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# Using Digital Technology to Protect Health in Prolonged Poor Air Quality Episodes: A Case Study of the AirRater App during the Australian 2019–20 Fires

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**Abstract:** In the southern hemisphere summer of 2019–20, Australia experienced its most severe bushfire season on record. Smoke from fires affected 80% of the population, with large and prolonged exceedances of the Australian National Air Quality Standard for fine particulate matter ($PM_{2.5}$) recorded in all major population centers. We examined if AirRater, a free smartphone app that reports air quality and tracks user symptoms in near real-time, assisted those populations to reduce their smoke exposure and protect their health. We distributed an online survey to over 13,000 AirRater users to assess how they used this information during the 2019–20 bushfire season, and why it was helpful to aid decision-making in reducing personal smoke exposure. We received responses from 1732 users (13.3%). Respondents reported the app was highly useful, supporting informed decision-making regarding daily activities during the smoke-affected period. Commonly reported activities supported by information provided through the app were staying inside (76%), rescheduling or planning outdoor activities (64%), changing locations to less affected areas (29%) and informing decisions on medication use (15%). Innovative and easy-to-use smartphone apps such as AirRater, that provide individual-level and location-specific data, can enable users to reduce their exposure to environmental hazards and therefore protect their health.

**Keywords:** smoke; particulate matter; smartphone app; digital technology

## 1. Introduction

Globally, landscape fires cause major environmental, economic, social and health impacts, both through the direct effects of fire and from consequential negative impacts on air quality [1,2]. Climate projections indicate a substantially greater fire risk in the future, with a warming climate driving conditions that precipitate landscape fires. These include more severe and prolonged droughts resulting in increased fuel loads and increased efficiency of ignition sources, such as dry lightning [3,4]. As a result, future fires are likely to be more frequent, larger, longer and more often, with prolonged and severe episodes of poor air quality more likely in many regions [5,6].

These conditions have major implications for human health, as landscape fire smoke has a well-established association with poor health outcomes—Johnston et al. estimated 339,000 deaths annually are attributable to landscape fire smoke exposure worldwide [2]. Although landscape fire smoke is complex in character and contains many chemicals harmful to health, the major component affecting health is particulate matter less than 2.5 microns in diameter, or $PM_{2.5}$ [2]. Effects on health are especially pronounced for specific population groups, such as the elderly, the young, and for those with existing medical conditions, including cardiovascular and respiratory conditions [7–12]. For example, a study of landscape fire events in the state of Washington (USA) from 2006–2017 found a 35% increase in the odds of same-day respiratory mortality for those aged 45–64 years when exposed to smoke from landscape fires [13]. Additionally, research from the 2010 fires in Moscow showed excess deaths of almost 11,000 during this period when compared to other periods without wildfires, and mostly from older age groups and for those with existing cardiovascular and respiratory conditions [14]. There is also some evidence for health impacts on pregnant women and their developing fetus [15,16].

Considering the interconnections between bushfire activity, climate change and health, there is an urgent and increasing global need to develop and adopt public health communication tools, both at the individual and the government/agency level, to assist vulnerable people to reduce their smoke exposure and to manage their health during landscape fire events. The use of digital technology is one possible adaptation solution, with smartphone apps playing a key and growing role in information dissemination and communication during disasters [17].

In recent times, a plethora of digital services have become available allowing consumers to track air quality. These include websites, and more commonly smartphone apps, that display air quality data from around the world (for example, IQAir, AirMatters, BreezoMeter and PurpleAir) or for specific locations (for example, SmokeSense in the United States and CanberraAir in Canberra, Australia). These technologies gather data from a mix of regulatory government air quality monitoring networks and/or low-cost air quality monitors, although difficulties ensuring the reliability and applicability of low-cost air quality monitors remain [18]. Smartphone apps specifically have the potential to support health during prolonged or extreme poor air quality events by providing vulnerable individuals with easily accessible information to inform health-protecting behaviors (for example, staying indoors to reduce exposure or taking preventative medications).

However, despite this proliferation, to date there has been a paucity of research on the efficacy of smartphone apps to help individuals reduce their smoke exposure and manage their health during extreme or prolonged smoke events, including analyzing factors that might be important in determining usability.

