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Evidence Review:

Using masks to protect public health during wildfire smoke events

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Key Points

- Respirators designed to filter particulate matter (PM), rather than other substances, are the most logical choice for public health intervention because: most of the evidence for health effects associated with wildfire smoke focuses on PM and no single respirator can protect against all gases and vapours found in wildfire smoke.
- Filtering half facepiece respirators (FHFR) such as N95 masks provide effective protection against PM. FHFRs are cost effective and can be stockpiled for use at the population level during wildfire smoke events.
- With proper fit and use, FHFR can reduce smoke exposure by 10-fold. Respirators need to be individually fit tested and fit checked to achieve this exposure reduction. Adequate FHFR fit may not be possible for people with certain face shape and size or facial hair.
- FHFR have a limited shelf life. Their stockpiling should not exceed 5 years.
- FHFRs have limited acceptability because they can cause discomfort and breathing resistance.
- FHFR may be particularly valuable for people with susceptibility to adverse effects of smoke who cannot avoid exposure (e.g. during transportation, work).
- Caution should be taken when considering FHFR for those in whom the increased work of breathing may have its own harms (e.g., people with certain respiratory and cardiovascular conditions).

Evidence gaps

- There is very limited evidence on the use of respirators as an individual-level mitigation approach during wildfire smoke events. The evidence found is equivocal. The effectiveness of respirators as a public health intervention has not been fully evaluated.

Considerations

- Respirators may have a role when individuals must be exposed to wildfire smoke, and proper mask use can be ensured. This may be the case for workers who must remain outdoors during smoke events. In such situations, N95 FHFRs can be recommended provided that:
- The respirator has a suitable protection factor. A N95 respirator that is properly fitted and worn would reduce exposure to one-tenth of the ambient PM levels. These respirators can be made available to the public and are moderately comfortable to wear.
- The respirator is properly fitted and the wearer is properly trained about how to use the respirator (e.g., how to don the respirator and perform a fit check) and understands the limitations of the device.
- Respirators are recommended for use only by eligible populations. Some populations who cannot achieve an adequate fit due to size (e.g., children), low likelihood of compliance, or facial hair should avoid using FHFR.

1. Introduction

Preventing harm to individuals living in the vicinity of wildfires is challenging given the complexity of wildfire prediction, management, and health impacts (as illustrated by the evidence reviews on *Wildfire Smoke*, *Smoke Surveillance*, *Health Effects of Smoke*, and *Health Surveillance*). A range of possible intervention measures may help communities mitigate the impact of their exposure to the smoke generated by wildfires. A parallel between the occupational health paradigm of exposure control and the public health arena of intervention can aid in the assessment of possible intervention options. The basic principles of occupational exposure control indicate that source control should be used when possible. Where source control is not feasible, engineering (e.g., ventilation) should be the next approach, followed by administrative controls (e.g., reducing time of exposure), and lastly, personal protective equipment such as respirators. Occupational settings are more readily controlled than community settings, but the principles offer useful parallel. In this review, we examine the use of personal protective equipment as an intervention tool to mitigate the effects of wildfire smoke on public health.

The objective of this evidence review is to clarify what type of respiratory protection can be used by members of the public, what air toxics can be mitigated by the use of such protective equipment, and to identify potential challenges around the effectiveness and efficacy of this intervention.

2. Methods

A systematic search strategy was devised to examine the use of masks during fire events as a public health protective measure. Literature up to the end of October 2013 was included.

Pubmed, Medline, and Embase were used to search for peer-reviewed literature; the Canadian Public Policy Collection (CEL) (including Canadian Public Policy and Canadian Health Research databases) was used to identify relevant grey literature. Non-English materials and literature relating to smoke and fires from sources other than vegetation were excluded.

The following search terms were entered: Respiratory protective devices, Masks, Fires or Smoke, fire* or wildfire*, public or communit* or population or environment*.

Two hundred thirty-three hits were obtained when combining the exposure and protection devices search terms; over 2.2 million entries were identified using the public and community health search terms. After combining the exposure and the public health search, 66 entries were identified and inspected manually. An additional search using Google Scholar did not identify any additional sources.

We excluded occupational exposures to wildfire from our search. Wildland firefighters are members of the population with specialized training and equipped with tools to suppress fires not only difficultly available to the public but also requiring test-fitting and education for proper use as well as considerable financial investment.

3. Respiratory Protection

To provide individual-level respiratory protection during a smoke event, the personal protective equipment must be able to filter very small particles and it must fit, providing a firm seal around the wearer's face to minimize hazardous agents from entering the respiratory system around the edges of the respirator. Personal protective equipment that provides respiratory protection includes respirators that either filter air or supply fresh, clean air.

3.1 Types of masks

3.1.1 Procedure masks

Procedure masks are also commonly referred to as surgical masks. These masks are designed to filter air coming out of the wearer's mouth and do not provide a good seal. As a result, procedure masks tend to be no more effective than commonly available paper dust masks, which are designed to filter out larger particles, such as dust created by sanding, and offer little protection from fine particles in smoke.

Wake and Brown evaluated such so-called nuisance dust masks (including face pads, handkerchiefs and pre-formed cup masks) for their filtration efficiency[1.] The evaluation examined coarse and fine size aerosols (9- and 1.5-µm respectively) at 30 and 150 l/min flow rates to mimic quiet and heavy breathing. Findings showed no difference between wet and dry handkerchiefs, which had the largest penetration (70–97%). The penetration of 1.5-µm particles was 60–90% for all dust masks tested. In all cases, higher airflow was associated with increased filtration (2).

