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Blinded by smoke: Wildfire smoke exposure and eye irritation in australian wildland firefighters

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ABSTRACT

Purpose: Wildfire occurrence is increasing worldwide, putting firefighters and general public at increased risk of eye injuries from smoke exposure. This study explored ocular symptoms and use of protective eyewear amongst wildland firefighters in Australia.

Methods: Australian wildland firefighters were invited to complete an online survey about the occurrence of eye irritation, use of protective eyewear and behaviours associated with occupational smoke exposure. Responses were analysed using logistic regression and qualitative inductive content analysis.

Results: 338 wildland firefighters completed the survey. Eye irritation was reported by 90 % of firefighters at least *sometimes* during work and by 70 % after work. Frequency of eye irritation was greater amongst females than males (OR 2.01, CI 1.22–3.31, $p < 0.001$). Protective eyewear was used *often* or *always* by 67 % of firefighters on the fireground, however 55 % had to remove their protective eyewear due to sweat, fogging or another reason. Goggles were more likely to be removed compared to sunglasses and safety glasses (OR 4.28, CI 2.75–6.68, $p < 0.001$).

Firefighters reported that, at times smoke exposure necessitated eye closure and impaired vision on the fireground. Firefighters also reported that protective eyewear helped to reduce eye symptoms, but its consistent use on the fireground was difficult. The severity and recovery from eye symptoms varied between participants.

Conclusion: Australian wildland firefighters frequently experience eye irritation from smoke exposure, and this can affect operational capabilities. These findings can support the development of evidence-based strategies to help protect and aid recovery of the eye surface following smoke exposure.

1. Introduction

Increased frequency and severity of large wildfires driven by climate change is subjecting millions of people worldwide to poor air quality and challenging the local emergency services response. The Black Summer fires of 2019–2020 exposed 11.2 million Australians [1] to smoke. In excess of 80,000 Australian emergency services personnel were involved in managing the fires [2,3]. In 2023, more than 10,000 wildland firefighters managed the Canadian wildfires [4]. This included workers from the 600,000 strong USA wildland firefighting workforce [5].

Due to their proximity to fires, firefighters' exposure to smoke is substantially higher than the general population and often beyond levels considered safe based on national standards [6,7,8]. Adverse respiratory and cardiovascular effects from occupational smoke exposure are extensively reported in wildland firefighters [9–12], however little attention has been paid to the impact on the ocular surface. Only one study to date reported that 80 % of emergency services personnel (firefighters and police) working on a large forest fire in Israel experienced eye irritation [13]. Two studies from wildfires in USA in 1991 and 1998 reported that eye problems, including injuries and corneal abrasions were responsible for up to 10 % of all firefighter presentations to hospital emergency departments [14,15]. However, low to moderate grade ocular problems are unlikely to lead to emergency hospital presentation which likely conceals the true incidence of eye problems amongst wildland firefighters.

A better understanding of the impact of wildfire smoke on eyes of firefighters can also inform on the potential impacts of wildfire smoke on the general community, who are increasingly exposed to large amounts

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of smoke, and for extended periods of time from uncontrolled wildfires [16,17]. Almost three quarters of the general community surveyed during the Australian Black Summer wildfires of 2019–2020 reported eye symptoms [18]. 18 % of emergency department presentations during a large wildfire in the Australian capital city in 2003 were caused by eye problems including irritation, ulcers and foreign bodies [19].

Personal protective eyewear is made available for Australian wildland firefighters along with guidelines for their use on the fireground [20,21]. Personal protective equipment aims to prevent dermal, respiratory, and ocular exposure to smoke and fire. National (AS/NZS 4824:2021 and AS/NZS 1337: 2010) [22,23] and international standards (ISO 16073:2019) along with agency-specific guidelines (such as Australasian Fire and Emergency Services Council (AFAC) guidelines [20] describe the protective clothing, footwear, headwear (including eye and ear protection) and respiratory protective devices that should be used by wildland firefighters. Eye protection can involve the use of sealed goggles, full-face respirators, or self-contained breathing apparatus (with full face mask) depending on the conditions (Fig. 1). Firefighting goggles aim to provide a sealed fit on the face, often using foam or rubber gasket around the edges and adjustable elastic straps as headbands. Goggles often contain ventilation gaps on the frame edge to enable air exchange and reduce fogging of the lenses during use.

To extend current understanding of the impact of wildfires on eye health, this study aimed to characterise eye symptoms reported by Australian wildland firefighters, their utilisation of protective eyewear and other behaviours associated with occupational smoke exposure of the eyes.

2. Method

A cross-sectional survey of Australian emergency services personnel was conducted between July 2021 and November 2022. Approval from the University of New South Wales Human Research Ethics panel (HC#210462) was obtained including the use of implied consent through participation in the survey.

All 34 AFAC member organisations were approached to participate. A survey invitation containing an online access link was distributed by participating emergency services agencies to their members via email, newsletters, and intranet sites. Employed or volunteer members older than 18 years of age with a history of smoke exposure through emergency wildfire management or planned burning were eligible to participate.

The survey, co-designed with operations and safety team members of the participating emergency service agencies is reproduced in Fig. 2. It comprised of 16 questions of which 12 were mandatory on eye symptoms and use of protective eyewear during and after wildfire duties and demographics. The survey included 8 Likert scale questions, 7 categorical questions, and 1 open-ended question used to elicit qualitative responses about how participants' eyes felt during or after occupational wildfire smoke exposure.

2.1. Statistical analysis

For analysis, the 5-option Likert scale responses were collapsed into three categories; *always* and *often* were combined, as were *rarely* and *never*, thus creating the three categories 'always/often', 'sometimes' and 'rarely/never'. Similarly, *strongly agree* and *agree* were combined and *strongly disagree* and *disagree* were combined to create the three categories: 'strongly agree/agree', 'neutral', and 'disagree/strongly disagree'. Age and years of experience were binarised (<50 and ≥50 years of age and <10 and ≥10 years of occupational wildfire smoke exposure).

