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Firefighter occupational factors and the risk of preterm birth: results from a survey of women firefighters in the USA

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ABSTRACT

Objectives Previous research has suggested that women firefighters may have a greater risk of adverse reproductive outcomes compared with non-firefighting women. In this study, we investigated the association between firefighter occupational factors and risk of preterm birth.

Methods This cross-sectional analysis of US firefighters surveyed in 2017 compared preterm birth among firefighters to non-firefighters using age-at-pregnancy-standardised prevalence ratios. Generalised estimating equations estimated relative risks and 95% CIs between firefighter occupational factors (career or volunteer, wildland status, shift schedule, fire responses, work restriction) and preterm birth risk. We adjusted for age-at-pregnancy, education, gravidity, BMI, and smoking and considered effect modification by age-at-pregnancy and career versus volunteer status.

Results Among 934 women who reported 1356 live births, 12% were preterm (n=161). Preterm birth prevalence among firefighters was 1.41 times greater than non-firefighters (95% CI 1.18 to 1.68). Among wildland and combination wildland/structural firefighters, volunteers had 2.82 times the risk of preterm birth (95% CI 1.19 to 6.67) compared with career firefighters. Firefighters who started restricting their work in the 2nd trimester had a nonsignificant 0.67 times lower risk of preterm birth than those who started in the 3rd trimester or did not restrict work at all (95% CI 0.43 to 1.03).

Conclusions Firefighters may have greater risk of preterm birth than non-firefighters, which could be influenced by roles in the fire service and work restrictions taken.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Women firefighters may be at greater risk of adverse pregnancy outcomes, including pregnancy loss, and potentially, preterm births.

WHAT THIS STUDY ADDS

⇒ The prevalence of preterm birth is elevated among firefighters compared with non-firefighters.
⇒ Compared with career firefighters (full-time, salaried), volunteer firefighters are a particularly vulnerable subgroup within the fire service.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This research suggests that women firefighters may benefit from increased occupational protections to reduce the risk of preterm birth.

INTRODUCTION

Firefighting exposes firefighters to a variety of toxic substances and physical hazards. However, research concerning the health of women firefighters is limited, and reproductive health topics remain understudied. Previous observational studies suggest that women firefighters experience more adverse reproductive outcomes, such as pregnancy loss, preterm birth and hospital admissions for adverse pregnancy, childbirth and postpartum outcomes compared with non-firefighters.[1–3] Some potential occupational exposures (air pollutants, perfluoroalkyl and polyfluoroalkyl substances (PFAS), and high temperatures) have also been associated with adverse reproductive outcomes among non-firefighters.[4–7] Firefighters could be particularly vulnerable to these exposures, given their high level of exposures.[8–10]

Research among career (full-time, salaried) firefighters in the USA has shown that pregnancies to working firefighters were more than twice as likely to result in self-reported pregnancy loss compared with non-firefighters.[1] However, exposures vary by firefighter type because of differences in time at fires, combustion products, activities and equipment used.[11 12] US firefighters can be categorised by employment status (career or volunteer (part-time or on-call) or by wildland firefighter status (wildland only, combination of wildland and structural firefighting, or structural only). Firefighters may have increased risk for miscarriage which varies by both employment and wildland fire response.[3] However, it is unclear whether there are similar patterns of risk regarding preterm births. Therefore, we analysed data from a cohort of US women firefighters to determine (1) the prevalence of preterm births for firefighters compared with a general population of non-firefighters and (2) potential occupational factors among firefighters that contributed to risk of preterm birth.

METHODS

Study participants

The Health and Wellness of Women Firefighters Study, a cohort of women firefighters from the