These types of masks may actually be detrimental, giving the wearers a false sense of security and encouraging them to increase their physical activity and time outdoors. **Therefore it is imperative that procedure masks not be confused with respirator masks, such as N95s.**

3.1.2 Respirators

There are two general classes of respirators, classified by mode of operation: air supplying and air purifying devices (3) (Figure 1).

Air-supplying respirators provide clean air via tanks. Self-contained breathing apparatus (SCBA) are the most common respirators in this category. These require specialized training, are much more cumbersome to use (due to factors such as weight), and are used by firefighters during fire extinction activities. Due to the need for specialized training, physical requirements necessary of the users, and equipment maintenance and cost, air-supplying respirators are not in the scope of the present review as a preventive measure realistically implementable at the population level.

Air-purifying respirators (APR) may have either filters, cartridges, or canisters that remove contaminants from the air by passing the ambient air through the air-purifying element before it reaches or is inhaled by the user. The type of cartridge, canister, or filter used on an APR is dependent on the nature of the inhalable hazards: (i) particulate respirators capture particles in the air (e.g., dusts, mists, and fumes) without protecting against gases or vapours; (ii) gas and vapour respirators use chemical filters to remove specific gases and vapours; (iii) combination respirators could have filters for both particles and gases (making them heavier to use). APRs are available in non-powered or powered designs. Non-powered APRs develop a negative pressure inside the facepiece upon inhalation, which draws in air through the air-purifying elements. Powered APRs have extrinsic parts that draw air through air-purifying elements and deliver the clean air to a tightly fitting headpiece, hood, or helmet. These devices, termed powered air purifying respirators (PAPRs), maintain positive pressure inside the respirator.

[1] Filtration efficiency is the degree to which a respirator's filter media remove particulate matter.

Non-powered APRs come in several types (Figure 1) depending on the type of inlet covering (filtering facepiece, mouth bit, quarter mask, half mask, or full facepiece). The most common types are: half facepiece and full facepiece respirators. A half facepiece respirator covers only the nose, mouth and chin. The most common type of half facepiece respirators are the filtering style where the entire facepiece acts as a filter medium attached via two straps (e.g., N95 respirators). A particulate filtering facepiece respirator is typically disposable since it cannot be cleaned after use, nor can the filtering media be replaced. In general, these must be disposed of when: (i) the filter media becomes heavily loaded and causes excessive breathing resistance, (ii) it is physically damaged (damp from users breath, torn, etc.), or (iii) the respirator becomes dirty or unhygienic. Reusable respirators in this category are elastomeric half facepiece respirators, which have a thermoplastic facepiece held against the face by two head straps, and with one or more filters/cartridges that must be attached onto the facepiece. These respirators can be reused as long as the cartridges are discarded and replaced when they become unsuitable for further use. Reusable respirators need to be cleaned and properly stored to optimize the protection they provide. Furthermore, reusable respirators require additional education as it is imperative that the appropriate hazard-specific cartridges or canisters are selected. Similar to the elastomeric half-facepiece, the full facepiece respirator is also made with rubber, silicone, or thermoplastic and covers the entire face from the hairline to below the chin.

In summary, APRs may protect against exposure to particulates, gases, and vapour or a combination thereof. For gases and vapours, the use of a cartridge or canister respirator is mandatory and requires the knowledge of the contaminant of interest. No single type of cartridge protects against all gases and vapours in wildfire smoke. The filtering half facepiece respirator (FHFR) is the most common and widely available respirator that can filter out particulate in the size range of wood smoke particles.

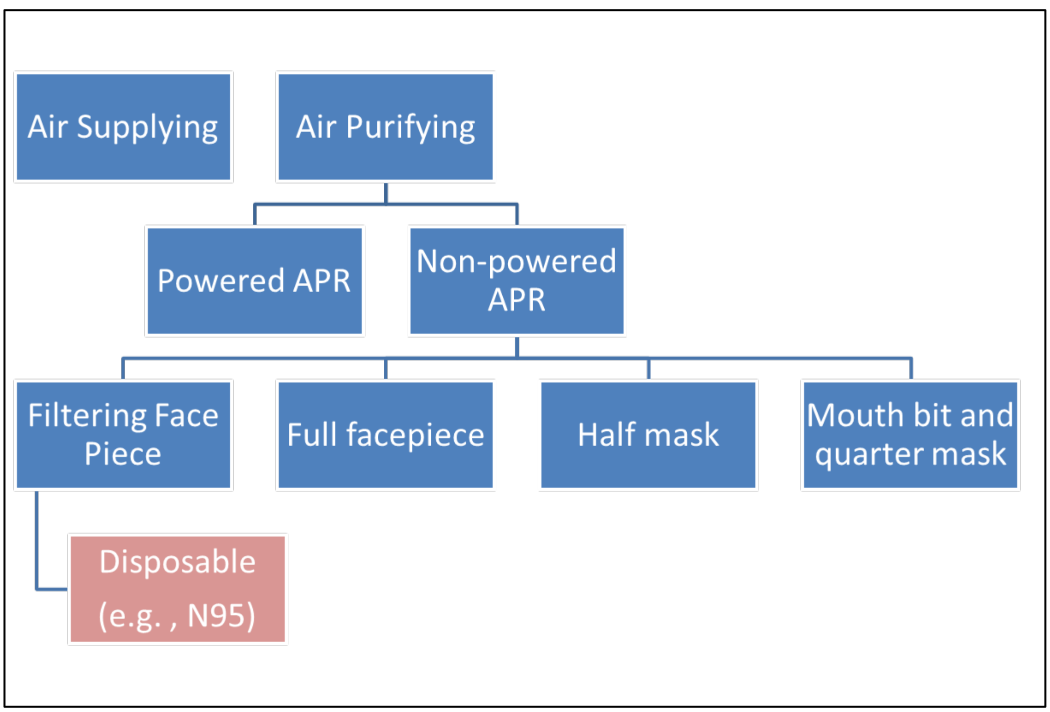

Figure 1. Classification of respirators. Note that nuisance dust masks are not included in this classification, as they provide poor respiratory protection and are not considered as respirators.