Ordinal and binary logistic regression analyses were performed using generalised linear models to examine the effects of age, gender, years of wildland firefighting experience and use of protective eyewear on the occurrence, management, and perception of eye irritation by participants. Analyses were adjusted by including age and gender, along with the predictor variable in the model. SPSS version 27 was used for analysis and significance was set at $p < 0.05$.

Inductive thematic analysis was carried out on the responses to the open-ended question (Q11). A member of the research team (SJ) familiarised themselves with the responses and inductively coded the data including the symptoms reported. Certain description of symptoms denoting the same meaning were grouped together e.g. 'scratchy' and 'itchy', 'pain' and 'sore', 'gritty' and 'sand in eyes', 'tired' and 'fatigued'. Themes were searched for based on the coding and were reviewed and refined by two authors (SJ & AB) until there was agreement on the names and definition of the final themes. This process allowed for determination of patterns in the responses without relying on a pre-existing theoretical framework, ensuring the themes were based on participant experiences and perceptions.

3. Results

Seven emergency services organisations with wildland firefighting workforces from 3 Australian states agreed to participate and distributed invitations to their members: NSW Volunteer Rescue, Fire and Rescue NSW, NSW Parks and Wildlife Service, Country Fire Association (Victoria), Department of Environment, Land and Water (Victoria), South Australian Metropolitan Fire Service, and Department for Environment and Water (South Australia). From these, 338 responses were received, and the demographics of participants are shown in Table 1.

Detailed results are provided in Figs. 3–5 and Tables 2 and 3. Key findings are highlighted in the text below.

3.1. Eye irritation and use of protective eyewear

90 % of participants reported that eye irritation was a problem at work at least *sometimes* (Q1, Fig. 3a). Eye irritation was felt *always* or *often* by 54 % of participants during work, and by 30 % after work (Q2 and Q3, Fig. 3a). Female participants and participants equal to or older than 50 years were more likely to report eye irritation to be a problem during or after work (Q1) (females: unadjusted Odds Ratio (OR): 1.91, 95 % CI 1.16–3.14, $p = 0.011$, equal to or older than 50 years: unadjusted OR: 1.71, 95 % CI 1.11–2.63, $p < 0.016$, Table 2a). Female participants were also more likely to report higher frequency of eye irritation (Q2) than males (unadjusted OR: 2.01, 95 % CI 1.22–3.31, $p < 0.01$, Table 2a).

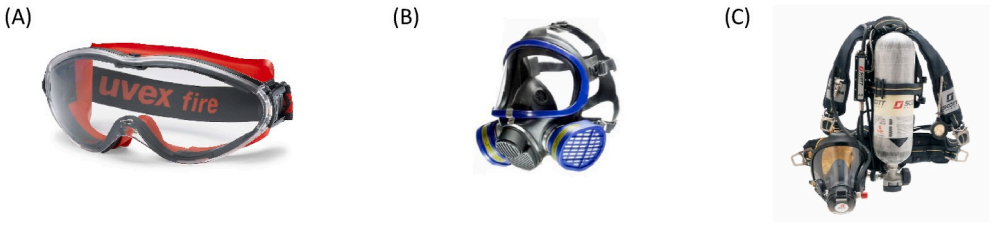

Fig. 1. Examples of eye protective devices used by wildland firefighters. (A) goggles (Ultravision fire goggles, Uvex), (B) full-face respirator (X-plore 5500, Drager), and (C) self-contained breathing apparatus (Scott Safety, AIR-PAK 75, Fisher Scientific).

1. Eye irritation is a problem either during or after work.* Never/Rarely/Sometimes/Often/Always
2. How often do you feel eye irritation?* Never/Rarely/Sometimes/Often/Always
3. I continue to feel eye irritation after I finish my work.* Never/Rarely/Sometimes/Often/Always
4. I rinse my eyes during or after work.* Never/Rarely/Sometimes/Often/Always
5. I use eye protection when working in smoky environments.* Never/Rarely/Sometimes/Often/Always
6. Please select one item from the following, which you use most frequently, to protect your eyes while working in smoky environments. Safety glasses (workplace approved)/Goggles/Sunglasses/Full face respirator/Face Shield/Other (eg regular spectacles)
7. The item in Q6 adequately protects my eyes from wildfire smoke.* Strongly disagree/disagree/neutral/agree/strongly agree
8. I have to remove the item selected in Q6 during my work due to sweat/fogging/other reason. Never/Rarely/Sometimes/Often/Always
9. I worry about long term effects (eye irritation and/or other problems) on my eyes from the smoke exposure.* Strongly disagree/disagree/neutral/agree/strongly agree
10. I have visited a doctor/eye care practitioner/pharmacy because of eye irritation. from my work in smoky environments* Yes / No / Unsure
11. Please describe in your own words how your eyes feel during or after exposure to wildfire smoke.
Demographic questions
12. Please identify your primary role in emergency services during wildfire periods* Firefighter (including voluntary)/ Paramedic/ State Emergency Service (SES) personnel including voluntary/ Rescue Operator (including voluntary) /Other
13. Please provide postcode of your primary worksite that you operate from
14. How many years have you been exposed to wildfire smoke while working in emergency services?* Less than 1 year/ 1-5 years/ 6-10 years/ More than 10 years
15. What is your age?* 18 - 29 years/ 30 - 39 years/ 40 – 49 years/ 50 - 59 years/ 60- 69 years/ 70+ years/ Prefer not to say
16. How do you describe your gender?* Male/ Female/ Non-binary/ Prefer not to say/ I use a different term

Fig. 2. Survey questions and response options. Mandatory questions are indicated with asterisks (*).

Table 1
Demographics of survey participants.