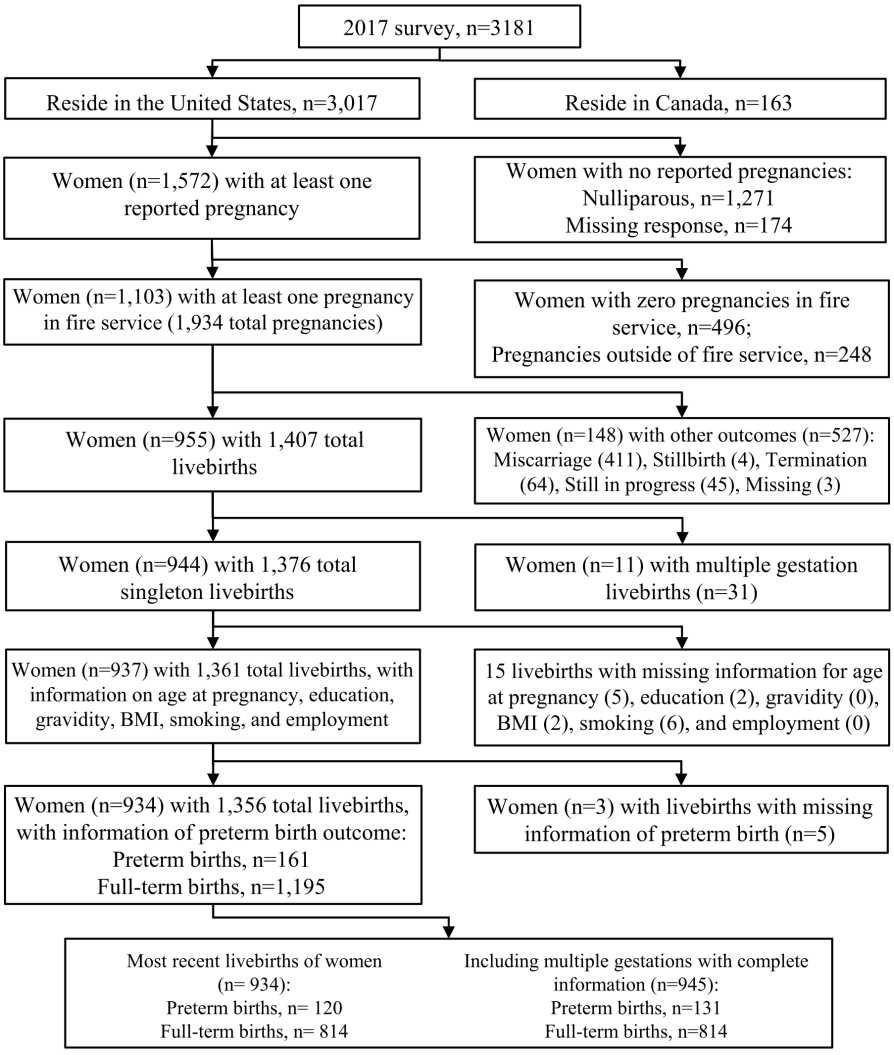

Figure 1 Women from the health and wellness of women firefighters study included in analysis of preterm births (934 firefighters and 1356 total live births).

USA and Canada, was conducted by the Center for Fire, Rescue & EMS Health Research of NDRI-USA to examine the work environment, health and perceived experiences of women firefighters. Recruitment and methodology have been previously reported.[3 13] Women firefighters are hard to recruit using traditional methods, so the study used snowball sampling, non-probability sampling where current participants recruit additional participants.[14] Participants were initially identified using affinity group email lists[1 13] and asked to complete surveys in 2017 and 2019. Data used in the current analysis were self-reported during the 2017 survey.

Among firefighters who completed the survey in 2017 (n=3181), we excluded Canadian firefighters (n=163) because strategies, tactics and protective equipment may vary by country (figure 1). Women who had never been pregnant (n=1271), were missing parity information (n=174) or had no pregnancies while working in the fire service (n=496) were excluded. We also excluded pregnancies that occurred while not working in the fire service (n=248). Singleton, live birth pregnancies (n=1376) were considered for our main analysis; miscarriages (n=411), stillbirths (n=4), terminations (n=64), pregnancies ongoing at the time of survey (n=45), multiple gestations (n=31), or pregnancies with missing outcomes (n=3) were excluded. Pregnancies with missing responses to whether the birth was preterm or full-term (n=5) were also removed. Missing responses for age-at-pregnancy, education, gravidity, BMI and smoking were excluded from our main analysis, which included a total of 934 women and 1356 pregnancies.

Data collection

Outcome measurement

Firefighters answered questions for a maximum of 10 pregnancies (<1% reported 10 pregnancies). For each live birth pregnancy, participants were asked 'Was your baby from pregnancy X born more than 3 weeks before his/her due date?' (yes, no, don't know/don't remember). A preterm birth was defined as a live birth born more than 3 weeks before the expected due date. 'Don't know/don't remember' responses were defined as missing.

Occupational factor measurement

Exposures of interest included employment status, wildland firefighter status and shift schedule (among career firefighters) based on report in 2017. Employment was categorised as either career or volunteer firefighter ('Are you primarily a career or volunteer firefighter?'). For wildland firefighter status ('Are you a wildland firefighter?'), wildland firefighters reported they only respond

to wildland fires, combination firefighters that they were wildland firefighters in addition to working for a career or volunteer fire department (Yes, I do wildland firefighting in addition to working for a career/volunteer department), and structural firefighters reported not being wildland firefighters. Participants were categorised as wildland/combination firefighter or structural firefighter. Shift schedule among career firefighters was categorised as working at least 24 consecutive hours at a time or working less than 24 consecutive hours at a time (online supplemental file 1). We also examined pregnancy-specific exposures (online supplemental file 1): working fire/rescue calls at pregnancy start ('Were you actively running fire or rescue calls when you found out you were pregnant for your pregnancy?' yes or no); fire responses during pregnancy ('Approximately how many working fires did you fight during your pregnancy?', 0, 1–4, >4 fires); work restriction due to pregnancy ('Were your duties restricted during your pregnancy?', yes or no); and start of work restriction during pregnancy ('Approximately how many weeks into your pregnancy were you when your duties were restricted?', weeks 0–12, 13–26 or 27+ which includes no restrictions taken).

Other variables of interest

All variables mentioned here are further described in online supplemental file 1. Individual-level variables of interest included highest education (some college or less, or college and above), BMI (<30 kg/m^2 or ≥30 kg/m^2) at the time of the survey, and Hispanic, Latina or Spanish origin (yes or no). Descriptive race categories included white, Black, Asian, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native, or other. Analytical race categories were white or other racial minority. Smoking was categorised as current/former or never-smoker at the time of the survey. Current smokers smoked more than 100 lifetime cigarettes and smoking in the past 30 days. Former smokers smoked more than 100 lifetime cigarettes but not in the past 30 days. Never-smokers smoked less than 100 cigarettes. Pregnancy-level variables of interest included age-at-pregnancy, gravidity (previously pregnant or not), previous preterm birth (nulligravid, yes, no), gestational hypertension (yes or not reported). Additional descriptive variables included presence of pregnancy/maternity policies, annual household income, menopausal status, current rank, and who restricted work during most recent pregnancy (doctor, department or self).

Statistical analysis

Prevalence of preterm birth compared with US general population

To compare firefighters in our analysis to non-firefighters, we calculated age-at-pregnancy standardised prevalence ratios (aSPRs) and 95% CIs of preterm birth for most recent live births while working in the fire service. aSPRs were calculated using indirect age-standardisation methods and two US studies as the comparison groups.[15 16] The first comparison group was the US general population, consisting of data on almost 3.8 million US births recorded in 2018 collected via birth certificates.[16] This report by Martin *et al*, published by the US Centers for Disease Control and Prevention, described birth trends using birth certificate data and included pregnancies with multiple gestations in their analysis. Because we could not obtain data excluding multiple gestations, we added firefighters to our analysis group who had been previously excluded because of multiple gestation pregnancies (n=11), for this analysis only.