4. Effectiveness and efficacy of respirators for particulate matter (PM) exposure

This review focuses on the use of respirators to protect against particulate matter (PM). PM is one of the primary pollutants in wildfire smoke (refer to reviews on *Wildfire Smoke* and *Health Effects of Smoke* for details), and it is the only pollutant type that can be filtered using respirators that are feasible for use in community settings. FHFRs can provide protection against particles in the size range typical of wildfire smoke. The efficacy and effectiveness of FHFRs, which depends on their ability to remove particles from ambient air and their ability to prevent leaks, will be discussed in the following sections.

4.1 Certification of filtering respirators

Globally, respirators are regulated by health and safety agencies[2]. In the United States, the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) are the main bodies that regulate respirator certification. In Canada, respiratory protection use largely follows the American guidelines; however, it is regulated by provincial workers' compensation boards or Ministries of Labour. In Europe, the European Committee for Standardization (CEN) also has standards for protection and classification. Certification is a key aspect in the selection of appropriate respiratory protection. This process will determine the degree and type of protection that will be provided to the wearer, who can then select a respirators certified to protect against known breathing hazards in the wearer's environment.

NIOSH certifies respirators in accordance with Title 42 of the Code of Federal Regulations. Efficiency is evaluated by testing the filter media under constant airflow. Unless there is a firm seal over the wearers face, a respirator will provide little protection, regardless of its filtration efficiency designation.

Unlike respirators, procedure masks and other similar devices are not subjected to NIOSH filter certification testing and are not required to be fit tested. This difference further stresses the need to distinguish respirators such as N95 from non-certified masks. Markings on a NIOSH-approved FHFR may appear on the facepiece itself or on the straps (Figure 2). In particular, the Testing and Certification (TC) number is a good indicator of proper certification. If there is no TC number on the packaging, the user instructions, or the product itself, it is not NIOSH-approved and therefore will not provide respiratory protection. Similarly, European norm (EN149) indicates that respirators have been tested and certified. Along with the manufacturer's name, the type of respirator (e.g., FFP2, the European equivalent of N95), certified respirators need to carry the "Conformité Européen" (CE) number.

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[2] The International Labour Organization standards present a comprehensive system of tools that have legally binding and non-binding applications at the national level. Their practical implementation can be adopted through codes of practices, especially for those governments without health and safety regulating bodies.

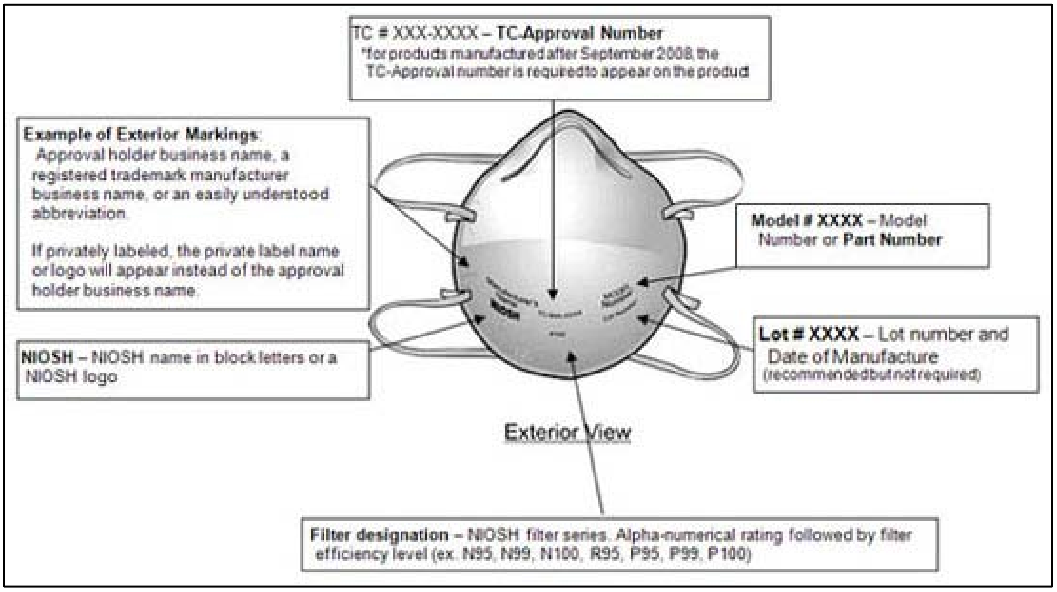

Figure 2. NIOSH certified N95 respirator markings, including TC number (7).

4.2 Filtration efficiency

In the United States, NIOSH certifies nine types of particle-filtering respirators with three classes of filters (N: not resistant to oil; R: somewhat resistant to oil; P: strongly resistant to oil) and three levels of efficiency (95, 99, and 99.97%) in each class. The efficiency indicates the degree to which the filter removes small (0.3 µm) particles as this represents the most difficult particle size to filter and thus the "weakest" filtration capability of a respirator. FHFRs such as N95 respirators can filter fine particulate matter in the size range of wood smoke particles. It should be noted that for 99.97% efficiency is expressed as 100 in the NIOSH filter category. In Europe, respirators are similarly classified according to their filtering efficiency at three levels (1 for 80%, 2 for 95%, and 3 for 99.97%), but using different classes (FFP: disposable respirators; P: half- and full-mask elastomeric respirator with particle filters). Therefore, the European equivalent to N95 is FFP2.