Gender	n (%)
Male	265 (78 %)
Female	68 (20 %)
Prefer not to say	3 (1 %)
Non-binary	1(<1 %)
I use a different term	1 (<1 %)
Age (years)	
18–29	58 (17 %)
30–39	75 (22 %)
40–49	95 (28 %)
50–59	80 (24 %)
60–69	27 (8 %)
70+	3 (1 %)
Years of occupational wildfire smoke exposure	
<1 year	8 (2 %)
1–5 years	67 (20 %)
6–10 years	63 (19 %)
>10 years	200 (59 %)
Role	
Firefighter	318 (94 %)
Rescue Operator	13 (4 %)
Other	7 (2 %)
State	
New South Wales	156 (46 %)
Victoria	96 (29 %)
South Australia	86 (25 %)

Almost 10 % of participants reported *never* or *rarely* using protective eyewear, while two-thirds (66 %) used protective eyewear *always* or *often* when working in smoky environments (Q5, Fig. 3b). Goggles were most commonly used by 56 % of participants, followed by workplace approved safety glasses (21 %) and sunglasses (17 %) (Fig. 3). Over half (55 %) of participants removed their protective eyewear *always* or *often* due to sweat, fogging or other reason (Q8, Fig. 3b).

Participants who *always* or *often* removed protective eyewear during work were more likely to report eye irritation being a problem either during or after work, compared to those who *rarely* or *never* remove protective eyewear (if protective eyewear *always* or *often* removed: unadjusted OR: 2.13, 95 % CI 1.05–4.33, p = 0.037, Table 2a). In addition, removing protective eyewear during work was associated with eye irritation continuing after work (if protective eyewear *always* or *often* removed: unadjusted OR: 5.32, 95 % CI 2.61–10.83, p < 0.001; if *sometimes* removed: unadjusted OR: 2.15, 95 % CI 2.15–4.48, p = 0.041, Table 2a).

3.2. Behaviours and beliefs associated with eye irritation and protective eyewear

Goggles were more likely to be perceived as protecting eyes adequately from wildfire smoke compared to sunglasses and safety glasses (unadjusted OR: 3.08, 95 % CI 2.01–4.71, p < 0.001, Table 2b). However, goggles were also more likely to be removed due to sweat, fogging or other reason compared to safety glasses and sunglasses (unadjusted OR: 4.28, CI 2.75–6.68, p < 0.001, Table 2b). Participants who continue to feel eye irritation after work were less likely to believe that their primary protective eyewear protects their eyes adequately from wildfire smoke (if *often* or *always* feel eye irritation after work: unadjusted OR: 0.33, 95 % CI 0.20–0.56, p < 0.001; if *sometimes* feel eye irritation after work: unadjusted OR: 0.56, CI 0.34–0.93, p = 0.023, Table 2b).

More than a third (38 %) of participants rinsed their eyes *always* or *often* either during or after work (Q4, Fig. 3a). Participants with greater than 10 years of wildland firefighting experience were less likely to rinse their eyes during or after work (unadjusted OR: 0.63, 95 % CI 0.42–0.94, p = 0.024, Table 2c). Participants who reported eye irritation to occur *always, often* or *sometimes* at work were more likely to rinse their eyes during or after work (eye irritation occurs *always* or *often*: unadjusted OR: 8.68, 95 % CI 3.64–20.66, p < 0.001, eye irritation occurs *sometimes*: unadjusted OR: 4.77, 95 % CI 1.20–11.41, p < 0.001, Table 2c). Participants who remove protective eyewear *always* or *often* or *sometimes* were more likely to rinse their eyes during or after work, compared to those who *never* or *rarely* remove their protective eyewear (if *always* or *often* remove protective eyewear: unadjusted OR: 4.89, 95 % CI 2.42–9.88, p < 0.001, if *sometimes* remove protective eyewear: unadjusted OR: 2.44, 95 % CI 1.18–5.06, p = 0.02, Table 2c).

Only 17 % of participants reported having sought professional healthcare advice for smoke-related eye irritation (Q10). Participants with more than 10 years of occupational wildfire smoke exposure were less likely to have visited a doctor or eyecare practitioner for smoke related eye irritation (unadjusted OR: 0.46, 95 % CI 0.24–0.86, p = 0.016, Table 2c). Participants who continued to feel eye irritation after work were more likely to see a doctor or an eyecare practitioner for smoke related eye irritation *(if often* or *always* feel eye irritation after work: unadjusted OR: 15.53, 95 % CI 4.57–52.76, p < 0.001*; if sometimes* feel eye irritation after work OR: 6.37, 95 % CI 1.85–21.20, p < 0.001, Table 2c). Participants who *always* or *often* worried about long term eye problems associated with occupational smoke exposure were more likely to visit doctor or eyecare practitioner for smoke related eye irritation (unadjusted OR: 5.71, 95 % CI 2.16–15.06, p < 0.001, Table 2c).

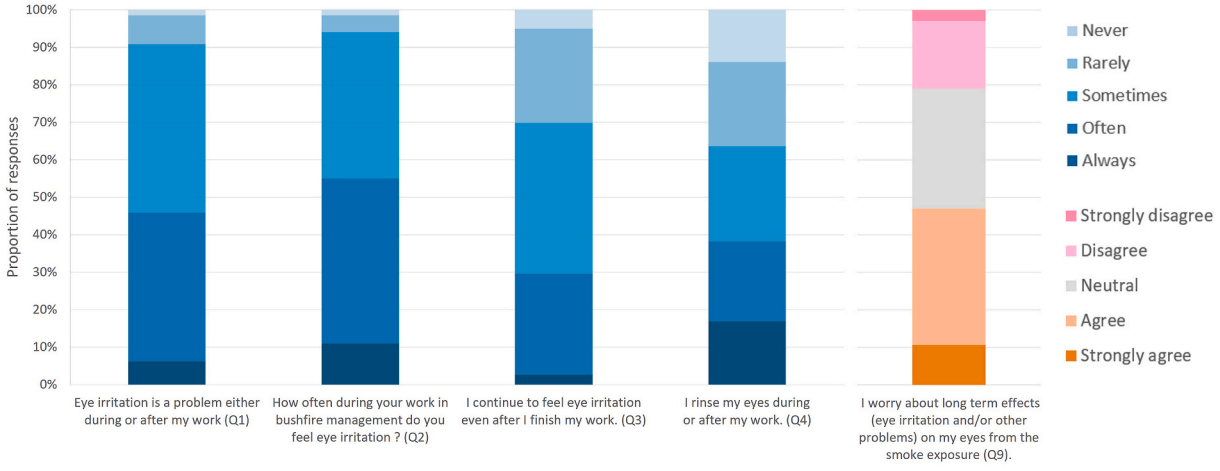

Fig. 3a. Responses of 338 Australian wildland firefighters to survey questions about eye irritation (Q 1–4, 9).