Prevalence of preterm birth compared with Nurses' Health Study II

Using the methods described above, we also compared preterm births during most recent live birth while in the fire service to the Nurses' Health Study II (NHSII).[15] The NHSII is a prospective cohort study of 116 608 US female nurses aged 25–42 at enrolment.[17] The study, by Lawson *et al*, examined a subset of NHSII participants who retrospectively self-reported details about their most recent pregnancy including outcome and occupational exposures.[15]

Firefighter occupational factors associated with risk of preterm birth

Statistical models

Analyses of firefighter occupational factors were restricted to women in the fire service. We used generalised estimating equations (GEE) with a Poisson distribution, log link function, exchangeable working correlation matrix and sandwich variance estimators, allowing us to directly estimate relative risks (RR) of preterm births, and 95% CIs.[18] A log-binomial distribution was initially considered; however, non-convergence in our models resulted in the selection of a Poisson distribution as a more numerically stable method.[18 19] GEE accounted for correlation between multiple potential pregnancies per firefighter, allowing us to consider all live births to firefighters that occurred while working in the fire service in our models.

A priori confounders

All variables selected for adjustment in models were specified a priori. We adjusted for age-at-pregnancy (model 1), a risk factor for preterm birth,[20] modelled as age-at-pregnancy and age-at-pregnancy-squared since its association with preterm birth risk has been reported to be non-linear.[16 20] We also included education, gravidity, BMI and smoking in model 2 as categorical variables because they have been previously associated with increased risk for preterm birth[21–24] and a priori hypothesised to be associated with occupational factors. For models examining pregnancy-specific exposures (worked fire/rescue calls, number of fire responses, work restrictions (yes or no), and timing of start of work restrictions), we additionally adjusted for employment status (model 3). Call volumes and policies generally vary between career and volunteer departments, and could impact occupational exposures.[3]

Effect modification assessment

We considered effect modification for the risk of preterm birth by age-at-pregnancy (<35 years or≥35 years) as women≥35 during pregnancy have increased risk of preterm birth compared with women who are <35,[20] and age-at-pregnancy may modify the association of potential firefighter occupational exposures and preterm birth. We also considered if associations varied by employment status (career or volunteer firefighter), because of overlap between employment and wildland firefighter statuses and that annual call volumes differ between career and volunteer fire departments.[25] We tested for effect modification by creating an interaction term for the occupational factor and potential modifying factor. We presented stratified results when effect modification was present.

Sensitivity analyses

Sensitivity analyses were performed to test the robustness of our findings. Models used in sensitivity analyses were based on main analysis models. We evaluated associations between occupational factors and risk of preterm birth in two scenarios to assess if length of recall affected results: (1) restricted to the most recent

pregnancy and (2) restricted to the first pregnancy. Second, we used multiple imputation with chained equations to assess whether the exclusion of pregnancies with missing responses of confounders (age-at-pregnancy, gravidity, BMI, smoking and education) influenced the results.[26] We included factors from the main analytical model, the outcome, factors associated with missingness and auxiliary factors correlated with predictors to be imputed (Kendall's t>0.20).[27] Twenty complete datasets were imputed and analysed. Estimates were pooled using Rubin's Rules.[28] Third, we adjusted for additional known risk factors for preterm birth which were not included in our main models, such as previous preterm birth (nulligravid, no, yes; including those that may have occurred while not working in the fire service),[22] and gestational hypertension (yes, not reported)[23] using write-in responses from participants who reported experiencing medical complications during pregnancy, specifically relating to gestational hypertension/preeclampsia. We performed statistical analyses using SAS V.9.4 software.

RESULTS

Our analysis included 934 firefighters and 1356 total live births, 12% of which were preterm (n=161) (figure 1). Among most recent live births, 13% were preterm (n=120). Participants had a median age of 38 (IQR=34–45), were mostly white (93%), non-Hispanic (95%) and married or in a partnership (81%) (table 1). About 17% of firefighters were obese, 4% were current smokers and 17% were former smokers. Median lifetime pregnancies was 2 (IQR 1–3), and only 6% (n=53) reported three or more live births while working in the fire service.

Participants were mostly career (88%) and structural firefighters (64%). Only 74% reported that their departments had policies related to pregnancy or maternity. Median time between most recent pregnancy and survey was 6 years (IQR 2–12) and median number of fires during pregnancy was three (IQR 0–8). Most restricted their duties during their most recent pregnancy (23% did not restrict).

Prevalence of preterm birth compared with US general population and NHSII

The prevalence of preterm births among all firefighters was 1.41 times greater (95% CI 1.18 to 1.68) than US women in 2018, and also elevated among volunteers (aSPR 2.29, 95% CI 1.51 to 3.34) and career firefighters (aSPR 1.28, 95% CI 1.05 to 1.56) (table 2).[16] Preterm birth among structural firefighters was also greater than US women (aSPR 1.77, 95% CI 1.45 to 2.13). We observed no difference in preterm birth comparing wildland/combination firefighters to US women (aSPR 0.72, 95% CI 0.46 to 1.08). Similar patterns were observed when we compared preterm births among firefighters to US nurses (table 2).[15]

Firefighter occupational factors and risk of preterm birth

Among firefighters, volunteer status was associated with increased risk of preterm birth but varied by wildland firefighter status (model 2 interaction p=0.09) (table 3). Among wildland/combination firefighters, volunteer firefighters had 2.82 times greater risk of preterm birth compared with career firefighters (95% CI 1.19 to 6.67), but this association attenuated and lost statistical significance among structural firefighters (RR 1.47, 95% CI 0.92 to 2.33). The association between shift schedule (>24 hours vs less than 24 hours) and risk of preterm birth was negligible (RR 0.88, 95% CI 0.58 to 1.32).