Respirators with HEPA (P100) filters offer the highest protection, but may be less comfortable as they provide more resistance to breathing. P100 respirators may be slightly more expensive than the N95 respirators, for which retail price is between $13 and $25/box of 20 units[3], compared to $10 to $20 each for P100 respirators.

Air-purifying respirators have an assigned protection factor which is thought of as their estimated performance level. The assigned protection factor (APF) is defined by the American National Standard for Respiratory Protection (ANSI Z88.2 1992) as "the expected workplace level of respiratory protection that would be provided by a properly functioning respirator or class of respirators to properly fitted and trained users". It is defined by the ratio of the concentration of contaminant outside the respirator to that inside it. OSHA's Code of Federal Regulation (CFR) 1910.134 provides APF values for FHFRs that are

[3] N95 Pricing from Ackland Grainger invoice for the H1N1 preparedness initiative by the Occupational Health and Safety Agency for Healthcare in BC H1N1 while P100 pricing from 3M website. Available at: http://solutions.3mcanada.ca/wps/portal/3M/en_CA/PPE_SafetySolutions_NA/Safety/

widely accepted in North America. According to this standard, the assigned protection factor of a filtering half facepiece is 10, meaning that it reduces ambient air concentration by 10-fold. A full facepiece has a protection factor of 50. It should be noted that these factors are only applicable for certified respirators and they are usually used in combination with the estimated concentration of a contaminant of interest in occupational settings. For the general population, the assigned protection factor value is likely less important than education about the proper use of respirators.

4.3 Fit testing and seal checks

A fit test is a test protocol conducted to ensure minimal amount of contaminant leakage around the facepiece. Fit testing is essential because the certification procedure evaluates filter efficiency but not face seal leaks. Chen and colleagues investigated face seal versus filter penetration for particles of 0.5–5µm (8,9) and showed that filtration and flow dynamics affect aerosol penetration in distinct ways. It was demonstrated that face seal leaks can be an important penetration pathway for aerosol particles. Moreover, measuring particle penetration under constant flow may not accurately predict filter efficiency under different breathing states (e.g., cyclic or pulsatile breathing). Grinshphun et al. examined both facepiece respirators and procedure masks in varying breathing conditions. Face seal leakage was found to represent the main pathway for fine particles for both respirator and mask (10). These findings indicate the importance of stressing public education with regard to proper fit of masks and seal checks.

Fit testing is the *sine qua non* condition for proper protection. It can be done quantitatively or qualitatively using a test agent. In workplaces where effective engineering controls are not feasible, respiratory protection programs, which include fit testing, are conducted annually for workers exposed to harmful breathing environments. Quantitative fit testing provides a numerical measure of overall penetration of a test chemical into the respirator. Qualitative fit testing relies on the wearer's ability to detect the penetration of a test chemical into the respirator. Either test could be carried out in a community with trained personnel and fit testing equipment, although the qualitative fit test is less costly in terms of training, equipment, and logistics.

Manufacturers of FHFRs often provide instructions to consumers for conducting a proper seal check, which is a procedure conducted by the respirator wearer to determine if the respirator is properly seated to the face. A seal check needs to be performed by the wearer every time the respirator is worn and can be either a positive pressure and/or negative pressure check. For a positive pressure check, the respirator wearer exhales gently into the facepiece while blocking the paths for exhaled breath to exit the facepiece; a slight positive pressure should develop inside the facepiece and cause the facepiece should slightly puff out. To do a negative pressure check, the respirator wearer inhales sharply while blocking the paths for inhaled breath to enter the facepiece; a negative pressure should develop inside the facepiece and cause the facepiece to slightly collapse in. A user seal check is sometimes referred to as a fit check (as opposed to a more rigorous fit test).

4.4 Considerations for proper protection: Evidence from occupational settings

4.4.1 Fit issues

Most published literature concerning the use of respiratory protection devices stems from the occupational settings where the support of employers and the presence of a respiratory protection program are key factors in sustained and proper use of personal protective equipment (11). The effectiveness of respirators is directly related to fit. In addition to individual fit-testing, research in occupational settings has demonstrated that facial hair in the sealing surface of a tight-fitting respirator lead to excessive leakage (12); it is thus strongly recommended that workers be clean shaven. Wearing a respirator can also alter the proper seating of eyeglasses at the nose bridge.

Face shape, which is influenced by race and age, is a major issue in terms of proper obtaining proper fit. Individuals with small anthropomorphic features will seldom obtain a tight fit around the breathing zone, as most respirators are designed for Caucasian anthropomorphic features. Zhuang et al. (13) found statistically significant differences in facial anthropometric dimensions between racial ethnic groups (African-American, Asian, Caucasian, Hispanic) and three age groups (18–29, 30–44, ≥45 years old). This points to the need to have more than one respirator style available so that a variety of individuals from different ethnicities and age groups could be successfully fit tested. Zuang et al. concluded that African-Americans and Hispanics may need larger sizes of respirators. Most of literature on face shape and respirator fit focused on the nose or chin as being the areas where face seal leaks occur (14,15). Consequently, sudden weight gain or loss can also alter the fit of a previously owned respirator.

4.4.2 Other considerations

A certain level of discomfort can result from proper use of respirators. FHFRs increase breathing resistance monotonically with duration of use. In addition, the dead space in FHFRs such as N95 allow for heat accumulation and humidity, which reduce respirator life and increase wearer discomfort. Recent research suggests that exhalation valves can provide some relief from humidity (16).

