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Secondhand cannabis smoke exposure and respiratory symptoms among adults living in a state with legalized medical cannabis with limited smoke-free protections

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ABSTRACT

Background: Little is known about the demographic and health correlates of secondhand cannabis smoke (SHCS) exposure, despite increased availability and use of cannabis across the U.S. This study examined the prevalence and correlates of SHCS exposure in a sample of N=5,410 adults living in Oklahoma and the association of SHCS exposure with self-reported respiratory problems.

Methods: Data were from a repeated cross-sectional online survey of adults ages 18 and older who completed measurements of past 30-day SHCS exposure in the respondent's home, in a vehicle, and/or in an indoor setting; harm perceptions of SHCS exposure; frequency of current respiratory symptoms; past 30-day use of cannabis, alcohol, and cigarettes

Results: Almost half (42 %) reported past 30-day SHCS exposure. In bivariate tests, those exposed were male, younger, non-Hispanic (NH) black or Hispanic, reported lower educational and financial attainment, had lower harm perceptions of SHCS exposure, endorsed more respiratory symptoms, and reported past 30-day cannabis and cigarette use (all p's < 0.01). In an adjusted regression model, young adulthood (ages 18–24), NH black race (vs NH White), and past 30-day cigarette smoking and cannabis use emerged as the strongest correlates of SHCS exposure. In interaction models, respiratory symptoms were highest among those reporting past 30-day SHCS exposure and past 30-day cannabis use.

Conclusion: SHCS exposure is common and associated with more frequent respiratory symptoms, particularly among cannabis users. Those exposed were more socially and economically vulnerable.

1. Introduction

Access to cannabis products have increased significantly in the past decade due to medical and recreational cannabis legalization across the U.S. Medical cannabis remains the predominant form of legalized use in the U.S., with more than half of states legalizing medical use. (National Conference of State Legislatures, 2022) Although cannabis has some benefits for specific health conditions (The National Academies of Sciences Engineering and Medicine, 2017), exposure to combusted cannabis smoke, and even cannabis vaping, could cause harm. (Benevenuto et al., 2022; Meier et al., 2022; Meier et al., 2020; Cohn et al., 2021; Loflin et al., 2015) Even with the emergence of non-combustible cannabis products, combusted cannabis remains the most common mode of use. (Johnson et al., 2016; Schauer et al., 2016; Russell et al., 2018) Secondhand cannabis smoke exposure (SHCS), similar to tobacco smoke exposure, may pose possible adverse health outcomes,

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includuing impacts to respiratory functioning, among other factors. (US Department of Health and Human Services, 2006) Few states have policies limiting medical or recreational cannabis use to non-combustible products only,. raising concerns about the health impacts of exposure to firsthand and secondhand cannabis smoke.

Cannabis smoke contains many of the same toxicants and carcinogens as tobacco smoke (Moir et al., 2008), up to 20 times the concentration of the carcinogenic polyaromatic hydrocarbons (Hoffmann et al., 1975; Ghasemiesfe et al., 2019), and 2–6 times the emission rates relative to secondhand tobacco smoke. (Zhao et al., 2020) Cannabis smoke can be a risk factor for a variety of health and respiratory problemsand other factors known to increase cancer risk. (Maertens et al., 2013; Maertens et al., 2009) As early as 2009 the California Environmental Protection Agency deemed cannabis smoke to be carcinogenic, increasing cancer risk, and reproductive health problems. (Tomar et al., 2009) Popular cannabis use practices, like consuming cannabis in a cigar and vaping cannabis in an electronic vaping device may further exacerbate exposure to toxicants. (Wu et al., 1988; Meier and Hatsukami, 2016; Islam et al., 2022) One recent study found higher rates of emphysema in the CT chest scans of cannabis smokers (inclusive of tobacco users) compared to cannabis and tobacco nonsmoker controls. (Murtha et al., 2022) Additionally, when matched for age, cannabis smokers, compared to tobacco-only users, had higher rates of emphysema and bronchial thickening, an indicator of airway inflammation.