Firefighters who started restricting work during the second trimester had 0.67 times the risk of preterm birth in the fully adjusted model (model 3) compared with firefighters who did not restrict their work or did so during the third trimester (95% CI 0.43 to 1.03), though this association was not statistically significant (table 4). Starting work restriction during the first trimester was not associated with risk of preterm birth (RR 1.13, 95% CI 0.77 to 1.64). Working fire/rescue calls at pregnancy start, number of fire responses during pregnancy and work restriction during pregnancy (yes or no) were not associated with the risk of preterm birth (tables 3–4).

Our sensitivity analyses generally supported our main analyses (online supplemental file 2). We did observe that when restricted to the first pregnancy in the fire service, the association between employment and risk of preterm birth among wildland/combination firefighters attenuated and was no longer statistically significant (online supplemental file).

DISCUSSION

The prevalence of preterm birth was greater among firefighters than non-firefighters and the risk of preterm birth varied based on employment, and wildland firefighter status. Among wildland/combination firefighters, volunteers had greater risk of preterm birth than career firefighters. This supports our previous analysis of risk of miscarriage among firefighters,[3] and other studies suggesting that firefighters may be at increased risk of adverse reproductive health outcomes.[1 2]

The prevalence of preterm birth among firefighters was greater compared with two groups of non-firefighters, US women who had a live birth in 2018 and US nurses from the NHSII.[15 16] These groups varied regarding data source and study design. Martin *et al*'s study used birth certificate data to evaluate almost 3.8 million US births in 2018, compared with our use of self-reported survey data. The women in Martin *et al* were slightly younger (29.0 vs 32 years old) and more racially diverse (52% non-Hispanic white, 23% Hispanic white) than our sample, who were majority non-Hispanic (95%) and white (93%).[16] The second comparison group consisted of a subset of nurses from the NHS II (6977 singleton live births).[15] Similar to our study, Lawson *et al* analysed retrospectively self-reported data on pregnancy outcomes and occupational exposures for the most recent pregnancy. Nurses were slightly older compared with firefighters (36 vs 32 years old), but a similar BMI (prepregnancy BMI 24.2 kg/m^2 vs 51% of firefighters reporting current BMI ≤24.9 kg/m^2).[15] However, we were unable to account for different occupational exposures of these occupations that could influence risk for preterm birth.

We used age-at-pregnancy to standardise our prevalence estimates between populations but were unable to account for other population-level differences, a limitation for all standardisation methods.[29] For example, wildland and combination firefighters are located mostly within the Western USA, but we were unable to obtain geographically specific preterm birth rates. Interpretations of our findings should consider that though efforts were made to identify reasonably similar comparison populations, population-level differences that were present, aside from age-at-pregnancy, could not be accounted for and may have influenced our results. Based on our study design, data sources and sample characteristics, our analysis of firefighters may be more similar to Lawson *et al* (nurses) than Martin *et al* (US general population), however, a comparison to the US general population is valuable to consider for generalisability. Overall, we did observe consistent patterns, supporting previous studies that used indirect comparison methods to demonstrate that adverse reproductive outcomes may be greater in firefighters compared with non-firefighters.[1–3]

Table 1 Characteristics of firefighters at survey in 2017 with at least one live birth, stratified by employment and wildland firefighter status, n=934*

	Employment status		Wildland firefighter status†		
	Volunteer n=116	Career n=818	Structural n=601	Wildland/combination n=331	Total n=934
Demographics					
	Median (IQR)				
Age in 2017	37 (32–46)	38 (34–45)	41 (35–47)	34 (34–38)	38 (34–45)
Total pregnancies	2 (2–4)	2 (1–3)	2 (2–3)	1 (1–2)	2 (1–3)
	N (%)				
Race					
White	109 (96)	759 (94)	548 (92)	319 (97)	868 (93)
Black	0	18 (2)	17 (3)	1 (<1)	18 (2)
Asian	0	3 (<1)	2 (<1)	1 (<1)	3 (<1)
Native Hawaiian or Other Pacific Islander	1 (1)	3 (<1)	2 (<1)	2 (1)	4 (<1)
American Indian or Alaska Native	0	4 (<1)	2 (<1)	1 (<1)	4 (<1)
Other	4 (4)	24 (3)	22 (4)	6 (2)	28 (3)
Missing	2	7	8	1	9
Hispanic, Latina or Spanish	4 (3)	40 (5)	35 (6)	8 (2)	44 (5)
Missing	2	4	5	1	6
BMI					
≤ 24.9 kg/m^2	34 (29)	443 (54)	218 (36)	258 (78)	477 (51)
25–29.9 kg/m^2	39 (34)	256 (31)	247 (41)	47 (14)	295 (32)
≥ 30 kg/m^2	43 (37)	119 (15)	136 (23)	26 (8)	162 (17)
Highest education completed					
Some college or less	73 (63)	488 (60)	308 (51)	252 (76)	561 (60)
College and above	43 (37)	330 (40)	293 (49)	79 (24)	373 (40)
Married or in partnership	87 (75)	667 (82)	458 (76)	295 (89)	745 (81)
Household income					
>US$75 000	62 (54)	532 (65)	503 (84)	90 (27)	594 (64)
≤US$75 000	53 (46)	285 (35)	96 (16)	241 (73)	338 (36)
Missing	1	1	2	0	2
Smoking status					
Current	14 (12)	21 (3)	31 (5)	3 (1)	35 (4)
Former	34 (29)	128 (16)	135 (22)	27 (8)	162 (17)
Never	68 (59)	669 (82)	435 (72)	301 (91)	737 (79)
Menopausal status					
Premenopausal	76 (70)	624 (78)	418 (72)	282 (87)	700 (77)
Perimenopausal	14 (13)	82 (10)	76 (13)	19 (6)	96 (11)
Postmenopausal	19 (17)	92 (12)	88 (15)	22 (7)	111 (12)
Missing	7	20	19	8	27
Occupational factors in 2017					
	N (%)				
Employment status					
Volunteer	116 (100)	–	90 (15)	26 (8)	116 (12)
Career	–	818 (100)	511 (85)	305 (92)	818 (88)
Participate in wildland fire activity					
No (structural)	90 (78)	511 (63)	601 (100)	–	601 (64)
Yes (combination)	23 (20)	287 (35)	–	310 (94)	310 (33)
Yes (wildland)	3 (3)	18 (2)	–	21 (6)	21 (2)
Missing	0	2	–	–	2
Current rank					
Firefighter	58 (50)	310 (38)	133 (22)	234 (71)	368 (39)
Firefighter/paramedic	23 (20)	187 (23)	177 (29)	33 (10)	215 (23)
Driver operator	4 (3)	65 (8)	53 (9)	16 (5)	69 (7)
Lieutenant	7 (6)	75 (9)	69 (11)	12 (4)	82 (9)
Captain	5 (4)	88 (11)	69 (11)	24 (7)	93 (10)
Chief	11 (9)	81 (9)	74 (12)	8 (2)	82 (9)
Paramedic	3 (3)	3 (<1)	6 (1)	0 (0)	6 (1)