As demonstrated, implementing a respiratory program within an occupational setting involves a number of barriers. Extrapolating their use to the population level (see section "Challenges around use of respirators in communities"), or even for selected groups, where all these barriers would exponentially grow, would be very challenging.

5. Evidence on the use of masks as a public health intervention

The value of respirator use depends on the severity of the fire and the spatio-temporal extent of its plume. Smoke events can last for weeks, thereby increasing the need to use protective measures which are lower in the hierarchy of control measures, such as respirators, in order to enable members of smoke-affected communities to continue regular activities. Henderson and colleagues examined the impacts of mitigation measures following both wildfires and prescribed burns. The effect of using air cleaners on indoor $PM_{2.5}$ was investigated, as well as the effect of keeping windows closed following four fires in Colorado where households' indoor and outdoor fine PM levels were monitored. They recommended the use of air cleaners inside the homes, whereas mitigation strategies for exposure outdoors remained elusive (17). However, they noted that respirators may be indicated for outdoor exposures, especially for wildfire smoke lasting such long periods. Respirators are not recommended for indoor use because, as described, other control measures such as air cleaners, which were shown to achieve a decrease of 63–88% in homes with the air cleaners operating when compared with homes where only windows were close, can be implemented.

The effectiveness of respirators in community settings has been evaluated in three studies found in our literature search. During the Hoopa Valley wildfires in California 1999, particulate FHFRs (N95) as well as procedure and dust masks were distributed (18). No masks were found to protect the community from adverse lower respiratory tract health effects among residents of the Hoopa Valley National Indian Reservation; the lack of success of the intervention was hypothesized to be due to hours of outdoor exposure, lack of fit-testing, and variability in filtration effectiveness of the respirators or masks used. In addition to efficacy issues, the value of recommending respirators to the general population during wildfire smoke episodes has been questioned because their use may encourage more outdoor activity (18) and therefore potentially increased exposure and health risks. On the other hand, Künzli and colleagues reported that wearing masks (the types of masks were not specifically defined) following the 2003 Southern California wildfires reduced self-reported symptoms (19). The authors reported that those not wearing a mask had symptom rates more than twice as high as those not wearing a mask. They also tested interaction between three levels of exposure (based on reported smell of fire) and symptoms among those who did and did not wear masks (type not specified). Self-reported sneezing increased with increasing exposure for both mask wearers (OR 1.58 for 1 to 5 days of fire smell versus 2.30 for >5 days as compared with no fire smell) and those who did not wear a mask (OR 2.01 and 2.81 respectively), but the gradient was less for those who wore masks. This difference was statistically significant across exposure categories for sneezing but not for other reported events including eye symptoms, cough, and wheeze. Interpretation of results should account for potential recall bias. Inferences of causation are limited by cross-sectional design.

After the 1997 haze disaster in Indonesia, Kunii et al. sought to understand factors determining the severity of respiratory problems. They measured CO, CO_2, SO_2, O_3, PM less than 10 µm in aerodynamic diameter (PM_{10}), and polycyclic aromatic hydrocarbon (PAH) levels, and also interviewed and conducted lung function tests on 543 affected individuals (20). Gender (female), history of asthma, and less frequent use of a mask were significantly associated with development or exacerbation of severe respiratory symptoms. The authors cautioned, however, that while their result might support the hypothesis that frequent use of masks alleviates the severity of respiratory problems, the success of such a mitigation measure was dependent on the use of proper respirator rather than an adaptation such as a handkerchief. Kunii and colleagues also noted that such masks are uncomfortable to use in situations of hot and hazy environments, can exacerbate symptomatology in individuals with cardiopulmonary conditions due to increased breathing difficulties, and could not be realistically sold or distributed to protect all those affected for several months as the filtration efficiency of disposable respirators fades within 8 hours of use[4].

At the global scale, the World Health Organization (WHO) guidelines for vegetation fires (1) provide guidance to members of the general public in the selection of respirators as function of the concentration of PM, more precisely PM_{10}. These guidelines are mostly based on the current understanding of PM adverse effects on the respiratory system; however, this knowledge is not specific to wildfire smoke PM.

6. Considerations for use of respirators as a public health intervention

FHFRs were designed for industrial workplace exposures and several barriers have been highlighted with respect to ensuring a good respiratory program with a good ‘fit’ for all workers. Such issues would be magnified in a community setting.

[4] The authors did not explain why infiltration efficiency fades in 8 hours of use. Presumably, this is related to loss of electrostatic charge in the filter medium and/or filter overload in a heavily contaminated atmosphere.

6.1 Education, training and fit

There are several drawbacks to recommending widespread respirator use in an area affected by wildfire smoke. Without proper education around the use of respirators, community members are likely to use respirators incorrectly and may not understand the importance of having a firm seal (21). As discussed previously, it is impossible to get a good seal on individuals with facial hair. Respirators may also give wearers a false sense of protection particularly in non-occupational settings where supervision of proper use would be limited, leading them to ignore other recommendations such as reducing physical activity or staying indoors and ultimately increase their exposure to smoke.

Finally, it is important to remember that an FHFR such as an N95 cannot protect from all inhalation hazards due to fire smoke. FHFRs do not remove gases. Only individuals using elastomeric respirators or PAPRs with appropriate cartridges/canisters can obtain protection from both particulate and gaseous hazards. Their use requires additional training and education and possibly medical assessment.