### *1.1. AirRater App*

AirRater is a free smartphone app developed by the University of Tasmania, launched in Tasmania in October 2015 (see www.airrater.org). The app was designed to assist people vulnerable to poor air quality to better manage their health. The app provides users with easily understood, near real-time air quality information, including $PM_{2.5}$ and temperature (gathered from official government sources) and pollen (gathered from local pollen monitors where available). Users can enter their respiratory symptoms (such as sneeze, wheeze or cough) into the app, which also records their location. Over time, AirRater helps the user determine potential environmental triggers of their symptoms, and can send a notification when these are recorded at high levels in the user's current location, enabling the user to take actions to protect their health. AirRater's functionality, and capacity to identify local drivers of respiratory disease are explained in detail elsewhere [19,20].

### *1.2. Research Aim*

Using a case study approach, this study aims to investigate if digital technology (such as the AirRater smartphone app, which provides user-friendly, real-time and location-specific air quality information) is useful in helping individuals to reduce their smoke exposure and therefore protect their health during a period of prolonged poor air quality (as experienced in the Australian 2019–20 summer season). We specifically investigate: if AirRater was successful in reaching individuals vulnerable to poor health outcomes during prolonged exposure to smoke; the types of impacts experienced by respondents; if information obtained through AirRater caused health protective behavior change and the features of AirRater that most enabled ease of use.

## 2. Materials and Methods

### 2.1. Study Setting

While fires are a common and well-established feature of the Australian forest landscape [21], the complex of megafires which occurred across Australia's eastern seaboard from September 2019 to February 2020 was exceptional in terms of geographic scale, duration, severity and the size of the population affected [22]. Several other large-scale fires also occurred during this period, including on Kangaroo Island in South Australia, and numerous fires through Western Australia (see Figure 1). Combined, these events burned approximately 97,000 km$^2$ [23] and caused significant smoke exposure for the most densely populated regions of Australia, with large exceedances of the Australian National Air Quality Standard for particulate air pollution [24] occurring from days to months and affecting 80% of the Australian population [25].

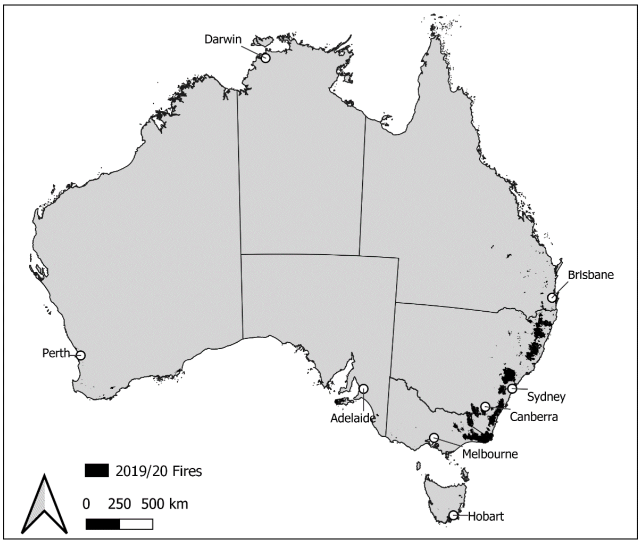
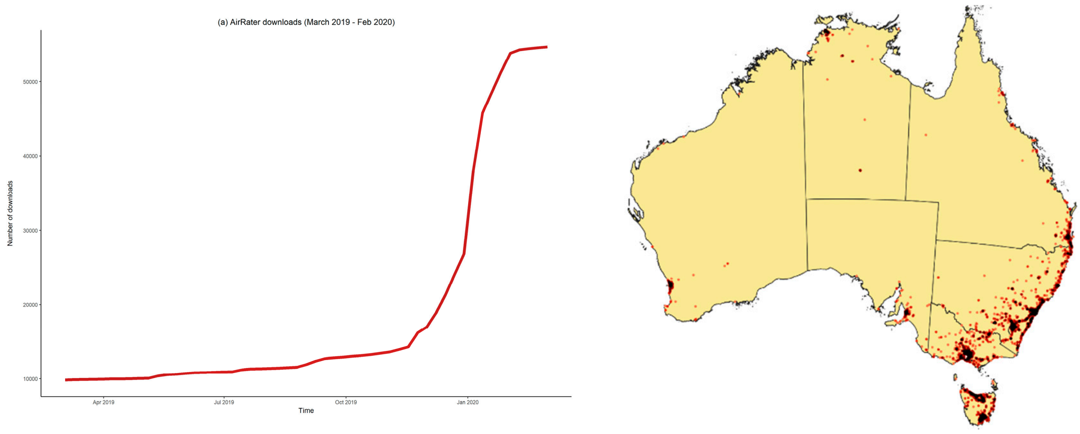