continued

Table 1 continued

	Employment status		Wildland firefighter status†		
	Volunteer n=116	Career n=818	Structural n=601	Wildland/combination n=331	Total n=934
Other	5 (4)	18 (2)	20 (3)	3 (1)	23 (2)
Missing	0	1	0	1	1
Shift schedule (career only)					
24 hours or more on shift	–	662 (81)	384 (75)	277 (91)	662 (81)
Less than 24 hours on shift	–	154 (19)	125 (25)	28 (9)	154 (19)
Missing	–	2	2	0	2
Department policy regarding pregnancy and/or maternity‡					
Yes	45 (39)	644 (79)	400 (67)	287 (87)	689 (74)
No	55 (26)	158 (19)	177 (29)	36 (11)	213 (23)
Don't know	16 (14)	16 (2)	24 (4)	8 (2)	32 (3)
Occupational factors for most recent pregnancy					
	Median (IQR)				
Age at pregnancy	28 (26–33)	32 (30–34)	32 (28–35)	32 (32–32)	32 (29–34)
Years since most recent pregnancy	8 (3–14)	5 (2–12)	8 (3–14)	2 (2–7)	6 (2–12)
Number of fire responses during pregnancy	2 (0–4)	3 (0–8)	1 (0–3)	8 (3-8)	3 (0–8)
Missing	8	19	18	9	27
	N (%)				
Work restricted during pregnancy	67 (58)	651 (80)	426 (71)	291 (88)	718 (77)
Missing	3	4	4	3	7
Time when work was restricted					
No restriction	42 (39)	161 (20)	165 (28)	37 (11)	203 (22)
3rd trimester	7 (7)	34 (4)	31 (5)	10 (3)	41 (4)
2nd trimester	25 (23)	396 (49)	178 (30)	243 (74)	421 (46)
1st trimester	33 (31)	217 (27)	212 (36)	37 (11)	250 (27)
Missing	9	10	15	4	19
Work restricted by doctor§	24 (36)	366 (56)	155 (36)	235 (81)	390 (54)
Work restricted by department§	15 (23)	286 (44)	82 (20)	218 (75)	301 (42)
Work restricted by self§	35 (52)	292 (45)	273(64)	54 (19)	327 (46)

Percentages may not sum to 100 due to rounding. Frequencies are calculated excluding missing values.
Combination= does wildland firefighting in addition to working for a career or volunteer department.
*All data were collected at time of survey in 2017 unless otherwise noted.
†Two firefighters did not report a wildland firefighter status and are not included in these columns.
‡Firefighters were asked to report if their department had policies relating to pregnancy or maternity. Further information was not collected.
§Among firefighters who reported that they restricted their work during pregnancy (n=718).
BMI, body mass index.

Occupational exposures could help explain why firefighters may experience elevated risk for adverse reproductive outcomes. Systematic reviews and meta-analyses have shown a positive association between air pollution and high environmental temperatures with adverse birth outcomes, including preterm birth, low birth weight and stillbirth.[5 30] PFAS are of concern in the fire service because they are used to manufacture turnout gear and some firefighting foams.[31] High prenatal PFAS exposures have been associated with increased risk of preterm birth,[32] and reducing PFAS exposures may decrease the risk of preterm birth and increase overall fertility.[7] Studies should investigate if they contribute to the potential excess of adverse reproductive outcomes among firefighters.

Our results suggest that among wildland and combination firefighters, volunteers have a greater risk of preterm birth compared with career firefighters, contrary to assumptions that volunteers, who generally respond to fewer annual calls, have fewer occupational exposures and lower risk of occupational diseases.[25] Mechanisms that may contribute to this difference include access to protective equipment and resources, work schedules (most volunteers are on-call all the time), and exposures related to their full-time jobs. Despite advancements in technologies to prevent or minimise firefighter occupational exposures, financial barriers may make these items less accessible to volunteers. Revenue for such expenses may be largely generated from local taxes, which may be dependent on community size and volunteers generally serve smaller communities. Volunteer departments may also have reduced access to other resources (eg, trained firefighters, department support, training, occupational health providers) compared with career departments. Our findings are consistent with our previous study that observed that volunteer firefighters had greater risk of miscarriage compared with career firefighters.[3]

We observed that wildland firefighter status modified risk of preterm birth. Wildland and structural firefighters may differ from each other in their cumulative fireground exposures, physical exertion and physiological strain, and mental strain. Wildland firefighters participate in activities not shared by structural firefighters (eg, hiking, constructing fire-lines, prescribed burning) and spend more time at fires compared with structural firefighters, concentrated over a shorter wildland fire season.[11] This differences may be exacerbated by the increased frequency

Table 2 Age-standardised prevalence ratios comparing preterm births among most recent live birth of firefighters with non-firefighting US populations