Escape respirators, which are designed typically for a short one-time use during emergencies, can help people while moving to a safe area. However, these types of respirators may be hard to fit as the seal is around the neck instead of the facepiece and may not fit individuals with small or very large neck sizes. Other escape respirators use a nose clip and mouthpiece clenched between the teeth, which circumvent the problems around face, neck size, and facial hair. Unfortunately, most of these types of respirators available in the market are designed to filter gases and not particles.

6.2 Heat stress and breathing resistance

When properly fitted, FHFR increase resistance to air flow and can contribute to heat stress. Healthy adults may find that the increased effort required for breathing makes it uncomfortable to wear a mask for long periods of time. In addition, breathing resistance increases with respirator efficiency. Most healthy adults can use an N95 respirator without excessive breathing resistance. At higher efficiencies, breathing resistance will increase and the user may experience more discomfort, especially if wearing respirators for long periods of time. With elastomeric respirators (excluding loose fitting PAPRs), the impact of breathing resistance would likely be higher compared with FHFR because of the increased cartridge size and dead space.

6.3 Respirator use with specific populations

Several groups are expected to be more susceptible to the health effects of wildfire smoke. These include the very young, pregnant women, the elderly, and individuals with pre-existing respiratory and cardiac morbidities (22; refer to review on *Health Effects*). Mitigation measures should be carried out with a focus on the most susceptible members of the community. However, use of FHFRs presents a tradeoff between the benefit of mitigating the effect of PM exposure from wildfire smoke and the added risks of wearing respiratory personal protective equipment.

6.3.1 Groups for whom FHFR are not advisable

Respirators are designed for adults working in industries such as health care and construction. There are no respirators that have been specifically designed to provide a proper seal for small children. Thus, FHFR are not appropriate for use by children.

6.3.2 Groups who may be candidates for use of FHFR

FHFR such as N95 respirators have a certain efficacy under ideal conditions, but these are difficult to achieve in an entire population. Despite the fact that they will not likely reach maximum efficiency, FHFRs will reduce wildfire smoke exposure to some extent.

Among vulnerable populations, the benefits of FHFR use (decreased exposure) must be weighed against the risks: ineffective use due to fit issues, strain on pulmonary and cardiovascular system due to increased work of breathing. Furthermore individual factors may outweigh those due to a vulnerability (e.g., a vulnerable person may not get a good fit). The evidence base does not support clear guidance on which populations are most likely to benefit. We offer some general considerations:

- Workers who provide essential services (e.g., emergency responders) may require FHFR. Many such groups are healthy and some have formal training of respiratory protection.
- Other workers who need to work outdoors for extended time periods.

6.3.3 Groups requiring further assessment prior to advising FHFR use

Pregnant women, the elderly and people with asthma and other cardiovascular and pulmonary conditions have not been adequately assessed with respect to the benefit of using FHFR compared with the risk of adopting such measures.

- Pregnant women are usually advised to be very cautious during haze episodes. However, there is little evidence demonstrating the effect of fire smoke on fetuses with the exception of a study conducted following the 2003 Southern California wildfires where the authors showed a slightly reduced average birth weight among infants exposed in utero (22). Women have increased strain on cardiovascular and respiratory systems during pregnancy so advice to use a FHFR should be individual and monitored.
- The elderly are at greater risk of pneumonia and chronic obstructive pulmonary diseases (COPD) following fire events. Similarly, people with pre-existing respiratory conditions such as COPD respond to biomass smoke at lower dosages and shorter durations of exposure than do people without pre-existing conditions (23). Because respirators can make breathing more difficult, their use may lead to physiological stresses such as increased respiratory and heart rates. Respirators can also contribute to heat stress. Thus, respirator use by those with cardiopulmonary and respiratory diseases can be dangerous, and should only be done after medical assessment and/or under a doctor's supervision (21).
- Asthmatics are possible candidates for use of FHFRs. In a study on children's health effects from the Southern California wildfire, respirator use was higher among asthmatics compared with non-asthmatics (19), and those adopting mitigation measures (masks[5], air filters, and/or staying indoors) showed less risk for wheezing and runny nose compared with those not taking preventive measures for the same exposure gradient. Similarly, Kunii et al. identified being asthmatic as a determining factor for use of masks[5] during the 1997 Indonesian haze, with a subsequent decrease in severity of pulmonary symptoms (20). This indicates potential effectiveness among asthmatics during a wildfire smoke situation.

[5] Types of masks used were not ascertained by the researchers.

6.4 Operational Considerations

6.4.1 Stockpiling: Reusable vs. disposable half facepiece respirators

Respirators such as N95s are readily available and inexpensive, making them feasible for public health interventions. However, availability of N95 FHFRs from local suppliers can become limited during periods of unexpected high demand. In the event of a prolonged smoke event, FHFRs would need to be replaced regularly. Keeping stockpiles of N95 respirators may not be feasible at the national level. (International assistance was required to provide respirators during a wildfire smoke event in Indonesia in 1997 (25)). Storing N95s may, however, be considered for smaller communities prone to wildfire smoke exposure, in which case wildfire preparation plans should specify who, where, and when to use respirators.

Plans to stockpile respirators should consider that all certified FHFR have an expiration date after which the respirator should not be relied upon to provide the expected level of protection. This shelf life, which is generally about 5 years for N95, varies depending on the storage condition variables (temperature, humidity, etc.).

6.4.2 Costs

Direct and indirect costs of using respiratory protection as a public health intervention should be considered. Direct purchase costs for FHFRs such as N95 are low. There are also indirect costs associated with community respirator interventions, even if targeted toward subgroups of the population. There are additional costs associated with ensuring proper fit of respirators (education, training, etc.), logistical costs (sourcing, storage, distribution, etc.), and maintaining stocks of FHFRs that have a limited shelf life. Despite these costs, distributing masks free of charge to the public was found to be feasible in a low income community in the Hoopa Valley (18).