Despite potential health risks, acceptance of cannabis use in personal spaces is relatively high, and perceptions of harm from being exposed to cannabis smoke are relatively low. In a 2015 study of 2,002 students in two U.S. universities, a greater proportion reported they would allow cannabis smoking in the home (17 %) compared to cigarette smoking (14.7 %), and over a quarter (27.3 %) said they would allow cannabis smoking in a vehicle, compared to 35.9 % who said they would allow cigarette smoking in a vehcile. (Padilla et al., 2015) In a national sample of U.S. adults, Schauer et al (Schauer et al., 2020) found that nearly a third perceived cannabis smoke as "not/a little" harmful, although most (80 %) did not favor public cannabis smoking. A 2022 paper from the International Cannabis Policy Study examined the prevalence and correlates of SHCS exposure among residents living in detached and multi-unit housing in Canada and in different cannabis legal environments in the U.S. (Driezen et al., 2022) Results showed that 20.6 % of adults living in U.S. states with legal non-medical cannabis and 15 % of adults living in U.S. states with no legal cannabis reported SHCS exposure in the past month. Further, males, racial and ethnic minorities, current cannabis users, and individuals with lower harm perceptions of cannabis smoke were more likely to report SHCS exposure. While this was a large sample with over 40,000 respondents combined, health effects, like respiratory symptoms were not examined.

Oklahoma is an especially unique location to study correlates and health risks of SHCS exposure. Medical cannabis use is legal in Oklahoma and Oklahoma leads the nation in the number of dispensaries per capita. (Hutchinson and Ray, xxxx; Cooper, 2020; Scavelli, 2020; Demko, 2021) About 10 % of the population has a medical cannabis card issued by the Oklahoma Medical Marijuana Association (OMMA). (Demko, 2021) Oklahoma has one of the highest rates of tobacco use in the U.S. (Substance Abuse and Mental Health Services Administration, 2019-2020) This is concerning because tobacco and cannabis are frequently co-co-used (Strong et al., 2018; Cohn and Chen, 2022), and their co-use could increase cancer risk. (Cohn et al., 2021) Oklahoma is the only state without any 100 % smoke-free policies, meaning it is still legal for people to smoke in public places like hotels, bars, and casinos. (Oklahoma Tobacco Settlement Endowment Trust, 2022) Oklahoma enacted broad preemption, meaning that more restrictive smoke-free laws passed at the local level cannot be adopted. This is alarming because, combustible and vaporized medical cannabis can be used in public places where tobacco use is allowed. (Oklahoma State Department of Health, 2020) According to a report by the American Non-Smokers' Rights Foundation, nearly four million Oklahomans are vulnerable to exposure to secondhand tobacco smoke resulting from preemption laws. This number is likely exacerbated by SHCS exposure. (American NonSmokers' Rights Foundation, 2022) Lastly, Oklahoma has high rates of socioeconomically disadvantaged and/or uninsured residents (United States Census Bureau, 2020) who are the most vulnerable to the health risks of smoke exposure, thereby increasing exposure-related health consequences.

Even though emerging evidence shows that cannabis secondhand smoke contains higher concentrations of fine particulate matter (Nguyen and Hammond, 2022) and is emitted at higher rates than tobacco smoke (Zhao et al., 2020), little is known about the extent to which SHCS exposure is associated with respiratory symptoms, particularly across both cannabis users and non-users. This study examined a) the prevalence and demographic correlates of SHCS exposure in a large sample of adults in Oklahoma and b) the interactive effects of past month SHCS exposure and past month cannabis use on self-reported respiratory problems. We hypothesized that respiratory problems would be most severe among individuals reporting past month SHCS exposure and cannabis use, even after controlling for sociodemographics and factors associated with respiratory problems (e.g., cigarette smoking). Because combusted cannabis use remains the most common form of use in the U. S. (Johnson et al., 2016; Schauer et al., 2016; Russell et al., 2018) it is vitally important to identify those who may be impacted by SHCS exposureso that future regulations can protect individuals.

2. Materials and methods

Data are from a cross-sectional multi-wave online survey (3 waves deployed 6 months apart, September 2020-September 2021). Eligible participants were $\geq$ 18 years old and living in Oklahoma (verified by self-reported zip code). Individuals were recruited from a professionally maintained panel vendor, Lucid, by being sent a study invitation. Eligible individuals provided consent and then completed the online survey (~12 min long). A total of 5,394 participants completed the survey. The sample was closely aligned with the racial and ethnic demographics of Oklahoma (i.e., 75.3 % White, 8.9 % Black, 0.4 % Native Hawaiian or Pacific Islander, 8.4 % American Indian or Alaskan Native, 5.6 % more than one race; 9.5 % Hispanic). (Schauer et al., 2015) Participants were compensated based on incentives provided by the panel to which they belonged (e.g., cash, gift cards, points to redeem reward prizes or gift cards; equating to roughly $1). There were 145 individuals who completed more than one wave, and data from their most recently completed survey wave were retained in analyses. The final analytic sample consisted of 5,410 adults who had responses to the items assessing SHCS exposure. Procedures were approved by the University of Oklahoma Health Sciences Center IRB (#11994). More details on the study methodology, data quality, and sample demographics are reported here. (Kendzor et al., 2022; Ehlke et al., 2022; Cohn et al., 2023).