**Figure 1.** Fire boundaries for the Australian 2019–20 fire season, within areas classified as temperate forests and woodlands [26,27].

Early research using statistical modelling estimates that smoke from this event was responsible for over 400 excess deaths, over 2000 hospitalizations for respiratory conditions and over 1000 hospitalizations for cardiovascular conditions [28]. This is compared to 35 deaths directly attributed to the bushfires [29].

During the 2019–20 bushfire season, downloads of AirRater increased over five-fold from pre-season levels (see Figure 2a), with substantial user downloads occurring outside the three jurisdictions where AirRater is currently funded to operate (Tasmania, the Australian Capital Territory and the Northern Territory) (see Figure 2b). This reflected the growing number and locations of people affected by fires and smoke throughout the season, especially in densely populated regions around Brisbane, Sydney and Melbourne.




(**a**) (**b**)

**Figure 2.** (**a**) Number of AirRater downloads from March 2019 to Feb 2020. (**b**) Map of Australia showing AirRater downloads (as of 6 March 2020). The darker areas indicate a greater concentration of downloads.

### 2.2. Study Methodology

During February 2020, an online survey request was emailed to 13,162 AirRater users who had given permission for follow-up when registering for the app, across six Australian jurisdictions highly affected by the 2019–20 summer bushfire season: New South Wales (1849 users), Queensland (204 users), Victoria (1133 users), South Australia (82 users), West Australia (177 users) and the Australian Capital Territory (9717 users). Differences in user numbers across jurisdictions reflect the time the app had been available in that region, and the relative populations of each region that were smoke affected. The survey was open for two weeks and reached 13,021 users, with a reminder sent at day 10.

Survey questions centered on three themes: the health of the respondent during the prolonged smoke events of summer 2019–20; high-efficiency particulate air (HEPA) room cleaner purchase and use and how the respondent used the information provided by AirRater. This paper focuses on two of these themes: the health of respondents and AirRater use. A mix of qualitative and quantitative questions were used. A full list of survey questions and response options can be found in Supplementary Materials (S1). Survey responses were downloaded in CSV format. R v3.5.3 [30] was used to analyze quantitative data, while qualitative data were analyzed using thematic analysis.

The University of Tasmania Health and Medical Human Research Ethics Committee approved this research (reference number H0015006).

## 3. Results

A total of 1732 survey responses were received, giving a response rate of 13.3%. The vast majority (94.1%; $n$ = 1630) replied to the survey questions for themselves, with a minority (4.3%; $n$ = 75) replying on behalf of someone they cared for (for example, a child). The remainder responded on behalf of a group, for example, as an educator in a day care facility, as sports club executive or as a work safety delegate for a work site, public amenity or at a public event.

### 3.1. Health-Related Outcomes

The majority of respondents (61.4%) identified one or more risk factors that could result in them being more vulnerable to poor health as a result of prolonged smoke exposure. Most noteworthy was having a pre-existing lung condition (35.9%), followed by being over 65 years (21.2%), noting that respondents could nominate more than one type of risk factor (see Figure 3).