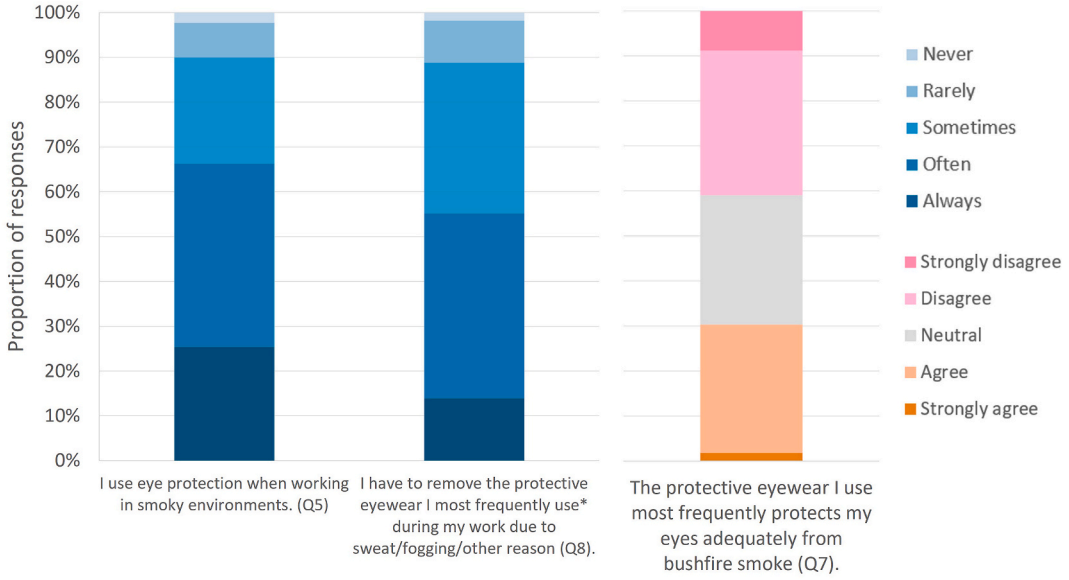

Fig. 3b. Responses of 338 Australian wildland firefighters to survey questions about protective eyewear use (Q 5,7,8). *The most frequently used protective eyewear used is reported in Q6 (see Fig. 3).

Table 2a
Predictors for the occurrence of eye irritation amongst 338 Australian wildland firefighters. Adjusted analyses were conducted to control for the effects of age and gender.

		Unadjusted analyses		Adjusted analyses	
		OR (95 % CI)	p-value	OR (95 % CI)	p-value
Eye irritation is a problem either during or after work					
Participants who are:	Female	**1.91 (1.16–3.14)**	**0.011**	n/a	
	Male (ref)				
Participants aged:	≥50 years	**1.71 (1.11–2.63)**	**0.016**	n/a	
	<50 years (ref)				
Participants who use protective eyewear:	Always/Often	1.94 (0.972–3.87)	0.06	1.827 (0.916–3.64)	0.087
	Sometimes	1.90 (0.89–4.08)	0.10	1.754 (0.815–3.77)	0.15
	Rarely/Never (ref)				
Participant whose primary protective eyewear is:	Goggles	1.07 (0.703–1.637)	0.746	1.148 (0.743–1.771)	0.53
	Sunglasses & safety glasses (ref)				
Participants who remove protective eyewear:	Always/Often	**2.13 (1.05–4.33)**	**0.037**	**2.03 (1.03–4.00)**	**0.041**
	Sometimes	1.06 (0.50–2.23)	0.89	1.05 (0.51–2.14)	0.091
	Rarely/Never (ref)				
How often do you feel eye irritation?					
Participants who are:	Female	**2.01 (1.22–3.31)**	**< 0.001**	n/a	
	Male (ref)				
Participants aged:	>50 years	1.56 (0.99–2.45)	0.053	n/a	
	<50 years (ref)				
Participants who use protective eyewear:	Always/Often	**2.29 (1.15–4.55)**	**0.018**	**2.15 (1.08–4.27)**	**0.029**
	Sometimes	1.74 (0.81–3.71)	0.153	1.64 (0.77–3.52)	0.20
	Rarely/Never (ref)				
Participant whose primary protective eyewear is:	Goggles	**1.64 (1.07–2.49)**	**0.022**	**1.70 (1.1–2.61)**	**0.017**
	Sunglasses & safety glasses (ref)				
Participants who remove protective eyewear:	Always/Often	1.73 (0.85–3.51)	0.13	1.89 (0.96–3.75)	0.067
	Sometimes	0.63 (0.30–1.34)	0.23	0.72 (0.35–1.48)	0.37
	Rarely/Never (ref)				
I continue to feel eye irritation even after I finish my work					
Participants who are:	Female	0.94 (0.58–1.52)	0.80	n/a	
	Male (ref)				
Participants aged:	>50 years	1.00 (0.64–1.54)	0.98	n/a	
	<50 years (ref)				
Participants who use protective eyewear:	Always/Often	1.83 (0.96–3.50)	0.067	1.011 (0.65–1.55)	0.96
	Sometimes	1.29 (0.63–2.63)	0.49	0.911 (0.55–1.50)	0.71
	Rarely/Never (ref)				
Participant whose primary protective eyewear is:	Goggles	1.41 (0.93–2.13)	0.104	1.45 (0.95–2.21)	0.083
	Sunglasses & safety glasses (ref)				
Participants who remove protective eyewear:	Always/Often	**5.32 (2.61–10.83)**	**<0.001**	**4.93 (2.53–9.61)**	**<0.001**
	Sometimes	**2.15 (1.03–4.48)**	**0.041**	1.97 (0.99–3.93)	0.054
	Rarely/Never (ref)				

OR = Odds ratio; CI = Confidence interval; ref = reference category.