	Observed events	Expected events	aSPR (95% CI)
Compared with US birth certificates*			
All firefighters (n=945)	131	92.8	1.41 (1.18 to 1.68)
Employment status			
Career (n=828)	104	81.0	1.28 (1.05 to 1.56)
Volunteer (n=117)	27	11.8	2.29 (1.51 to 3.34)
Wildland firefighter status			
Wildland/combination (n=333)	23	32.9	0.72 (0.46 to 1.08)
Structural (n=610)	107	60.6	1.77 (1.45 to 2.13)
Compared with US nurses from the Nurses' Health Study II†			
All firefighters (N=934)	120	76.5	1.57 (1.30 to 1.88)
Employment status			
Career (n=818)	94	67.0	1.40 (1.13 to 1.72)
Volunteer (n=116)	26	9.5	2.75 (1.80 to 4.03)
Wildland firefighter status			
Wildland/combination (n=331)	22	26.8	0.82 (0.51 to 1.24)
Structural (n=601)	97	49.5	1.96 (1.59 to 2.90)

Combination= does wildland firefighting in addition to working for a career or volunteer department.
*Martin *et al*[16] (https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_13-508.pdf) included 3 791 712 births (including multiple gestations) to women in the USA collected from registered birth certificates in 2018.
†Lawson *et al*[15] (https://pubmed.ncbi.nlm.nih.gov/18976732/) included 6977 women from the Nurses' Health Study II who self-reported details about their most recent singleton live birth pregnancy while working as a nurse between 1993 and 2000.
aSPR, age-at-pregnancy standardised prevalence ratio.

and duration of wildland fires in recent years.[33] Communities affected by wildland fires have also reported increased respiratory events, cardiovascular diseases, mortality and adverse pregnancy outcomes,[4 34 35] highlighting the importance of understanding the impact of these exposures in both environmental and occupational settings.

We did not observe an association between any work restriction during pregnancy (yes or no) and risk of preterm birth. However, our results suggest that when work restrictions begin could potentially be important. Firefighters who started work restrictions during the 2nd trimester may have had lower risk of preterm birth than those who did not restrict work or restricted during the 3rd trimester. However, this association was not statistically significant, therefore additional research is warranted. This aligns with previous research that gestational weeks during the second trimester fall within a critical exposure period where exposure to $PM_{2.5}$ was associated with increased risk of preterm birth.[36] Moreover, non-occupational prenatal wildfire exposure during the 2nd trimester was positively associated with risk of preterm birth, but exposures during the 1st or 3rd trimesters were not.[4] Because we lacked information on how work was restricted (eg, move to light duty roles, reduced hours) or the restriction reason (eg, underlying medical condition, high risk pregnancy), future research should collect information on type of work restrictions and investigate the temporality between exposures and restrictions during pregnancy to better inform departmental policies.

We did not observe associations between reported fire responses during pregnancy (working fire/rescue calls at pregnancy start or the number of fire responses during pregnancy) and risk of preterm birth. However, we lacked information on details of fireground exposures (eg, time at fire, role at fire, type of fire) and cumulative history of fire exposure. Collection of this information could help clarify these associations.

This was a large, novel investigation of occupational factors and preterm birth among firefighters. This timely study adds to a sparse body of literature highlighting the need to consider additional occupational protections for women firefighters. In addition, this study provides initial evidence of a potential period of vulnerability during a firefighter's pregnancy that warrants further investigation.[4 36] Importantly, our results were robust across both references samples (US birth certificates and US nurses) and for sensitivity analyses performed.[15 16]

Still, there are important limitations to consider. First, our results may not be generalisable to the entire fire service, an

Table 3 Associations between occupational factors in 2017 and risk of preterm birth among 934 firefighters and 1356 pregnancies*†

	Preterm births N (%)		RR (95% CI) Model 1‡	RR (95% CI) Model 2§
Firefighter subgroups				
Employment, stratified by wildland firefighter status				
Structural firefighter	No	Yes		
Career	713 (87%)	103 (13%)	1.00 (Ref.)	1.00 (Ref.)
Volunteer	104 (81%)	25 (19%)	1.54 (0.98 to 2.41)	1.47 (0.92 to 2.33)
Wildland/combination firefighter	No	Yes		
Career	352 (94%)	22 (6%)	1.00 (Ref.)	1.00 (Ref.)
Volunteer	24 (71%)	10 (29%)	3.86 (1.56 to 9.52)	2.82 (1.19 to 6.67)
Interaction *p*-value¶			<0.01	0.09
Work practices				
Shift schedule of career firefighters	No	Yes		
Less than 24 hours on shift	229 (87%)	34 (13%)	1.00 (Ref.)	1.00 (Ref.)
24 or more hr on shift	835 (90%)	92 (10%)	0.78 (0.52 to 1.15)	0.88 (0.58 to 1.32)

Combination= does wildland firefighting in addition to working for a career or volunteer department.
*Generalised estimating equations with Poisson distribution and sandwich variance estimators were used to estimate relative risks and 95% CIs.
†Three pregnancies had missing information for shift schedule and were not included in those models.
‡Model 1 is adjusted for age-at-pregnancy, modelled as age-at-pregnancy and age-at-pregnancy.[2]
§Model 2 is additionally adjusted for highest education completed (some college/at least college degree), gravidity (yes/no), BMI (<30 kg/m^2/≥30 kg/m^2) and smoking status (current or former/never). Highest education completed, BMI and smoking status were measured in 2017 at time of survey. Gravidity was assessed for each pregnancy.
¶P value for interaction term between employment and wildland firefighter status.
BMI, body mass index ; RR, relative risk.