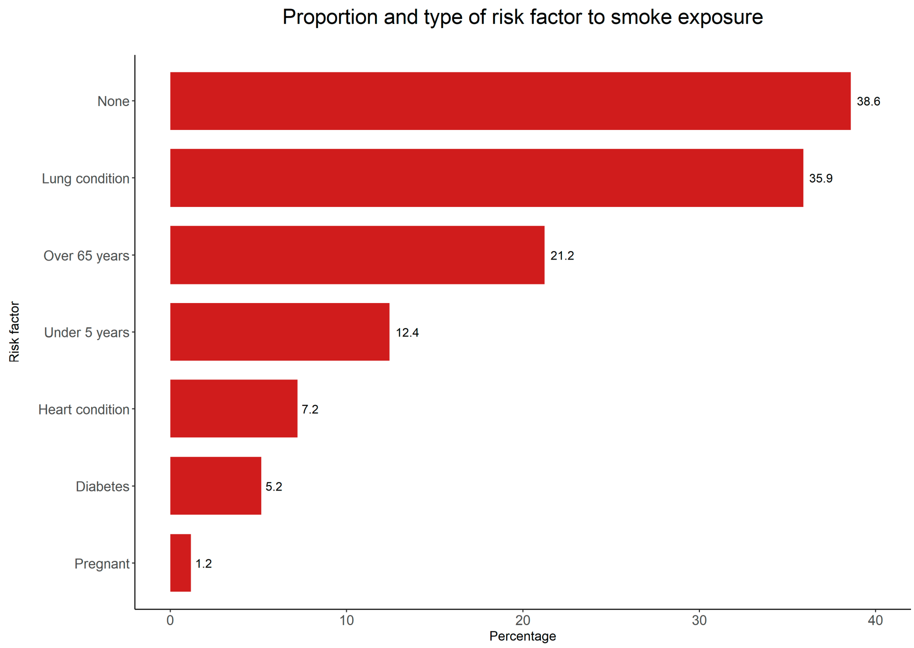



**Figure 3.** Proportion of respondents reporting a risk factor to smoke exposure.

When asked about symptoms related to smoke exposure, the majority of respondents (79.8%; $n$ = 1382) reported that smoke from the bushfires had affected their health or the health of the person they cared for, citing a wide variety of symptoms. These included minor physical symptoms such as irritated or dry throat (61.4%), irritated or watery eyes (60.8%) and sneezing (30.2%), through to potentially more severe physical symptoms such as shortness of breath (37.7%) and chest tightness (31.5%). Mental or mood-based symptoms were also reported by respondents, with almost half (46.6%) reporting feeling anxious, stressed or worried; 22.4% reporting feeling irritable, angry or short-tempered and 21.3% reporting feeling depressed (see Figure 4, noting respondents could report more than one symptom).

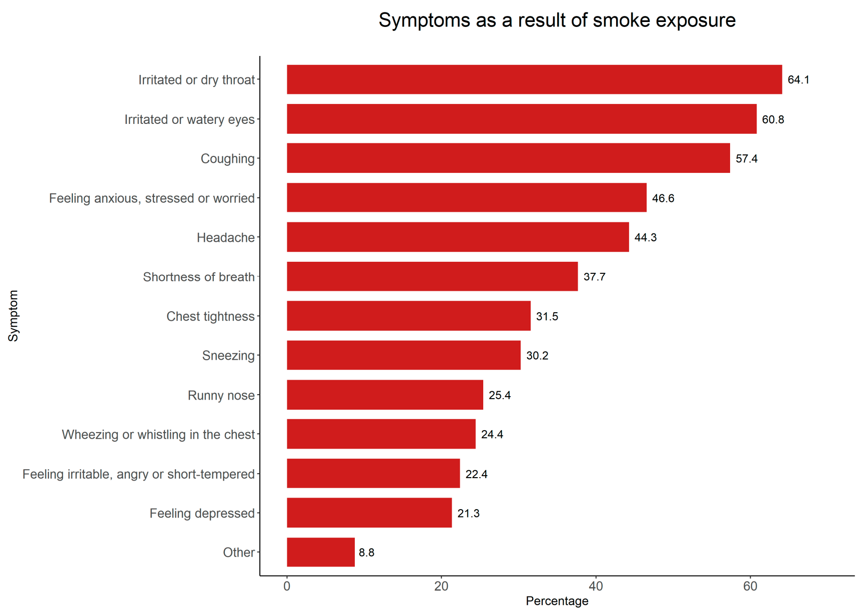



**Figure 4.** Symptoms reported as a result of smoke exposure.

Other symptoms reported ($n$ = 143) included nose bleeds, nausea, flare-ups of asthma symptoms, chest pain, inability to sleep, tiredness and lethargy. Several respondents noted decreased mental health related to an inability to exercise safely, solastalgia, and stress related to previous bushfire events.