Table 2b
Predictors for the use of protective eyewear amongst 338 Australian wildland firefighters. Adjusted analyses were conducted to control for the effects of age and gender.

		Unadjusted analyses		Adjusted analyses	
		OR (95 % CI)	p-value	OR (95 % CI)	p-value
I use eye protection when working in smoky environments					
Participants who are:	Female	1.55 (0.95–2.53)	0.079	n/a	
	Male (ref)				
Participants aged:	>50 years	1.02 (0.67–1.55)	0.93	n/a	
	<50 years (ref)				
For those with wildland firefighting experience of:	>10 years	1.17 (0.79–1.73)	0.44	1.13 (0.73–1.74)	0.58
	<10 years (ref)				
Participant whose primary protective eyewear is:	Goggles	**1.71 (1.12–2.59)**	**0.012**	**1.74 (1.14–2.67)**	**0.011**
	Sunglasses & safety glasses (ref)				
I have to remove my protective eyewear during work due to sweat/fogging/other reason					
Participants who are:	Female	1.31 (0.80–2.14)	0.29	n/a	
	Male (ref)				
Participants aged:	>50 years	1.50 (0.69–1.61)	0.83	n/a	
	<50 years (ref)				
Participants with wildland firefighting experience of:	>10 years	0.78 (0.52–1.17)	0.24	0.70 (0.45–1.10)	0.12
	<10 years (ref)				
Participants for whom primary protective eyewear is:	Goggles	**4.28 (2.75–6.68)**	**< 0.001**	**4.46 (2.83–7.01)**	**<0.001**
	Sunglasses & safety glasses (ref)				
The protective eyewear I primarily use, protects my eyes adequately from wildfire smoke					
Participants who are:	Female	0.84 (0.52–1.36)	0.48	n/a	
	Male (ref)				
Participants aged:	>50 years	**0.64 (0.42–0.97)**	**0.036**	n/a	
	<50 years (ref)				
Participants with wildland firefighting experience of:	>10 years	0.81 (0.55–1.21)	0.31	0.93 (0.60–1.43)	0.74
	<10 years (ref)				
Participants for whom primary protective eyewear is:	Goggles	**3.08 (2.01–4.71)**	**<0.001**	**2.92 (1.91–4.47)**	**< 0.001**
	Sunglasses & safety glasses (ref)				
Participants who continue to feel eye irritation after finishing work:	Always/Often	**0.33 (0.20–0.56)**	**<0.001**	**0.36 (0.21–0.60)**	**< 0.001**
	Sometimes	**0.56 (0.34–0.93)**	**0.023**	**0.55 (0.34–0.90)**	**0.015**
	Rarely/Never (ref)				

OR = Odds ratio; CI = Confidence interval; ref = reference category.

Age and gender of participants was not significantly associated with participants reporting visits to a doctor or eyecare practitioner for smoke related eye irritation (Table 2c).

Almost half (47 %) of participants reported that they worry about the long-term eye problems associated with occupational smoke exposure (Q9, Fig. 3a). Participants for whom eye irritation occurs *always, often* or *sometimes* were more likely to worry about the long-term eye problems associated with occupational smoke exposure (eye irritation occurs *always* or *often* unadjusted OR: 9.37, 95 % CI 4.08–21.56, $p < 0.001$; eye irritation occurs *sometimes:* unadjusted OR: 2.61, 95 % CI 1.14–5.96, $p = 0.023$, Table 2c). Participants who continued to feel eye irritation after work were more likely to worry about the long-term eye problems associated with occupational smoke exposure (if *often* or *always* feel eye irritation after work OR: 12.00, 95 % CI 6.61–21.77, $p < 0.001$; if *sometimes* feel eye irritation after work OR: 3.46, 95 % CI 2.08–5.77, $p < 0.001$, Table 2c). Participants who use protective eyewear in smoky environments were more likely to worry about the long-term eye problems associated with occupational smoke exposure, compared to those who *rarely* or *never* use protective eyewear (if *always* or *often* use protective eyewear OR: 3.22, 95 % CI 1.60–6.50, $p < 0.001$; if *sometimes* use protective eyewear OR: 2.20, 95 % CI 1.03–4.70, $p < 0.001$, Table 2c). Participant's age, gender and years of wildland firefighting experience were not significantly associated with participants worrying about long term eye problems associated with occupational smoke exposure (Table 2c).

4. Qualitative findings

Almost all participants (318 of 338, 94 %) responded to the question (Q11) '*Please describe in your own words how your eyes feel during or after exposure to wildfire smoke*'. Two overarching themes were identified in the thematic analysis: 'impact during active duty' and 'recovery experience'. These themes and associated sub-themes are further explored in Table 3 with supporting quotes. The terms used by firefighters to describe their symptoms in Q11 are summarised visually in Fig. 5.

5. Discussion

This is the first study to explore eye symptoms amongst Australian wildland firefighters and to characterise the eye-related challenges experienced on the fireground. Almost all (90 %) of firefighters participating in this survey reported eye symptoms at least sometimes during work and for 70 % of participants, this persisted after finishing work. Although protective eyewear was reportedly used by two thirds of participants, more than half needed to remove their protective eyewear while working. Firefighters reported acute transient impairments to their vision on the fireground due to the intense eye irritation caused by smoke exposure. Recovery of eye symptoms was facilitated by rinsing eyes and moving to a cleaner air environment and although eye symptoms improved within hours for some participants, in others symptoms continued for several days.

Compelling descriptions of eye symptoms were provided by the firefighters including the alarming finding that severity of eye symptoms can necessitate eye closure on an active fireground. It warrants urgent investigation to determine, at a minimum, the frequency and duration of the occurrence of such eye closures near active fires. The findings of this study also suggest that the frequency of occurrence of eye symptoms in wildland firefighters is greater than that which occurs in the general community during wildfires [18]. The continuation of symptoms for hours and even days after a firefighting shift has ended in some firefighters is also significant because such symptoms can reduce the quality of life for wildland firefighters, through impacts on functional vision, sleep quality and activities of daily living [24–26]. Furthermore, little is

Table 2c
Predictors for behaviours associated with eye irritation occurrence amongst 338 Australian wildland firefighters. Adjusted analyses were conducted to control for the effects of age and gender.

