND smoke AND physical activity	
Limits: Scholarly (peer reviewed) journals; not limited by date or language	Results (17 total); 2 saved for consideration (Mamen, 2013; Wolkow, 2012)
Search #7:	
Fire AND smoke AND physical activity	
Limits: Scholarly (peer reviewed) journals; not limited by date or language	Results (2 total); 0 saved for consideration (1 redundant article)

¹ Through the University of British Columbia, 55 databases are hosted by Ebsco, including Pubmed/Medline (with full text);

² Language focus was English wherever this is noted (in all tables), however additional languages were included

Table B: PubMed – Key Search Statements and Results (Primary Search)

Key Search Statements	
Search #1:	
Wildfire or bushfire AND intervention	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (9 total) 0 saved; 1 redundant.
Search #2:	
Firesmoke AND staying AND indoors* also tried synonyms such as bushfire bush fire, fire smoke, wild fire and wildfire (*also: wild AND fire AND indoors)	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (1 total) saved. (Kunzli, 2006)
Search #3:	
Reducing AND time AND outdoors AND smoke	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (3 total); 2 saved for consideration (Diette, 2008; Dasgupta, 2006)
Search #4:	
public AND events AND firesmoke (*adding “outdoor events” “festivals” did not add any wildfire results)	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (19 total) 3 saved for consideration (Finlay, 2012; Damon, 2010; Watson, 2005)
Search #5:	
Fire AND smoke	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (1436 total) reviewed first few pages; 3 saved for consideration (Antonio, 2013; Rukavishnikov, 2013; Dudley, 2013; 0 useful articles)
Search #6:	
fire AND smoke AND reducing AND time AND outdoors	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (0)
Search #7:	
fire AND smoke AND physical activity	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (15 total) including 2 redundant and 1 saved for consideration (Ghio, 2012)
Search #8:	
fire AND smoke AND physical activity	
Limits: scholarly (peer reviewed) journals; not limited by date or language	Results (8 total); 0 saved for consideration

Table C: Google Scholar – Key Search Statements and Results (Primary Search)

Key Search Statements	
Search #1:	
Wildfire or Bushfire AND intervention	Limits: scholarly (peer reviewed) journals; not limited by date or language
Results (20,700) 1 saved on 1 st three pages (Bowman, 2005); 1 redundant article	
Search #2:	
Firesmoke AND staying AND indoors	Limits: scholarly (peer reviewed) journals; not limited by date or language
Results (3,730 total) including 13 saved (from review of first 5 search result pages (Phuleria, Henderson/Elliott ppt, etc); <6 of usefulness	
Search #3:	
Wildfire AND physical activity	Limits: scholarly (peer reviewed) journals; not limited by date or language
Results (14,800 total) including 3 saved from review of first 4 pgs of results (Therriault, 2001; Sugerman 2012)	

Table D: Web of Knowledge

Citation search for articles that cited Prabjit Barn's (2008) infiltration efficiency article, titled: "*Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness*" Results (15 total) including 7 saved

Table E: Google (grey literature) Secondary Search

Key Search Statements	
Search #1:	
wildfire AND smoke AND marathon AND cancel	Limits: not limited by date or language
Results (26,900,000 results); saved 7 from first 2 pages	
Wildfire AND smoke AND outdoor events	
Limits: not limited by date or language	Results: (42,300,000 results); saved 3 from first 2 pages

Table F: Informal enquiries among content experts

Key Sources	
Conversations with Evidence Review experts and their contacts to identify wildfire smoke events that may have involved advisories	Results: Kelowna, BC fires, Northern Manitoba, Alberta, Tasmania, Australia

Table G: Examples of outdoor event cancellations (in chronological order)