2.1. Measures

Participants provided demographic information, including age, biological sex, race and ethnicity, annual household income ($\leq$$19,999 to $\geq$$100,000), employment status (employed full or part-time, retired, unemployed, student), and education.

Participants who reported past year cigarette, alcohol, or cannabis use were asked to report the number of days they used each of those substances in the past 30-days (0–30). Those who reported using that substance on $\geq$ 1 more days were classified as having used that particular substance in the past 30-days.

To assess perceptions of SHCS exposure, participants were asked: "How harmful do you believe it is to be exposed to second hand smoke from someone else who is smoking cannabis/marijuana?," 1 = no harm to 4 = a lot of harm.

The 8-item American Thoracic Society Questionnaire (ATSQ) (Ferris, 1978) was used to measure the frequency (1 = never to 5 = every day) of

current respiratory symptoms (e.g., coughing frequently/first thing in the morning, wheezing, shortness of breath when walking/exercising, phlegm, mucous when coughing, pain or chest tightness, tiring easily). A sum scorea was computed, ranging from 8 to 40, with higher scores indicating more frequent respiratory symptoms.

General health was assessed with: "In general, would you say your health is…" with 5 response options (1 = poor to 5 = excellent), using an item from the Health Information National Trends Survey (HINTS).

Using items adapted from the Secondhand Smoke Module of the Behavioral Risk Factor Surveillance System (Centers for Disease Control and Prevention, 2011), a dichotomous variable was created to assess number of days exposed to cannabis smoke in the last 30-days in: a) respondent's home, b) vehicle, and c) indoor setting. Exposure on ≥ 1 day in at least one setting was categorized as SHCS exposure.

3. Analytic plan

ATSQ scores were normally distributed. A small number (n = 18) of participants did not answer every question and thus had a total score < 8. Bivariate tests were used to examine the differences between those exposed and not exposed SHCS on demographics, harm perceptions, general health, and substance use behavior. A multivariable logistic regression model was used to identify the most significant correlates of SHCS exposure, with all variables entered simultaneously into the model. Finally, an analysis of covariance (ANCOVA) test was conducted to examine the main and interactive associations of past 30-day SHCS exposure (yes/no) and past 30-day cannabis use (yes/no) on self-reported respiratory symptoms, controlling for sex, age, race/ethnicity, employment status, cannabis smoke harm perceptions, past 30-day cigarette smoking, and wave. Analyses were conducted using SPSS 27.

4. Results

The total sample was primarily NH White (70.3 %), had at least some college or technical degree education (62.1 %), and were 40 years old (SD=16.33). Just over half were female (56.7 %), worked full- or part-time (53.8 %), and 27 % reported annual income of <$20,000.

Table 1 shows characteristics of those who did and did not report SHCS exposure. Almost half (42.1 %) reported past 30-day SHCS exposure. A greater proportion of those exposed (versus not) were male (46.5 % vs. 41.3 %), younger (ages 18–44), NH Black (10.7 % vs. 5.8 %) and Hispanic (11.5 % vs. 6.4 %), and endorsed past 30-day cigarette use (54.3 % vs. 24.4 %), alcohol use (55.2 % vs 44.5 %), and cannabis use (56 % vs. 17.1 %). Those reporting SHCS exposure had, overall, lower education and income, more frequent respiratory symptoms (M=16.87 vs. 14.20), and lower harm perceptions of SHCS exposure. General health and study wave unrelated to SHCS exposure. Fig. 1 shows exposure by number of locations, with 29.3 % reporting SHCS exposure in 1 location, 29.6 % reporting exposure in 2 locations, and 41.1 % reporting exposure in all 3 locations (home, vehicle, outdoors). Among those reporting SHCS exposure in only 1 location, 3.5 % were exposed in a vehicle, 11.5 % were exposed at home, and 14.2 % were exposed indoors.