		Unadjusted analyses		Adjusted analyses	
		OR (95 % CI)	p-value	OR (95 % CI)	p-value
I rinse my eyes during or after my work					
Participants who are:	Female	0.80 (0.45–1.21)	0.223	n/a	
	Male (ref)				
Participants aged:	>50 years	0.71 (0.47–1.06)	0.091	n/a	
	<50 years (ref)				
Participants with wildland firefighting experience of:	>10 years	**0,63 (0.42–0.94)**	**0.016**	0.68 (0.44–1.03)	0.08
	<10 years (ref)				
Participants who use protective eyewear:	Always/Often	**3.29 (1.47–7.36)**	**<0.01**	**4.37 (2.29–8.35)**	**<0.001**
	Sometimes	2.11 (0.89–5.00)	**0.002**	**2.78 (1.36–5.65)**	**0.005**
	Rarely/Never (ref)				
Participants who remove protective eyewear:	Always/Often	**4.89 (2.42–9.88)**	**<0.001**	**4.80 (2.46–9.35)**	**< 0.001**
	Sometimes	**2.44 (1.18–5.06)**	**0.02**	**2.34 (1.17–4.65)**	**0.016**
	Rarely/Never (ref)				
Participants for whom eye irritation occurs:	Always/Often	**8.68 (3.64–20.66)**	**<0.001**	**9.87 (4.09–23.82)**	**< 0.001**
	Sometimes	**4.77 (1.20–11.41)**	**<0.001**	**5.12 (2.12–12.34)**	**<0.001**
	Rarely/Never (ref)				
Participants for whom primary protective eyewear is:	Goggles	**1.99 (1.33–2.99)**	**0.023**	**1.93 (1.27–2.91)**	**0.002**
	Sunglasses & safety glasses (ref)				
I have visited a doctor/eye practitioner for smoke related eye irritation					
Gender	Female	1.68 (0.88–3.23)	0.12	n/a	
	Male (ref)				
Age	>50 years	0.88 (0.48–1.59)	0.65	n/a	
	<50 years (ref)				
Participants who continue to feel eye irritation after finishing work:	Always/Often	**15.53 (4.57–52.76)**	**<0.001**	**16.21 (4.74–55.44)**	**<0.001**
	Sometimes	**6.37 (1.85–21.20)**	**< 0.001**	**6.65 (1.92–23.01)**	**0.003**
	Rarely/Never (ref)				
Participants with wildland firefighting experience of:	>10 years	0.46 (0.24–0.86)	**0.016**	**0.36 (0.18–0.73)**	**0.004**
	<10 years (ref)				
Participants who worry about long term eye problems associated with occupational smoke exposure:	Always/Often	**5.71 (2.16–15.06)**	**<0.001**	**5.95 (2.23–15.84)**	**<0.001**
	Sometimes	0.51 (0.13–2.00)	0.33	0.54 (0.14–2.08)	0.37
	Rarely/Never (ref)				
Participants whom eye irritation occurs:	Always/Often	**4.71 (1.07–20.67)**	**0.04**	6.32 (0.81–48.99)	0.08
	Sometimes	1.83 (0.40–8.341)	0.44	1.55 (0.19–12.86)	0.69
	Rarely/Never (ref)				
I worry about long term eye problems associated with occupational smoke exposure					
Participants who are:	Female	1.06 (0.65–1.72)	0.83	n/a	
	Male (ref)				
Participants aged:	>50 years	0.97 (0.64–1.47)	0.88	n/a	
	<50 years (ref)				
Participants with wildland firefighting experience of:	>10 years	0.85 (0.57–1.26)	0.42	1.28 (0.82–1.98)	0.29
	<10 years (ref)				
Participants for whom eye irritation occurs:	Always/Often	**9.37 (4.08–21.56)**	**<0.001**	**10.42 (4.47–24.30)**	**<0.001**
	Sometimes	**2.61 (1.14–5.96)**	**0.023**	**2.70 (1.18–6.20)**	**0.019**
	Rarely/Never (ref)				
Participants who continue to feel eye irritation after finishing work:	Always/Often	**12.00 (6.61–21.77)**	**<0.001**	**10.97 (6.18–19.46)**	**<0.001**
	Sometimes	**3.46 (2.08–5.77)**	**<0.001**	**3.16 (1.94–5.16)**	**<0.001**
	Rarely/Never (ref)				
Participants who use of protective eyewear:	Always/Often	**3.22 (1.60–6.50)**	**<0.001**	**3.27 (1.62–6.62)**	**0.001**
	Sometimes	**2.20 (1.03–4.70)**	**<0.001**	2.22 **(1.03–4.76)**	**0.041**
	Rarely/Never (ref)				

OR = Odds ratio; CI = Confidence interval; ref = reference category.

Table 3
Thematic qualitative analysis with supporting quotes of 318 Australian wildland firefighters' responses when asked to describe how their eyes felt during or after exposure to wildfire smoke.