Approximately one third of respondents (32.6%) reported missing school or work as a result of smoke and/or fires, with 7.2% reporting this occurred five times or more. For 6.5% of respondents, this was due to school or work being closed.

Approximately one third of respondents sought medical advice about their symptoms, with visiting a general practitioner (GP) (22.6%) and talking to a pharmacist (12%) the most prominent activities (see Figure 5, noting this reports only the types of medical advice when advice was sought). Several respondents sought online advice, searching information on minimizing smoke in the house; reading government advice and directives; using 'Dr Google' and researching international advice. Some respondents left their place of residence to avoid smoke, for example, to an air-conditioned motel for an extended time, and other respondents reported seeking advice from complementary medicine practitioners. Two-thirds of respondents did not seek medical advice.

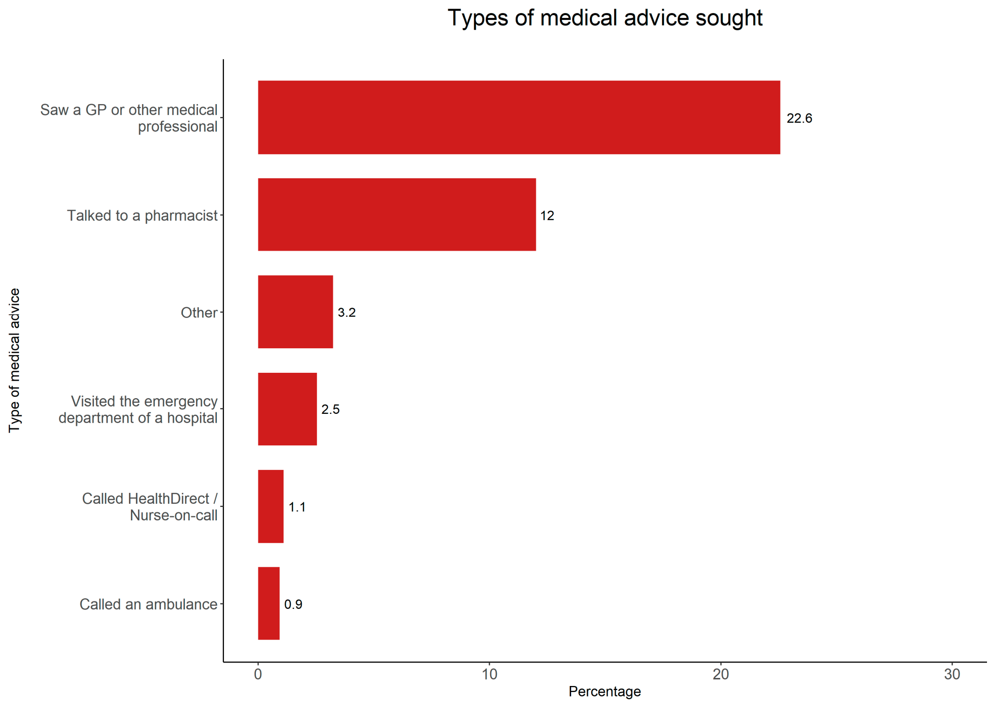



**Figure 5.** Types of medical advice sought for health conditions associated with smoke exposure.

## *3.2. AirRater Use*

Almost 60% of respondents found AirRater 'extremely useful' or 'very useful' in helping to manage symptoms associated with smoke, with a further 20.2% rating it as 'quite useful'. The features respondents liked most about AirRater included the map showing air quality information nearby (74.7%), the ability to save multiple locations (for example, both home and work) (43.7%) and automated notifications when smoke levels were elevated (37.8%) (see Figure 6, noting respondents could choose multiple features).