Location & date of wildfire smoke incident	Type of outdoor event + Outcome	Justification	Reference
Pasadena Southern California (Nov 15, 2008)	Cancelled marathon, half-marathon, 5K and bike race	"Due to the unhealthy air quality."	(32)
Edmonton, Alberta (Aug 20, 2010)	Marathon, not cancelled; adapted registration policy giving runners the option of switching to a half-marathon if they were concerned about their health / the smoke.	Thick air from BC wildfires and race organizers concerned	(33)
Seattle, WA (Sept 12, 2012)	Marathon cancelled & schools and outdoors events also cancelled.	"Because everyone is affected"	(34)
Hobart, Tasmania Australia (Jan 9, 2013)	International marathon with Olympic athletes (high profile event) with 2,000 registered entrants who travelled long distances to attend Air on the event day was quite clear and race went ahead as scheduled. No known reported health incidents resulted.	Real time air quality monitoring data (hourly PM _{2.5} cut-off values of 25, 50, and 100µg/m ³) informed the decision for racers and the event organizers, with 100µg/m ³ being the criteria for consideration of full event cancellation.	(28)
Oregon wildfires (Aug 9, 2013)	Coast Guard outdoors haunted house. Event was cancelled.	Not specified.	(35)
Yosemite wildfires; counties affected were Washoe, Douglas, Carson, Lyon, Storey and Churchill in Nevada, and Mono and El Dorado in California. (Aug 29, 2013)	Prep football games canceled due to smoke; high school football season openers cancelled through the weekend (all outdoor events of Nevada Interscholastic Activities Association involving its member schools in 8 counties in Nevada and California).	Decision was "due to ongoing health concerns about smoke from the big wildfire in California." Nevada Interscholastic Activities Association officials said the uncertainty of conditions the next two days prompted them to err on the side of caution. Pollution from the smoke registered its lowest level in 5 days in Reno when the air quality index improved to the "moderate" range.	(36)
Yosemite forest fires (Aug 30, 2013)	Lake Tahoe public outdoor events and businesses. No public events over the Labor Day weekend were cancelled despite the smoke, but smoke did cause changes in some peoples' tourist activity plans.	"Because of the smoke."	(37)

Note: ambient hourly PM concentrations are available online for these cases; were not reported in the media articles.

Table H: Studies evaluating the efficacy and effectiveness of public health advisories to stay indoors, reduce outdoor physical activity, and cancel large outdoor events during wildfire smoke events

Study	Population	Exposure	Advice Given	Recalled Advice	Compliance	Health Effects	Comments
Mott et al. (2002) Retrospective cross-sectional Hoopa Valley National Indian Reservation, Northern CA (1999)	n=289 Aboriginal residents (one interview per home visited); 32% had pre-existing cardiopulmonary conditions	70 days wildfire smoke; ambient daily PM ₁₀ exceeded USEPA air quality standard ($\geq 150 \mu\text{g}/\text{m}^3$ for 15 days). PM ₁₀ levels exceeded 500 $\mu\text{g}/\text{m}^3$ for 2 days	Stay indoors Wear mask Evacuate area Close windows Reduce physical activity outdoors Use A/C Advised via radio or scanner (<i>not defined</i>) (51.7%) Physician or clinic personnel (37%) Word of mouth from a friend or family member (21%) Telephone messages (% not provided)	Stay indoors (65%) Close windows (20%) Limit outdoor activities (16%) Did not hear advisories (18%) Not provided by subgroup	Stayed indoors (34%) Not provided by subgroup	↓ Respiratory symptoms if heard a PSA (OR=0.25; 95% CIs not provided)	Possible: <ul style="list-style-type: none">▪ Memory recall bias (although lag time between end of exposures and survey not provided)▪ Sample self-selection bias likely (only 26% of reserve homes surveyed)▪ Misattribution of cause-effect (34% reported they did not take action because of advice)

Study	Population	Exposure	Advice Given	Recalled Advice	Compliance	Health Effects	Comments
Kunzli et al. (2006) Retrospective cross-sectional	n=5,551 elementary + 873 high school students in the Child Health Study (CHS) since 1993/1996 Southern CA (2003)	3 months wildfire smoke; ambient hourly PM ₁₀ 10-20 times normal (~1,000 µg/m ³)	Spend less time outdoors Wear masks Use A/C Advised via media (specifics not provided)	Not provided	Reducing time spent outdoors (#1 action performed); % not provided More asthmatics than non-asthmatics stayed indoors or wore a mask	↑ Respiratory symptom rate associated with having stayed indoors (1.2 to 1.6-fold increase); needs to be controlled for asthma rates ↑ Respiratory symptoms if they smelt wildfire smoke for ≥6 days (duration = larger influence than if stayed indoors)	Results may be attributable higher # of asthmatics staying indoors Symptomatic young people oversampled Possible: <ul style="list-style-type: none">▪ Memory recall bias (>2 month lag time between end of exposure & survey)▪ Self-selection bias unlikely (68-98% response rate)▪ Misattribution of cause-effect