The multivariable logistic regression model and 95 % confidence intervals of correlates of SHCS exposure is in Table 1. Compared with adults ages 65+, adults ages 18–24 (aOR=3.92), 25–34 (aOR=2.88), 35–44 (aOR=2.76), and 45–54 (aOR=2.26) were more likely to report SHCS exposure (all p's < 0.001). Compared to white, NH Black (aOR=2.07) and Hispanic respondents (aOR=1.79) were more likely to report SHCS exposure (all p's < 0.001). Additionally, respondents reporting more frequent respiratory symptoms (aOR=1.05), lower harm perceptions of SHCS exposure ("no harm" aOR=2.82; "a little harm" aOR=2.05; "some harm" aOR=1.58), past 30-day cigarette smoking (aOR=1.73), and past 30-day cannabis use (aOR=4.10) were more likely to report SHCS exposure (all p's < 0.001). SHCS exposure was less likely among those who were not employed and not looking for work (aOR=0.70) and among those who had some college education or who completed technical school (aOR=0.71).

There was a significant interaction of SHCS expsoure and past 30-day cannabis use on respiratory symptoms, $F(1,5207) = 5.08$, $p < 0.05$. Table 2 shows the adjusted means, standard errors across the groups. A univariate ANCOVA with Bonferonni post-hoc adjustment was used to test differences between means. See Fig. 2. Past 30-day cannabis users who reported SHCS exposure endorsed more frequent respiratory symptoms ($\underline{M}_{adjusted} = 17.49$) compared to non– cannabis users who were exposed to SHCS ($\underline{M}_{adjusted} = 16.38$, $p < 0.01$), cannabis users who were not exposed [$\underline{M}_{adjusted} = 14.76$, $p < 0.001$], and to non-users who were not exposed ($\underline{M}_{adjusted} = 14.67$, $p < 0.001$). Furthermore, non-past cannabis users who reported SHCS exposure endorsed more frequent respiratory symptoms ($\underline{M}_{adjusted} = 16.38$) compared to non– cannabis users who were not exposed ($\underline{M}_{adjusted} = 14.67$; $p < 0.001$). Cannabis users ($\underline{M}_{adjusted} = 14.76$) and non-users ($\underline{M}_{adjusted} = 14.67$) who were not exposed did not differ ($p > 0.05$). Lastly, past 30-day cannabis users who were not exposed reported more severe respiratory symptoms compared to non-users who were exposed ($p < 0.001$). In main effects analyses, SHCS exposure and past 30-day cannabis use were associated with more frequent respiratory symptoms (p's < 0.01)].

4.1. Post-hoc analyses

Because cigarette smoking could influence respiratory symptom severity and is highly correlated with cannabis use, we re-examined interactions of past 30-day cannabis use and SHCS exposure separately among past 30-day cigarette smokers and non-smokers (Supplemental Table 1). Analyses among current cigarette smokers additionally controlled for number of days smoked cigarette in the past 30-days (e.g., dose of cigarette exposure). In the sample, 22 % of non-cigarette smokers reported past 30-day cannabis use, while 57 % of past 30-day cigarette smokers reported past 30-day cannabis use. Among non-smokers, the 2-way ANCOVA interaction was not significant ($F(1,3413) = 0.13$, $p = 0.71$). In main effects analyses, past 30-day cannabis use ($F(1,3413 = 5.13$, $p < 0.05$) and SHCS exposure ($F(1,3413) = 31.18$, $p < 0.001$) were independently associated with more frequent respiratory symptoms, such thatnon-smokers who reported SHCS exposure endorsed more frequent respiratory symptoms than those not exposed ($M_{adjusted} = 14.63$ vs 13.04) and non-smokers who reported past 30-day cannabis use endorsed more frequent respiratory symptoms compared to non-cannabis users ($M_{adjusted} = 14.62$ vs 13.96). Among current cigarette smokers, the interaction remained significant ($F(1,1794 = 4.12$, $p < 0.05$). In post-hoc analyes, all groups differed significantly from each other but there were no differences between cannabis users and non-users who were exposed ($p = 0.05$), and no differences between cannabis users and non-users who were not exposed ($p = 1.0$).

5. Discussion

Almost half the sample (~42 %) reported past month SHCS exposure in their home, a car, and/or other public space. Among those reporting SHCS exposure, the majority (41.1 %) endorsed exposure in all 3 locations. Exclusive exposure only in a vehicle, at home, or outdoors only was low (3.5 %, 11.5 %, and 14.2 % respectively). Rates of SHCS exposure among U.S. adults how been shown to range from 27.5 % in the past week (Schauer et al., 2020) to 20 % in the past month in legal cannabis states and 15.5 % in illegal cannabis states. (Driezen et al., 2022) Higher rates of exposure in our sample could be attributed to the relatively high number of residents in the states with a legal, medical cannabis license; respondents' incorrectly attributing the smell of tobacco smoke for cannabis smoke, given high rates of cigarette smoking in Oklahoma; the wide availability of smoking environments because of preemption in Oklahoma; or differences in defnitions of exposure across

Table 1
Sociodemographic characteristics of *N*=5,410 adults in Oklahoma (2020–2021), and adjusted odds ratios (aOR) of correlates of secondhand cannabis smoke (SHCS) from multivariable logistic regression modeling.