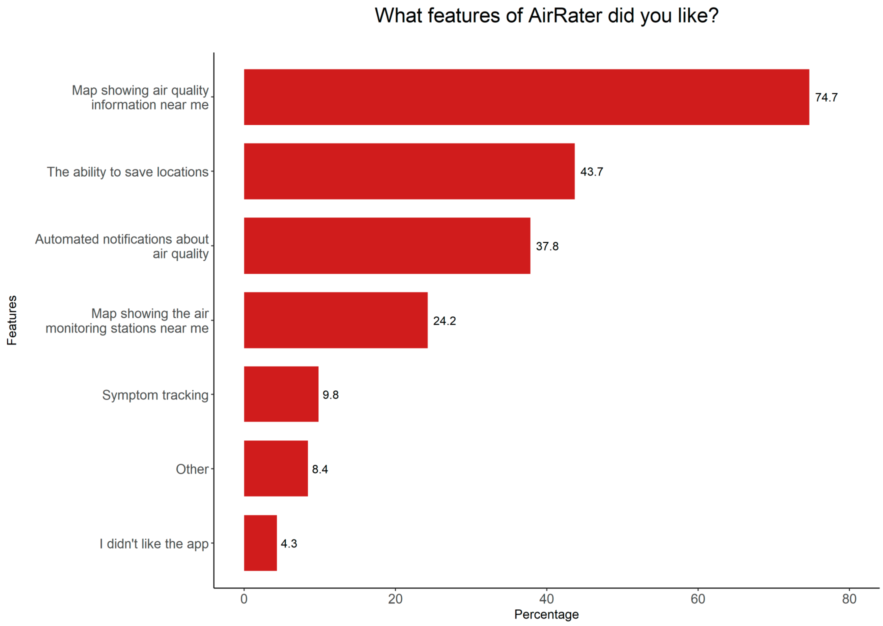



**Figure 6.** Features of AirRater most liked by respondents.

Other AirRater features liked by respondents included having access to near real-time updates (1-h average updates as opposed to 24-h rolling averages typically reported by regulatory agencies); the ability to easily see air quality information in multiple locations and seeing air quality trends. Respondent statements supporting these preferences can be found in Supplementary Material (S2).

A small percentage of respondents (4.3%) did not like the app, citing technical reasons. Respondents who liked some features of the app also commented on technical difficulties experienced at times. Some respondents commented on the reliability of the air quality data in their region as a limitation of the app.

When asked how information from AirRater was used, almost 95% of respondents reported they changed one or more behaviors to reduce their smoke exposure. Over three-quarters (75.9%) of respondents stayed indoors, and around two-thirds (66.2%) of respondents used AirRater to determine when it was best to close or open their windows and doors. Just under two-thirds (64.1%) used AirRater information to reschedule or plan their outdoor activities, while just over one-fifth (20.7%) were more aware of the link between air quality and their own health (see Figure 7, noting respondents could choose multiple options).

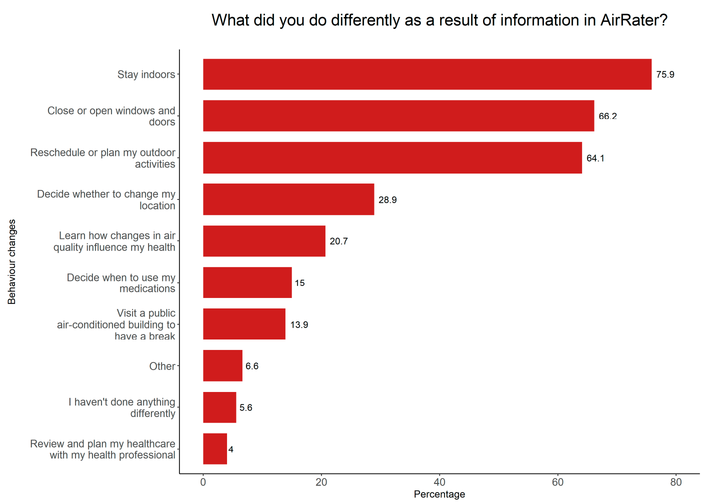



**Figure 7.** Behavior changes as a result of local information provided by AirRater.

Other behavior changes informed by the app aimed at reducing smoke exposure included: deciding on exercise plans; deciding on work patterns; deciding when to wear a face mask and helping to explain or inform others of the situation. Respondent statements supporting these behavior changes can be found in Supplementary Material (S2).