Study	Population	Exposure	Advice Given	Recalled Advice	Compliance	Health Effects	Comments
Kolbe and Gilchrist (2009) Retrospective cross-sectional	n=389 aged ≥16 years Albury, New South Wales, Australia (2003)	38 days wildfire smoke; ambient daily PM ₁₀ max =415 µg/m ³ ; ambient hourly PM ₁₀ max=938 µg/m ³	Stay indoors Reduce outdoor physical activity Use masks Advised via mainstream news media (TV, radio, newspaper) & fact sheets for GPs & hospitals, as well as elderly & child care facilities, schools Targeted at-risk first; then, whole community	Stay indoors was the #1 message heard among 53.5% of the 74% who were aware of PSAs. Did not hear advisories (26%) Elderly = least likely to hear advisories	Not provided by type of advice ↑ Likelihood of staying indoors, reducing outdoor activity, and/or preventing smoke getting into homes if heard a PSA (OR: 2.74; 95% CI: 1.50-5.02) Most likely to comply if parents of child ≤16-years	Not provided.	Possible: <ul style="list-style-type: none">▪ Memory recall (surveyed during 2 week period shortly after bushfires)▪ Sample self-selection bias unlikely (81% response rate)▪ Misattribution of cause-effect (most people surveyed reduced their time outdoors whether they had heard an advisory or not)

Study	Population	Exposure	Advice Given	Recalled Advice	Compliance	Health Effects	Comments
Sugerman et al. (2012) Retrospective cross-sectional	n=1,802 primarily aged 35-64 yrs, Caucasian, >High School, pre-existing chronic medical conditions including: hypertension (31%), asthma (15%), COPD (3%), congestive heart failure (3%), angina (5%) San Diego, CA (2007-08)	3 month wildfire (5-7 days of continuous exposure inside & outside their homes); for 7 consecutive days, ambient daily PM ₁₀ exceeded US EPA health std ($\geq 150 \mu\text{g/dL}$); PM ₁₀ =500 $\mu\text{g/dL}$ in some areas Resided >1 mile away from fires	Stay indoors Reduce outdoor physical activity Close windows & doors Wet ash before cleanup Put A/C on 'recirculate' Use HEPA filters Use N95 ³ respirators during ash cleanup Other Advised via media on TV, AM/FM radio, newspaper, internet during 3-weeks of broadcasting	Heard a PSA, in general (88%) Use HEPA-filters or N95 respirators during ash cleanup (<5%) Stay indoors = #1 msg, if asked to recall without prompting; % not provided ▼ Recall if first language ≠ Engl, elderly, lower ed & income, no full-time job ▲ Recall if 18-64 yrs, asthmatic & incr inhaler use, COPD, depressed, fulltime job, >2 days smoke exp	Stayed indoors (59%) Reduced outdoor physical activity (88%) Closed windows & doors (76%) Wet ash before cleanup (76%) Used A/C (16%) Used HEPA-filters (10%) Used N95 respirators during ash cleanup (8%) Not provided by subgroup	Not provided	Possible: <ul style="list-style-type: none">▪ Memory recall bias (surveyed 5-8 months after wildfires)▪ Sample self-selection bias likely (48% response rate)▪ Misattribution of cause-effect (most people surveyed reduced their time outdoors whether they had heard an advisory or not)▪ Underrepresentation of low income homes (no cell phone directory list available)

³ N95 is the National Institute for Occupational Safety and Health (NIOSH) certification rating for filtering half facepiece respirators with 95% filtration efficiency for 0.3- μm particles.