Variable	*Total Sample*	Exposed to cannabis secondhand smoke in the past 30-days?[a]		aOR	95 % CI	p-value
		No (n = 3126) 57.8 %	Yes (n = 2,284) 42.1 %			
Sex, n (%)* **						
Male	2340 (43.3)	1279 (40.9)	1061 (46.5)	REF		
Female	3070 (56.7)	1847 (59.1)	1223 (53.5)	0.88	0.76–1.02	0.09
Age, n (%)* **						
18–24	1116 (20.6)	546 (17.5)	570 (25.0)	**3.92**	**2.73–5.60**	**0<.001**
25–34	1189 (22.0)	573 (18.3)	616 (27.0)	**2.88**	**2.05–4.06**	**0<.001**
35–44	1132 (20.9)	5670 (18.2)	562 (24.6)	**2.76**	**1.96–3.87**	**0<.001**
45–54	778 (14.4)	468 (15.0)	310 (13.6)	**2.26**	**1.60–3.21**	**0<.001**
55–64	633 (11.7)	480 (15.4)	153 (6.7)	1.38	0.96–1.99	0.07
65+	562 (10.4)	489 (15.6)	73 (3.2)	REF		
Race/Ethnicity, n (%)* **						
White, NH	3805 (70.3)	2330 (74.6)	1475 (64.6)	REF		
Black, NH	427 (7.9)	183 (5.9)	244 (10.7)	**2.07**	**1.61–2.67**	**0<.001**
Hispanic	512 (9.5)	224 (7.2)	288 (12.6)	**1.79**	**1.36–2.16**	**0<.001**
Other,[b] NH	662 (12.2)	386 (12.4)	276 (12.1)	0.97	0.79–1.19	0.79
Education, n (%)* **						
Less than 12 years	398 (7.4)	172 (5.5)	226 (9.9)	1.17	0.81–1.70	0.35
High school diploma/GED	1464 (27.1)	770 (24.6)	694 (30.4)	0.83	0.63–1.11	0.22
Some college/technical school	1503 (27.8)	876 (28.0)	627 (27.5)	**0.71**	**0.54–0.94**	**0.01**
Associate's degree	547 (10.1)	347 (11.1)	200 (8.8)	0.73	0.53–1.00	0.05
Bachelor's degree	974 (18.0)	634 (20.3)	340 (14.9)	0.77	0.58–1.01	0.60
Graduate school	522 (9.6)	326 (10.4)	196 (8.6)	REF		
Family income[c], n (%)* **						
< $20,000	1384 (27)	657 (22.5)	727 (33.0)	1.28	0.96–1.70	0.84
$20,000 – $39,999	1292 (25.2)	752 (25.8)	540 (24.5)	0.99	0.75–1.30	0.90
$40,000 – $59,999	870 (17.0	552 (18.9)	318 (14.4)	0.87	0.66–1.16	0.36
$60,000 – $79,999	574 (11.2)	356 (12.2)	218 (9.9)	0.91	0.68–1.22	0.57
$80,000 – $99,999	396 (7.7)	227 (7.8)	169 (7.7)	1.24	0.90–1.70	0.17
$100,000 or more	609 (11.9)	375 (12.8)	234 (10.6)	REF		
Employment, n (%)* **						
Full- or part-time work	2908 (53.8)	1594 (51.0)	1314 (57.5)	REF		
Not employed (not looking for work)[d]	1530 (28.3)	1054 (33.7)	476 (20.8)	**0.70**	**0.58–0.85**	**0<.001**
Unemployed (looking for work)	586 (10.8)	256 (8.2)	330 (14.4)	1.13	0.89–1.42	0.30
Student	231 (4.3)	130 (4.2)	101 (4.4)	0.91	0.63–1.31	0.62
Other	155 (2.9)	92 (2.9)	63 (2.8)	0.72	0.46–1.14	0.17
Respiratory symptoms, Mean (SD) * **	15.34 (7.48)	14.23 (6.95)	16.85 (7.91)	**1.05**	**1.03–1.06**	**0<.001**
General health, n (%)						
Poor	274 (5.1)	157 (5.0)	117 (5.2)	0.68	0.45–1.03	0.06
Fair	1393 (25.9)	781 (25.1)	612 (27.1)	0.94	−0.70–1.27	0.72
Good	2015 (37.5)	1170 (37.5)	845 (37.4)	1.10	0.38–1.44	0.0.48
Very good	1234 (23.0)	735 (23.6)	499 (22.1)	1.13	0.85–1.50	0.38
Excellent	459 (8.5)	274 (8.8)	185 (8.2)	REF		
Perceptions of harm from SHCS exposure, n (%) * **						
No harm	1712 (31.7)	736 (23.6)	967 (42.8)	**2.82**	**2.23–3.56**	**0<.001**
A little harm	1548 (28.6)	836 (26.8)	712 (31.2)	**2.05**	**1.61–2.58**	**0<.001**
Some harm	1210 (22.4)	804 (25.8)	406 (17.8)	**1.58**	**1.24–2.02**	**0<.001**
A lot of harm	934 (17.3)	746 (23.9)	188 (8.2)	**REF**		
Past 30-day cigarette use, n (%)* **						
No	3518 (65.5)	2406 (77.2)	1112 (49.3)	REF		
Yes	1854 (34.5)	709 (22.8)	1145 (50.7)	**1.73**	**1.48–2.02**	**0<.001**
Past 30-day alcohol use, n (%)* **						
No	2746 (51.0)	1729 (55.5)	1010 (44.8)	REF		
Yes	2636 (49.0)	1385 (44.5)	1246 (55.2)	1.08	0.93–1.25	0.27
Past 30-day cannabis use, n (%)* **						
No	3431 (65.5)	2527 (82.4)	904 (41.7)	REF		
Yes	1805 (34.5)	539 (17.6)	1266 (58.3)	**4.10**	**3.54–4.75**	**0<.001**
Wave						
1	1804 (33.3)	1046 (33.5)	758 (33.2)	**0.83**	**0.70–0.98**	**0.03**
2	1817 (33.6)	1066 (34.1)	751 (32.9)	0.994	0.84–1.17	0.94
3	1789 (33.1)	1014 (32.4)	775 (33.9)	REF		