Over two-thirds (69.5%) of respondents also sought air quality information from alternate sources. These included various state government air quality and health websites (e.g., ACT Health, Victoria Environment Protection Authority and New South Wales Department of Planning, Industry and Environment), other apps and websites (e.g., AirVisual, CanberraAir, AQICN, PurpleAir, AirMatters) and traditional news sources such as radio, TV and online. Checking the visibility of nearby landmarks and viewing and smelling the air were also used in conjunction with formal government sources.

When asked about the features of the app or website users found most useful, ease of use and navigation (45.7%), ease of understanding information (43.6%) and access to near real-time data (40.9%) were cited as the top three features (see Figure 8, noting respondents could choose more than one response). Trustworthiness of information (31.8%) and access to local information (30.8%) were also important.

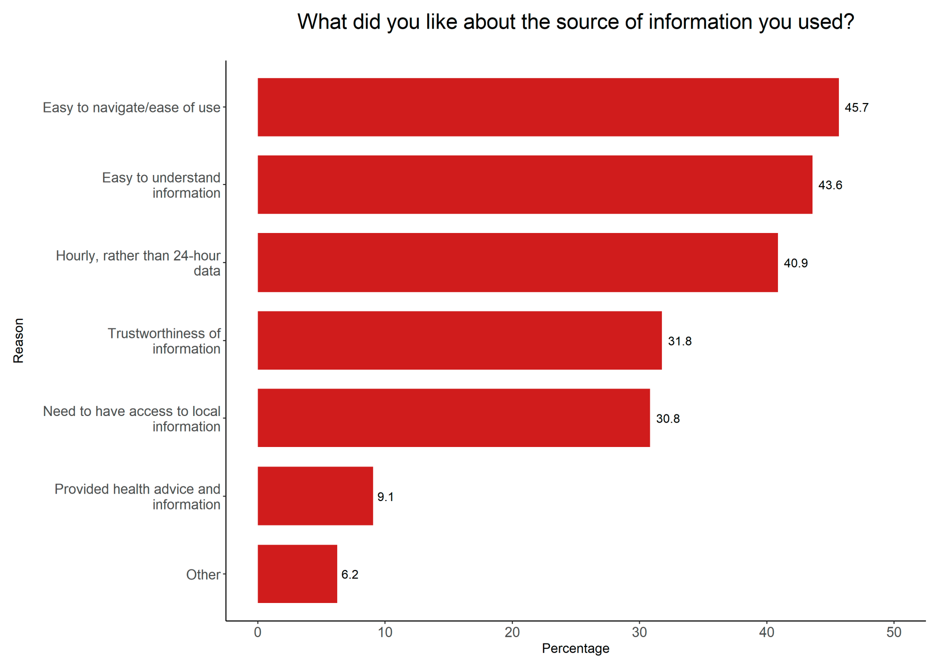



**Figure 8.** Features of information source most liked by respondents.

## 4. Discussion and Conclusions

Our study shows that prolonged and severe smoke events, such as those occurring in Australia over the 2019–20 summer season, have substantial and potentially serious health and social impacts mainly for vulnerable individuals. Our results further demonstrate the AirRater smartphone app supported these individuals to make decisions to reduce their smoke exposure. This suggests that digital technologies such as AirRater, that provide easily interpreted, reliable, real-time and location-specific air quality information, are useful in helping vulnerable individuals to make decisions about reducing their smoke exposure and protecting their health during these types of events.

Behaviors such as staying indoors, limiting exercise on days of poor air quality, and reducing the movement of air from outdoors to indoors (i.e., closing doors and windows) have previously been identified by Laumbach et al. [31], as measures that successfully reduce smoke exposure. In addition, health protection measures such as using preventive medications, visiting air-conditioned buildings and wearing face masks, have similarly been identified by Vardoulakis et al. [32], as behaviors supporting reduced smoke exposure. These measures are strongly recommended by public health authorities (for example, New South Wales Department of Health [33] and the Centre for Air Pollution, Energy and Health Research [34]). Survey respondents report these types of behavior changes based on air quality information supplied by AirRater, demonstrating that when individuals have access to relevant and accurate information, they are able to act on the recommended advice to protect their health.

Furthermore, the most-liked features of air quality information sources highlighted by survey respondents demonstrate that easy to understand, timely, localized and trusted information is critical to decision-making. These information characteristics are strongly recommended by Vardoulakis et al. [32] to manage health risks due to smoke exposure, and are highlighted as key features of smartphone apps for asthma management [35].