Table 4 Associations between pregnancy-specific occupational factors and risk of preterm birth among 934 firefighters and 1356 pregnancies*†

	Preterm births n (%)		RR (95% CI) Model 1‡	RR (95% CI) Model 2§	RR (95% CI) Model 3¶
Fire responses during pregnancy					
Worked fire/rescue calls at pregnancy start	No	Yes			
No	119 (89%)	14 (11%)	1.00 (Ref.)	1.00 (Ref.)	1.00 Ref.)
Yes	1071 (88%)	146 (12%)	1.19 (0.71–2.00)	1.21 (0.73–2.02)	1.20 (0.72–2.00)
No of fires responded to during pregnancy	No	Yes			
0 fires	309 (87%)	46 (13%)	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)
1–4 fires	470 (87%)	73 (13%)	1.13 (0.79–1.63)	1.11 (0.77–1.60)	1.15 (0.80–1.65)
≥5 fires	383 (92%)	34 (8%)	0.71 (0.45–1.10)	0.83 (0.53–1.29)	0.83 (0.54–1.29)
Work restriction during pregnancy					
Was work restricted during pregnancy?	No	Yes			
No	261 (87%)	39 (13%)	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)
Yes	918 (89%)	115 (11%)	0.87 (0.60–1.25)	0.95 (0.65–1.38)	1.00 (0.68–1.46)
Timing of start of work restriction	No	Yes			
None/during 3rd trimester	317 (86%)	51 (14%)	1.00 (Ref.)	1.00 (Ref.)	1.00 (Ref.)
2nd trimester	502 (92%)	41 (8%)	0.57 (0.37–0.86)	0.64 (0.42–0.98)	0.67 (0.43–1.03)
1st trimester	351 (86%)	59 (14%)	1.06 (0.73–1.55)	1.09 (0.75–1.59)	1.13 (0.77–1.64)

*Generalised estimating equations with Poisson distribution and sandwich variance estimators were used to estimate relative risks and 95% CIs.
†A total of 102 total pregnancies had missing information for worked fire/rescue calls (6), number of fires (40), work restriction (23) and time of work restriction (35) and were not included in those models.
‡Model 1 is adjusted for age-at-pregnancy, modelled as age-at-pregnancy and age-at-pregnancy.[2]
§Model 2 is additionally adjusted for highest education completed (some college/at least college degree), gravidity (yes/no), BMI (<30 kg/m^2/≥30 kg/m^2) and smoking status (current or former/never). Highest education completed, BMI and smoking status were measured in 2017 at time of survey. Gravidity was assessed for each pregnancy.
¶Model 3 is additionally adjusted for employment status (career/volunteer).
BMI, body mass index; RR, relative risk.

acknowledged limitation of snowball sampling recruitment.[14] Firefighters identified were more likely to be well connected, or receptive towards research, which may be influenced by health status. Women who experience preterm births may be at greater risk for mental health conditions which could affect their sociability.[37] In addition, while study promotion did not emphasise reproductive health topics, firefighters who were concerned about or who had experienced adverse reproductive outcomes may have been more likely to participate. These factors may have contributed to selection bias in our study and affected the results. Future research should consider how to increase enrollment from volunteers, wildland and combination firefighters, and firefighters from smaller departments. The relatively low numbers of wildland/combination firefighters and volunteer firefighters in our analysis likely contributed to the limited statistical power.

Another limitation is misclassification; employment, wildland firefighter status, shift schedule, BMI and smoking were measured at survey in 2017 and assumed to be valid proxies for each pregnancy. However, mothers who experience adverse pregnancy outcomes are more likely to experience mental health changes,[37] which could impact behavioural and lifestyle characteristics. These potential behavioural and lifestyle changes could have even greater impact if the pregnancy occurred more recently. In sensitivity analyses adjusted for BMI and smoking status (among other variables), we observed that the association between volunteers and risk of preterm birth in wildland or combination firefighters attenuated and was no longer statistically significant when we restricted to first pregnancies. This may suggest that earlier pregnancies have a greater probability of exposure misclassification, that misclassification of confounders are affecting estimates, or both. Future studies can address this issue by collecting pregnancy-level measures of all variables of interest. In addition, identifying as a wildland or combination firefighter during an index pregnancy may not equate to participating in wildland fire suppression during that pregnancy, which would have attenuated the observed association. Finally, our understanding of the effects of cumulative wildfire exposure on reproductive outcomes is limited, so it is possible that pregnancies that occurred outside of wildfire season could still be impacted by previous work.

Our findings contribute to growing evidence suggesting that women firefighters may have an excess risk of adverse reproductive outcomes compared with non-firefighters which varies by occupational factors. Women firefighters may benefit from increased occupational protections to reduce the risk of preterm birth. Research replicating these novel associations is needed to inform future policy development and personal decision-making.