[a]Column percent.
[b]Other race was defined as Asian, Native Hawaiian or Other Pacific Islander, American Indian/Alaska Native, more than 1 race.
[c]Refuse to answer coded as missing (n = 285).
[d]Not employed not looking for work defined as homemaker, retired, and unable to work or disabled.
Some numbers may not up to 100% of the total due to missing values.
Omnibus test of model coefficients for each individual covariate: *p < 0.05 **p < 0.01 ***p < 0.001.

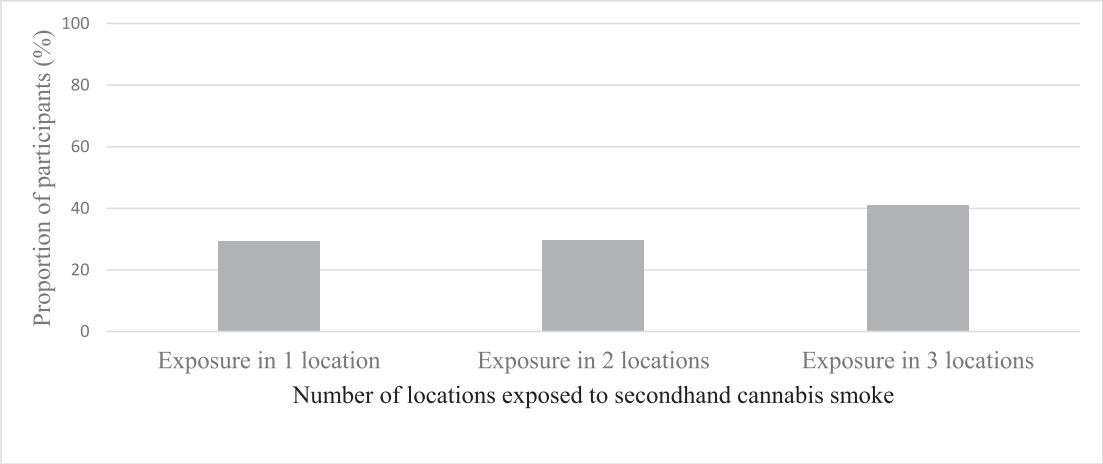

Fig. 1. Proportion of participants (*N*=5,410 adults in Oklahoma) who reported secondhand cannabis smoke exposure by number of locations exposed (home, vehicle, non-home indoor), 2020–2021.