Our key finding—that apps with features such as AirRater can reduce smoke exposure and support health management during poor air quality events—is potentially generalizable across regions where landscape fire smoke poses a potential health risk. For example, this has been demonstrated by the Smoke Sense app in the United States [36]. However, these regions must have robust, supported and widely distributed air quality monitoring networks and a reliable population-wide internet connection. As we found in our study, there are limits to usability when lack of reliable air quality data leads to unreliable information. A further caveat is that our findings likely reflect utility amongst a subset of the population, as AirRater's overall user base is more likely to be drawn from those with a concern about air quality and health impacts. Furthermore, the AirRater user base (or the user base for any air quality information app) is more likely to include those with adequate digital, health and language literacy to facilitate downloading an app and understanding the information, and sufficient economic and social means to act or change behaviors based on that information [19].

While our study specifically examined the use of AirRater during an extreme event, the findings are broadly consistent with previous evaluations of the app that focused on app use during periods with no major air quality exceedances, or in more predictable periods of poor air quality, such as increased seasonal pollen loads, increased smoke as a result of planned burns, and urban air pollution caused by winter wood heater use. These evaluations found that users had still applied app information to support health-promoting decisions about their home environment, activities and medication use [19]. Our findings on the prevalence and nature of the health impacts experienced during the 2019–20 summer are also consistent with the FluTracking survey [37] and the Asthma Australia survey [38], which investigated the extent to which respondents experienced health symptoms as a result of smoke exposure over the course of summer 2019–20.

Strengths of our study include the timing of survey, which was distributed, responded to and closed before COVID-19 became a widespread public health emergency in Australia. The responses therefore reflect participant views in the few weeks between the bushfire and smoke crisis and the COVID-19 pandemic, with subsequent surveys on the fire season unlikely to yield similar results. Our study is limited by self-reporting bias and is likely to be completed by those with a strong interest in health and air quality, and more likely to be completed by those with higher levels of literacy as discussed earlier.

While accurate air quality information is clearly helpful for individual decision making, delivery of this information via digital technology is heavily reliant on a reliable internet connection and a level of literacy and numeracy that enables decision-making to be effective. Where this is not the case, consistent public health advice, distributed through multiple networks that do not rely on reliable internet connections and high levels of literacy, is paramount [39]. Solutions to these issues deserve further attention by researchers and policymakers.

Our findings also highlight the ongoing role that access to reliable and accurate public health information plays in a natural disaster. While Finch et al. [40] show that social media potentially has several beneficial roles in these circumstances, the specific use of smartphone apps in natural disaster and emergency response situations deserves greater research and policy consideration. For example, further investigation is needed into the health economic benefits of providing timely and accurate air quality information and public health advice, which allows health protective behaviors to occur, as opposed to an increased load on emergency services in response to smoke exposure.

In summary, digital technology such as the AirRater smartphone app appears to be highly useful to inform individual decision-making aimed at protecting health during periods of prolonged and severe poor air quality, such as those experienced in the 2019–20 Australian bushfires. With increasing likelihood of these types of events globally due to a warming climate, the expansion of technologies such as AirRater, coupled with investment in robust air quality monitoring networks, is likely to bring greater benefits to vulnerable individuals in affected communities around the world.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2571-6255/3/3/40/s1, S1: Survey questions and response options; S2: Respondent statements.

**Author Contributions:** Conceptualization, S.L.C., P.J.J., A.J.W. and F.H.J.; Data curation, S.L.C. and G.J.W.; Formal analysis, S.L.C.; Funding acquisition, P.J.J., A.J.W. and F.H.J.; Investigation, S.L.C.; Methodology, S.L.C.; Project administration, S.L.C.; Resources, G.J.W. and C.L.; Software, S.L.C., G.J.W. and C.L.; Supervision, F.H.J.; Validation, S.L.C. and P.J.J.; Visualization, D.M.J.S.B. and F.H.J.; Writing—original draft, S.L.C.; Writing—review and editing, S.L.C., P.J.J., G.J.W., A.J.W., C.L., D.M.J.S.B. and F.H.J. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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