THEMES	SUB-THEMES & SUPPORTING QUOTES
Impact during active duty	Severe eye symptoms on the fireground can require eye closure and thus impair vision
	"It is difficult to keep them [eyes] open which makes it hard to be situationally aware of the dangers around me in an emergency setting." p263
	"Eyes sting and water and even with goggles, sometimes [I] just have to shut my eyes for a while, even near active flame as they sting badly." p176
	"If you are hit with thick smoke it's unbearable, your eyes will instantly water and you will have to close them leaving you with no bearings." p6
	"There have been multiple times where the eye pain caused by smoke has limited my vision to a point where I need to find a safe space and just crouch down to gather myself before trying to find less dense smoke." p26
	Protective eyewear can reduce eye symptoms
	"Normally [eyes are] irritated during especially smoky periods, but this goes away when I don goggles." p208
	"Wearing goggles helps reduce the effects [tearing and irritation] but not eliminate it completely." p197
	Protective eyewear can be challenging to use at the fireground due to fogging and poor fitting
	"Goggles are better but they are uncomfortable, hot and they fog up, so sometimes you need to balance protection vs ability to function, it's a conundrum." p59
	"If in the direct line of thick smoke my eyes can sting quite badly as the goggles don't seal properly on my face." p137
	"None of the goggles supplied by my workplace fit adequately on me, such that they do not prevent the smoke exposure and fog up immediately so that they cannot be worn while performing the required duties." p136
	"I sometimes struggle to find a good pair of goggles to also fit over my glasses and seal without fogging glasses and goggles due to being hot sweaty and humid at times." p97
	Eye symptoms vary between participants[a]
	"Bit unsettled however not painful" p99
	"[Eyes] often run for the first fire of the season and then adapt." p150
	"They [the eyes] become watery and sting a small amount."p160
	"A very intense pain like acid in the eyes" p302
	"Like my eyelids are lined with sandpaper" p245
	"Lots of little, tiny paper cuts behind your eyelids" p122
	"Only once I've had really extended constant exposure during a planned burn, which resulted in soreness and sensitivity for 3 days." p271
	Intensity of smoke corresponds with severity of symptoms in some participants but not all
	"Very sore during exposure to thick smoke, otherwise a little sore and dry after more routine exposure." p131
	"Thick smoke will cause major irritation." p216
	"In heavy smoke my eyes feel like they are wrapped in barbed wire." p47
	"Even with exposure to small amounts of smoke, they [my eyes] start burning and watering, I am usually unable to open them." p31
	"My eyes now react very quickly to wildfire smoke, they start to water immediately even when smoke is light." p49
Recovery experience	Time to recovery varies between participants
	"Acute eye irritation … subsides quickly once I'm out of the smoke." p156
	"Sore and they [my eyes] water for about an hour but then recover fully." p10
	"For the most part my eyes naturally go back to normal after a few hours and a quick cleaning." p242
	"My eyes can feel dry in the evening but is usually fine the following day." p201
	"[My eyes] Can take several hours after a wash to feel back to normal after completing work." p190
	"Lots of black stuff comes out of them [my eyes] for 24 h or so post-fire." p82
	"After long exposure to smoke my eyes can be sore for a number of days." p45
	"Almost constant feeling of having something in my eye in day-to-day life." p170
	Different methods to aid recovery are used
	"Itching irritation does happen but usually quickly passes once you are out of the smoke." p127
	"After work, if my eyes have been lightly to moderately irritated, then washing my eyes with water stops the irritation." p197
	"[My eyes can be] stingy and irritated and often with small foreign matter which requires washing out. I use saline for this when required which cleans and also soothes." p257
	"My eyes … end up dry and sore. I use eye drops for dry eyes." p252
	"A long shift with lots of smoke will leave eyes a bit red and sore but clears up with a good sleep in clean air." p107
	"I always require a medical person to wash my eyes out to remove grit/soot." p177
	"On one occasion prolonged smoke exposure while wearing goggles caused severe dryness and pain, red eyes. Visited medical at end of shift who cleaned my eyes with baby shampoo. Instant relief." p66

[a] The terms used by firefighters to describe their eye symptoms are summarised visually in Fig. 5.

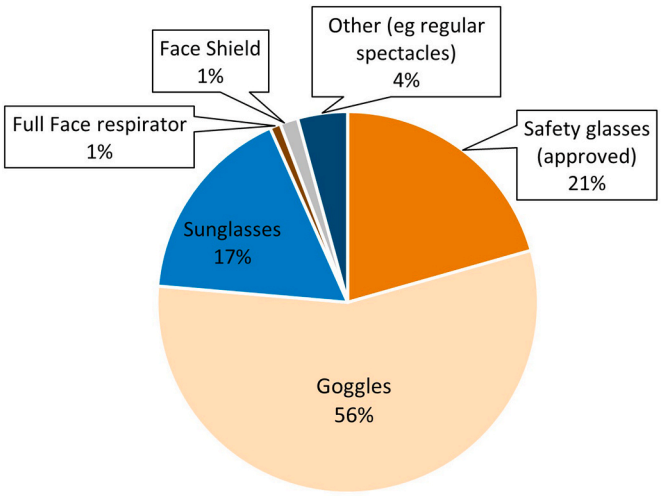

Fig. 4. Eye-and headwear most frequently used by participants (%) to protect eyes while working in smoky environments (based on responses to survey question 6).

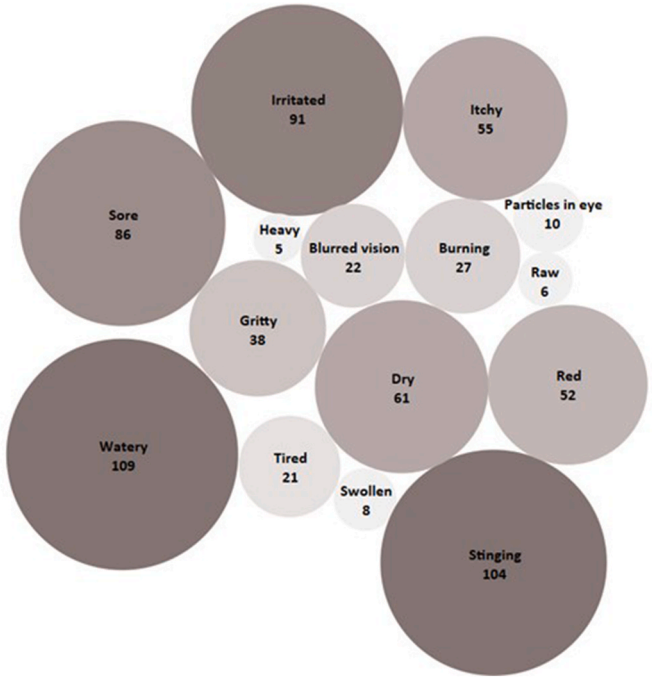

Fig. 5. Packed bubbles chart summarising the terms used by Australian wildland firefighters (n = 314) to describe their eye symptoms during or after exposure to wildfire smoke (free-text response to Q11). The size of the bubbles and the number inside corresponds to the number of participants who described their experiences using each term.

known about the factors which may modulate the severity of symptoms experienced by individual wildland firefighters, for example, the type and use of protective eyewear and the density of smoke in the immediate vicinity and the duration of continuous exposure. It is also unclear whether cumulative and/or repeated smoke exposure can aggravate symptoms. This is pertinent because wildland firefighting shift durations typically range from 8 to 14 hours and exposure is rarely seasonal, because although wildfires typically occur in summer, planned burns which reduce fuel for wildfires, are conducted throughout the year, weather permitting.