Table 2
Adjusted means and standard errors of secondhand cannabis smoke (SHCS) exposure (yes/no) and past 30-day cannabis use (yes/no) on respiratory symptom severity in N=5,410 adults in Oklahoma (2020–2021).

Cannabis use behavior	SHCS Exposure	
	No Exposure	Yes Exposure
No past 30-day cannabis use		
M	14.67	16.38
SE	0.24	0.29
Past 30-day cannabis use		
M	14.76	17.49
SE	0.36	0.27

Note. Means adjusted for age, sex, race/ethnicity, employment status, cannabis harm perceptions, wave, and past 30-day cigarette smoking.

studies (e.g., outdoors only, home-only, etc.). Consistent with previous research (Schauer et al., 2020; Driezen et al., 2022; Anastasiou et al., 2020), younger, socioeconomically disadvantaged, racial and ethnic minority individuals, and those with lower cannabis risk perceptions were most likely to report SHCS exposure. Additionally, individuals with poor health indicators, including past month cigarette smoking, past month cannabis use, and more severe respiratory problems were at increased risk of reporting SHCS exposure, consistent with prior work. (Schauer et al., 2020; Anastasiou et al., 2020) Special attention is warranted for those at an increased risk for SHCS exposure, as they appear to be especially predisposed to health issues.

Analyses in the full sample revealed an interaction of SHCS exposure and past 30-day cannabis use on respiratory symptom severity, controlling for sociodemographics and current cigarette smoking. Specifically, individuals who used cannabis in the past month and who reported SHCS exposure endorsed the most severe respiratory problems. Cannabis users experience both direct smoke exposure from their own use and indirect exposure, likely increasing the degree of toxic or carcinogenic chemicals entering the lungs and upper airway. (Hoffmann et al., 1975; Ghasemiesfe et al., 2019) Even non-cannabis users in the study endorsing SHCS exposure reported more frequent respiratory symptoms than non-cannabis users who were not exposed, suggesting a link between SHCS exposure and respiratory problems beyond cannabis use behavior. Other work suggests that non-cannabis users show evidence of passive cannabis smoke exposure, confirmed by higher levels of cannabinoids in both blood and urine. (Cone et al., 2015) When data were re-analyzed seprately across current and non-current cigarette smokers, the interaction of cannabis use and SHCS exposure was no longer significant among non-smokers, though main effect of SHCS exposure and direct cannabis smoke exposure (e.g., current cannabis use), on respiratory symptoms were visible even among non-smokers. It is possible that the multiplicative effects of cannabis use and SHCS exposure on respiratory symptoms are driven, in part, by cannabis and cigarette co-use. (Weinberger et al., 2023; Weinberger et al., 2022; Weinberger et al., 2020) This hypothesis is partially supported by our post-hoc analyses, which showed that respiratory symptom severity was most severe among current cigarette smokers who endorsed past 30-day cannabis use and SHCS exposure. Taken together, these results underscore the negative impact of cannabis user in conjunction with cigarette smoking. It is important to note that respiratory symptoms were still elevated among non-cigarette smokers who reported SHCS exposure in the past month. Demonstrating the effect of cannabis SHS exposure on health outcomes in a population where confounding of cigarette smoking is lower provides a strong indication of its true effect. We caution interpretation of the post-hoc analyses that stratified by current smoking status. Cannabis users who do not smoke cigarettes represent a distinct a less common subgroup from cannabis users on a whole. It is more common for cannabis users to report concurrent cigarette smoking in our sample (57 %) and US national data (60 %) (Schauer et al., 2015) than no cigarette smoking.

Among those reporting SHCS exposure, nearly 60 % used cannabis in the past month, and nearly 70 % perceived little to no harm from SHCS. Thus, we have a large group of particularly vulnerable adults who are at risk for experiencing more frequent respiratory problems, without recognizing the potential harm stemming from SHCS exposure. Given the overlap of toxicants and carcinogens in tobacco and cannabis smoke (Moir et al., 2008; Nguyen and Hammond, 2022), and the known dangers of respiratory disease from secondhand tobacco smoke exposure (US Department of Health and Human Services, 2006), more research is needed to assess the long-term risks of SHCS exposure. Cessation interventions targeting cannabis users could help alleviate respiratory problems. It is worth noting that cannabis smoking has not been consistently linked with cancer in the same way that tobacco smoking has (Cohn et al., 2021; Ghasemiesfe et al., 2019), although cannabis smoke does contain carcinogens that are linked to cancer risk. (Tomar et al., 2009) It is also important to note that while the association between cannabis use and SHCS exposure in this study is consistent with previous research, it might also be an underestimate of exposure if there is a moderate to high proportion of individuals who do not accurately distinguish between cannabis and tobacco smoke exposure in their environment. We did not assess tobacco smoke exposure in this study. Misclassification of cannabis versus tobacco smoke exposure should be queried in future research.