6.4.3 Communication, risk perception, and uptake of respiratory protection interventions

There has been a slight shift in management policies around prescribed burns and wildfires in North America. Historically, US agencies and land management professionals advocated for quick suppression of all fires to prevent impacts on human settlement, and evacuating populations when quick suppression could not be accomplished. With increasing evidence that evacuation may not be the ideal strategy to protect the public, there has been a shift toward the Australian model of “Stay and Defend or Leave Early”. Consequently, the question of preparedness and individual-level risk mitigation has gained more importance and legitimacy. The role of media in the public’s risk awareness and preparedness for wildfires has grown in recent years (27). Cova and colleagues proposed a framework for preparedness for wildfire events where the capacity to stay and defend is composed of “personal capacity” (i.e., mental and physical readiness), “conditions of the ground” (i.e., landscape and maintenance of the physical property), and “available equipment,” which requires the presence of personal protective equipment including respirators (28).

The role of the media on behaviour modification and impact on public health was examined during the severe wildfires in 2003 in Victoria and southern New South Wales in Australia. Kolbe and Gilchrist reported widespread respiratory impacts from an extreme bushfire smoke pollution event among residents of the city of Albury (29). Over 70% of people responding to a mail survey reported changing behavior during the smoke event. People who saw, heard, or read media advisories in which different suggestions, including remaining indoors and wearing masks outdoors, were almost three times more likely to report behaviour change than those who did not. Although use of respirators is not part of Australian public health advisories, 6% of the survey respondents reported wearing masks. However, the main protective measure adopted was to remain indoors. While the authors did not expand on reasons for adopting the recommendation of remaining indoors over the use of masks, it can be speculated that barriers such as masks availability, or comfort issues could explain this difference.

6.5 Existing recommendations for respirator use in wildfire smoke events

There is only one reported event of wildfire smoke where mass distribution of filtering respirators at the national scale was deployed (30). Assistance to Indonesia during the 1997 fires was provided by the United Nations, non-governmental organizations (NGOs), and other nations (e.g., Taiwan provided 100,000 respirators; UNICEF provided 21,650 respirators) (31). There were widespread acute health impacts of this haze event, though it is not known what, if any, effect the distribution of respirators had on the severity of health outcomes[6].

Some published mitigation measures recommend the use of respirators or masks, while others specifically advice against the use of masks, particularly nuisance or dust masks (see Appendix for an overview of wildfire smoke guidance with specific reference to masks or respirators).

- The WHO developed the *Health Guidelines for Episodic Vegetation Fire Events* to increase awareness of the potentially serious public health impacts of haze and provide a framework for governmental management and response plans. These guidelines discuss the development of National Haze Action Plans to ensure preparedness of the population to the potential health impacts of vegetation fire pollution (1). As part of the guidelines, WHO provides guidance to members of the general public in the selection of respirators as function of the concentration of PM_{10}.
- In the United States, the California Environmental Protection Agency (EPA) smoke guidelines currently being adopted for national use by national agencies such as the US EPA, Centers for Disease Control and Prevention (CDC), and Forest Service, recommend the use of respirators among a list of specific strategies, while cautioning that their use is only for healthy individuals who need to work outside. Public health officials are instead given guidelines to recommend reducing physical activity and avoid outdoor activity by remaining indoors based on the EPA's air quality index for the general and vulnerable populations. While the California plan is under scrutiny by federal agencies, different states adopt separate strategies.
- In other parts of the world, similar divergence in recommending respirators as a preventive measure is noted. Following the Southeast Asian wildfire episodes (1990, 1991, 1994, 1997 and 1998), countries affected by poor air quality conditions adopted an inter-agency framework for wildfire management where respirators are part of the mitigation measures for public health impact. In

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[6] One such mask was tested in laboratory settings (32) and found to provide 80–90% filtration efficiency for the particle sizes present in biomass smoke at normal resting or moderately active respiratory rates. However, despite this relatively high filtration efficiency, the magnitude of the face seal leakage (up to 100% for sub-micron particles) indicates that selection of tight-fitting respirators and fit-testing is essential for protection. It should also be noted that this investigation was done in accordance with NIOSH certification testing parameters as defined during that decade. However, even with contemporary respirators that comply with today's certification requirements, leakage remains an important factor to take into account for proper respiratory protection.

particular, in 1997 in Indonesia, the widespread and commercial distribution of respirators similar to N95s to the general public for an air pollution event was unprecedented.

7. Evidence gaps

At present, given the paucity of research around their effectiveness for general population use there is a clear need to advance our understanding of the feasibility of adopting such mitigation measure. Along with this line of research, development of personal respiratory protection suited for use by the general population is another important research effort to deploy. Education of the population regarding specific respirators to use, who should use them, how and when to wear them will increase their effectiveness and clear communication strategies are a key element in effective preparation for wildfires (33). A respirator program should be part of an overall wildfire preparedness plan. The respirator program should include which situations would warrant FHFR use, locations of stockpiles, and a program of fit-testing and education for users.

8. Summary

Despite efforts to prevent and control fires, measures may be necessary to help mitigate public health impacts of wildfire smoke exposure, and FHFRs may be beneficial in some circumstances. This review focused on respirators that protect against PM because (i) PM from wildfire smoke has been associated with adverse health outcomes in multiple studies across a range of settings and populations, and (ii) respirators that protect against particulate matter (i.e., N95) are less expensive and have fewer technical requirements than those that protect against vapours and gases. N95 respirators will not protect the wearer from detrimental exposure to non-particle components of smoke (e.g., CO, gas-phase PAHs). The use of specialized breathing equipment protecting from several fire smoke's toxic agents, such as that used by firefighters for example, is not feasible due to logistical, cost, and training reasons.