Eye irritation was frequently reported by the wildland firefighters in this survey, more so by females, older participants, and those who had to remove their protective eyewear due to sweat, fogging, or other reasons. This aligns with population data which reports that the prevalence of dry eye disease increases with age and in women and that it can be exacerbated with exposure to poor air quality [27,28].

Half of survey participants reported worrying about their long-term eye health following repeated occupational smoke exposure. This concern was greater in those who frequently experience eye symptoms during work and in whom symptoms continue after work. Whether repeated smoke exposure can cause problems with eye health or vision in the long term is yet to be investigated. It is beyond the scope of this study to ascertain whether frequent eye symptoms or worry about repeated smoke exposure can act as occupational stressors. Other occupational stressors including reduced sleep, anxiety and fatigue have however been associated with burnouts and reduced workforce retention in the firefighting sector [29–31].

The challenges surrounding adequate use of protective eyewear in a fireground are not surprising and have been reported previously by firefighters [32,33]. This survey compiled experiences of Australian wildland firefighters from seven different emergency service agencies, which provide their workforce with differing protective eyewear options. The use of safety glasses and sunglasses as the primary form of protective eyewear by over a third of the participating firefighters in this study is a concern because unlike goggles, safety glasses and sunglasses do not seal around the eyes and hence do not completely protect against gases released from burning vegetation. Additionally, regular commercial sunglasses are not impact resistant against high velocity particles, which is a protection offered by polycarbonate lenses and side shields in safety glasses. It is noteworthy however, that goggles pose different challenges when used as protective eyewear on the fireground. Although, they were used by half of the surveyed firefighters, and 70 % of them reported needing to remove goggles frequently on the fireground. This finding along with the experience of spectacles fitting poorly underneath goggles, as reported by some firefighters, demonstrates the challenges of using goggles to protect the eye surface from wildfire smoke on the fireground. This issue has been reported by firefighters in China for whom scratches to the lenses of goggles, blurred vision due to water mist on the inside and outside of goggle lenses and poor fitting of spectacles underneath goggles were common complaints [33].

An alternative approach could recognise the limitations of goggles and consider whether use of adjuvant therapeutic and non-therapeutic strategies could mitigate the impact of smoke on the eye surface. Survey responses suggest that some firefighters are already employing these types of strategies including rinsing their eyes or using over the counter or nonprescription eye drops. Rinsing the eyes with sterile saline can be recommended to remove soot particles deposited on the eye's surface and in the tears during a wildfire [34]. Routine use of non-preserved lubricating eyedrops, gels, or ointments can be recommended following a wildfire shift to help restore tear film homeostasis [35]. Conversely, non-prescription decongestant or vasoconstrictor (alpha-adrenoreceptor agonists) eye drops which were reportedly used by survey participants are unsafe for long-term use and should be avoided due to their risk for producing chronic rebound hyperaemia and conjunctivitis [36,37]. Firefighters should be educated on evaluating their ocular signs and symptoms and determine when a consult with an eye-or health care practitioner is necessary to rule out damage to their eyes, especially because pre-existing eye surface disease may affect recovery of the eye surface following wildfire smoke exposure [38]. Consideration should also be given to prescribing of therapeutic eyedrops including topical antihistamines, non-steroidal anti-inflammatory drugs or corticosteroids to alleviate any significant symptoms and conjunctival inflammation experienced as a result of occupational smoke exposure.

Research conducted on eye problems amongst wildland fighters has to date centred around acute presentations to hospitals [14,15,19]. However, this survey reports that fewer than 1 in 5 firefighters will seek professional eye care advice for their eye symptoms. Research on

barriers to accessing mental health support by firefighters suggests that stigma of being perceived as 'weak', fear of confidentiality breach or of being placed on leave restricts firefighters from seeking help [39,40]. Conversely, increased knowledge facilitates help-seeking [39], suggesting that educating wildland firefighters on the risks to eye health from occupational smoke exposure and the therapies which health care practitioners can offer to manage their symptoms may increase eye-care seeking behaviour amongst wildland firefighters.

This study has some limitations that should be considered. Due to privacy concerns, a survey invitation could not be directly sent to firefighting personnel and was instead distributed by participating emergency services agencies through announcements posted on internal webpages, newsletters, and emails. This type of voluntary participation made it impossible to determine the rate of participation and may have introduced selection bias. Firefighting personnel who experienced eye symptoms or were compliant with protective eyewear use may have been more likely to participate in the survey which may have contributed to response bias. Additionally, recall bias may have influenced the responses provided by participants, although it is difficult to determine whether this would have caused an over or under estimation of their ocular symptoms. Despite this, the severity and magnitude of eye symptoms consistently reported by participants was such that it should raise alarm bells regarding the eye health of all Australian wildland firefighters.

6. Conclusion

This is the first study to demonstrate that Australian wildland firefighters frequently experience eye irritation from smoke exposure on the fireground and this can affect vision and operational capabilities. The findings of this research including the reported limitations of goggles as protective eyewear on the fireground, can support the development of other evidence-based strategies to help protect and aid recovery of the eye surface following smoke exposure.

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CRediT authorship contribution statement

Sukanya Jaiswal: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Isabelle Jalbert:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Nicholas Olsen:** Writing – review & editing, Supervision, Methodology. **Anthea Burnett:** Writing – review & editing, Supervision, Methodology. **Blanka Golebiowski:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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