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REFERENCES

1 Jahnke SA, Poston WSC, Jitnarin N, *et al*. Maternal and child health among female firefighters in the U.S. *Matern Child Health J* 2018;22:922–31.
2 Park J, Ahn Y-S, Kim M-G. Pregnancy, childbirth, and puerperium outcomes in female firefighters in Korea. *Ann Occup Environ Med* 2020;32:e8.
3 Jung AM, Jahnke SA, Dennis LK, *et al*. Occupational factors and miscarriages in the US fire service: a cross-sectional analysis of women firefighters. *Environ Health* 2021;20:116.
4 Abdo M, Ward I, O'Dell K, *et al*. Impact of Wildfire smoke on adverse pregnancy outcomes in Colorado, 2007–2015. *Int J Environ Res Public Health* 2019;16:3720.
5 Chersich MF, Pham MD, Areal A, *et al*. Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis. *BMJ* 2020;20:m3811.
6 Specht IO, Hammer PEC, Flachs EM, *et al*. Night work during pregnancy and preterm birth—A large register-based cohort study. *PLoS One* 2019;14:e0215748.
7 Waterfield G, Rogers M, Grandjean P, *et al*. Reducing exposure to high levels of perfluorinated compounds in drinking water improves reproductive outcomes: evidence from an intervention in Minnesota. *Environ Health* 2020;19:42.
8 Graber JM, Black TM, Shah NN, *et al*. Prevalence and predictors of per- and Polyfluoroalkyl substances (PFAS) serum levels among members of a suburban us volunteer fire department. *Int J Environ Res Public Health* 2021;18:3730.
9 Trowbridge J, Gerona RR, Lin T, *et al*. Exposure to Perfluoroalkyl substances in a cohort of women firefighters and office workers in San Francisco. *Environ Sci Technol* 2020;54:3363–74.
10 Burgess JL, Fisher JM, Nematollahi A, *et al*. Serum per- and polyfluoroalkyl substance concentrations in four municipal us fire departments. *Am J Ind Med* 2022.
11 IARC. *Painting, firefighting, and shiftwork*. Lyon, France: International Agency for Research on Cancer, World Health Organization, 2010. http://monographs.iarc.fr/ENG/Monographs/vol98/mono98.pdf
12 Rodríguez-Marroyo JA, Villa JG, López-Satue J, *et al*. Physical and thermal strain of firefighters according to the firefighting tactics used to suppress wildfires. *Ergonomics* 2011;54:1101–8.
13 Hollerbach BS, Kaipust CM, Poston WSC, *et al*. Injury correlates among a national sample of women in the US fire service. *J Occup Environ Med* 2020;62:634–40.
14 Sadler GR, Lee H-C, Lim RS-H, *et al*. Recruitment of hard-to-reach population subgroups via adaptations of the Snowball sampling strategy. *Nurs Health Sci* 2010;12:369–74.
15 Lawson CC, Whelan EA, Hibert EN, *et al*. Occupational factors and risk of preterm birth in nurses. *Am J Obstet Gynecol* 2009;200:51.e1–51.e8.
16 Martin JA, Hamilton BE, Osterman MJK. Births: final data for 2018. *Natl Vital Stat Rep* 2019;68.
17 Rich-Edwards JW, Goldman MB, Willett WC, *et al*. Adolescent body mass index and infertility caused by ovulatory disorder. *Am J Obstet Gynecol* 1994;171:171–7.
18 Pedroza C, Truong VTT. Estimating relative risks in multicenter studies with a small number of centers — which methods to use? A simulation study. *Trials* 2017;18:512.
19 Zou G. A modified poisson regression approach to prospective studies with binary data. *Am J Epidemiol* 2004;159:702–6.
20 Kenny LC, Lavender T, McNamee R, *et al*. Advanced maternal age and adverse pregnancy outcome: evidence from a large contemporary cohort. *PLoS One* 2013;8:e56583-e.
21 Ruiz M, Goldblatt P, Morrison J, *et al*. Mother's education and the risk of preterm and small for gestational age birth: a DRIVERS meta-analysis of 12 European cohorts. *J Epidemiol Community Health* 2015;69:826–33.
22 Kazemier BM, Buijs PE, Mignini L, *et al*. Impact of obstetric history on the risk of spontaneous preterm birth in singleton and multiple pregnancies: a systematic review. *BJOG* 2014;121:1197–208.
23 Madan J, Chen M, Goodman E, *et al*. Maternal obesity, gestational hypertension, and preterm delivery. *The Journal of Maternal-Fetal & Neonatal Medicine* 2010;23:82–8.
24 Shah NR, Bracken MB. A systematic review and meta-analysis of prospective studies on the association between maternal cigarette smoking and preterm delivery. *Am J Obstet Gynecol* 2000;182:465–72.
25 Evarts B, Stein GUS. *Fire department profile 2018*. 2020. National Fire Protection Association.
26 Azur MJ, Stuart EA, Frangakis C, *et al*. Multiple imputation by chained equations: what is it and how does it work? *Int J Methods Psychiatr Res* 2011;20:40–9.
27 White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med* 2011;30:377–99.
28 Rubin DB. *Multiple imputation for nonresponse in surveys*. New York: Wiley, 1987.
29 Boyle P, Parkin DM. Cancer registration: principles and methods. statistical methods for registries. *IARC Sci Publ* 1991;95:126–58.
30 Bekkar B, Pacheco S, Basu R, *et al*. Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US. *JAMA Netw Open* 2020;3:e208243.
31 Laitinen JA, Koponen J, Koikkalainen J, *et al*. Firefighters' exposure to perfluoroalkyl acids and 2-butoxyethanol present in firefighting foams. *Toxicol Lett* 2014;231:227–32.
32 Meng Q, Inoue K, Ritz B, *et al*. Prenatal exposure to Perfluoroalkyl substances and birth outcomes; an updated analysis from the Danish national birth cohort. *Int J Environ Res Public Health* 2018;15:1832.
33 Hoover K, Hanson LA. Wildfire statistics Congressional Research Service; 2021, Report No.: IF10244.
34 Cleland SE, Serre ML, Rappold AG, *et al*. Estimating the Acute Health Impacts of Fire-Originated $PM_{2.5}$ Exposure During the 2017 California Wildfires: Sensitivity to Choices of Inputs. *Geohealth* 2021;5:e2021GH000414.
35 Liu Y, Austin E, Xiang J, *et al*. Health Impact Assessment of the 2020 Washington State Wildfire Smoke Episode: Excess Health Burden Attributable to Increased $PM_{2.5}$ Exposures and Potential Exposure Reductions. *GeoHealth* 2021;5:e2020GH000359.
36 Sheridan P, Ilango S, Bruckner TA, *et al*. Ambient fine particulate matter and preterm birth in California: identification of critical exposure windows. *Am J Epidemiol* 2019;188:1608–15.
37 Misund AR, Nerdrum P, Bråten S, *et al*. Long-Term risk of mental health problems in women experiencing preterm birth: a longitudinal study of 29 mothers. *Ann Gen Psychiatry* 2013;12:33.