Since the most studied wildfire smoke exposure is PM, and given the fact that respirators such as N95s which are widely available in North America have been evaluated in a few studies, the evidence presented above was limited to those respirators (FHFR).

While in many situations, populations may be better protected through other interventions, masks have a role when individuals must be exposed to wildfire smoke, and proper mask use can be ensured. This may be the case for workers who must remain outdoors during smoke events. In such situations, N95 FHFRs can be recommended provided that:

- The respirator has a suitable protection factor. A N95 respirator that is properly fitted and worn would reduce exposure to one-tenth of the ambient PM levels. These respirators can be made available to the public and are moderately comfortable to wear.
- The respirator is properly fitted and the wearer is properly trained about how to use the respirator (e.g., how to don the respirator and perform a fit check) and understands the limitations of the device.
- Respirators are recommended for use only by eligible populations. Some populations who cannot achieve an adequate fit due to size (e.g., children), low likelihood of compliance, or facial hair should avoid using FHFR.
- Appropriate and clear guidance is provided. Many Indigenous communities have pre-existing health vulnerabilities, and culturally-sensitive education messages to mitigate their exposure to fire smoke need to be carefully tailored.

The use of FHFR may be warranted despite the limitations, because they can be expected to provide some level of protection from PM. These are relatively inexpensive respirators that can be distributed to a large segment of the population, especially subpopulations at higher risk from smoke exposure. The use of FHFR for some members of the general population for whom respirator use is unlikely to pose additional health impacts and an effective face seal can be achieved, may be helpful in mitigating some of the health effects associated with exposure to wildfire smoke. A range of interventions can be used to minimize health impacts of wildfire smoke. These include reducing activity outdoors, remaining indoors with air cleaners, using an air shelter, and evacuation. When used in conjunction with these other interventions, masks may have a role in protecting the public's health.

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Appendix: Existing mitigation measures with specific mention of mask or respirator use[7].

Jurisdiction	Agency/Program	Recommendation
US: California	California Environmental Protection Agency	• Use of respirators is one item among a list of specific strategies for healthy individuals who need to work outside for short-term.[8]
US: Idaho	Department of Health and Welfare	• N95 recommended for residents who must be outside. N95 are made available to the public free of charge along with recommendations for using them.[9]
US: Alaska	Department of Environmental Conservation	• Warns against the use of "facemasks" or dust masks as well as bandanas and wet towels. Recommends staying indoors to limit exposure to smoke.[10] • The drawbacks around the use of respirator masks (fit testing, seal checks, facial hair, etc.) are delineated to limit their use and explain how the effectiveness is limited.
US: Arizona	Arizona Department of Health Services	• Among the personal measures recommended, "common" masks are not recommended.[11] • HEPA respirators are suggested for people who do not have lung disease.
US	National Jewish Health	• Warns against the use of dust masks. • Refers to CDC's National Institute for Occupational Safety and Health for proper use of N95.[12]
Canada: Alberta	Environmental Public Health, Alberta Health Services	• Use of masks is not recommended as a personal measure to mitigate exposure.[13]
Australia: Government of Western Australia	Department of Health	• Indicates that most masks will not provide adequate protection.[14]

[7] Note that these guidelines are not necessarily evidence based, but are provided here for reference. Please refer to the original sources for further detail.

[8] http://www.arb.ca.gov/carpa/toolkit/data-to-mes/wildfire-smoke-guide.pdf

[9] http://healthandwelfare.idaho.gov/Health/EnvironmentalHealth/WildfireSmoke/tabid/2172/Default.aspx

[10] http://dec.alaska.gov/air/smoke_qa.htm

[11] http://www.azdhs.gov/phs/oeh/pdf/fireplan506.pdf

[12] http://www.nationaljewish.org/about/mediacenter/pressreleases/2012/wildfire-smoke/

[13] https://myhealth.alberta.ca/alberta/Pages/Lower-smoke-exposure.aspx

[14] http://www.public.health.wa.gov.au/cproot/5033/2/Bushfire%20users%20guide%20%20Final.pdf

Jurisdiction	Agency/Program	Recommendation
Singapore		• N95 respirators recommended as a function of air quality category (from normal to hazardous based on the Pollutants Standard Index) for healthy individuals who work outside for prolonged time and for the general public when air quality is in the hazardous range.[15] • Not recommended for children, respiratory compromised individuals, elderly, use indoors, short exposures (e.g., commuting from home to school or work). • For women in the in the 2nd and 3rd trimesters of pregnancy, N95 advised only for short durations. • Online guidance provided on where to buy N95 respirators.
Indonesia	Minister of Environment and National Disaster Management Coordinating Board	• Recommends use of N95 and facilitates its distribution during severe haze episodes.[16]
Thailand	The Directorate General of the Center of Communicable Disease Control and Environmental Health	• Recommends the introduction and distribution of FHFR, especially for vulnerable populations (pregnant women, elderly).[17]
Global	WHO guidelines	• Recommends use of N95 for susceptible individuals involved in outside activities for PM_{10} concentrations 350–500 µg/m^3, healthy people involved in outside activities for PM_{10} 500–600 µg/m^3, susceptible people in indoor facilities without atmospheric controls for PM_{10} 600–800 µg/m^3, healthy persons in indoor facilities without atmospheric controls for PM_{10}>800 µg/m^3.[18]

[15] http://www.gov.sg/government/web/content/govsg/classic/subsite/haze/mask

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