The results have clinical and policy implications. Healthcare

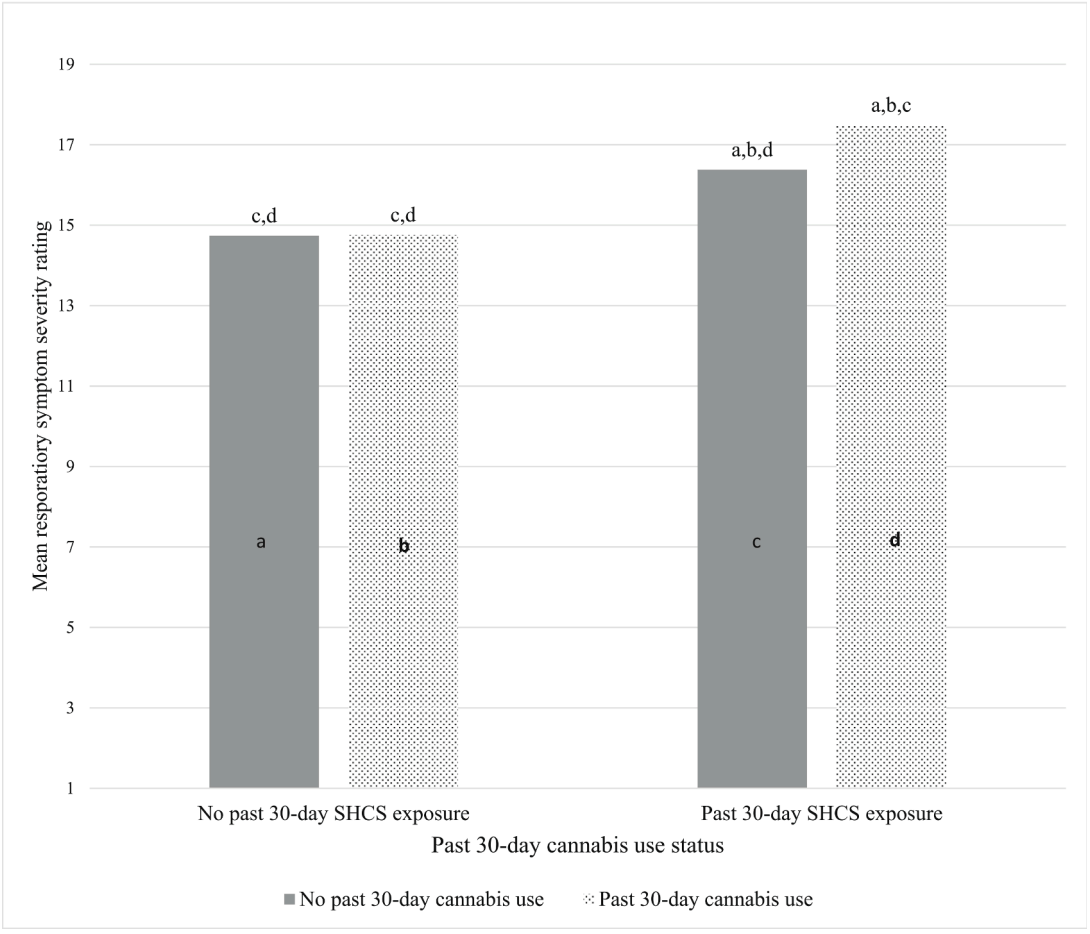

Fig. 2. Adjusted mean differences in respiratory symptoms as a function of past 30-day secondhand smoke (SHCS) exposure and past 30-day cannabis use in *N*=5,410 adults in Oklahoma (2020–2021). Note: a = differs from no SHCS exposure, no past 30-day cannabis use; b = differs from no SHCS exposure, past 30-day cannabis use; c = differs from SHCS exposure, no past 30-day cannabis use; d = differs from SHCS exposure, past 30-day cannabis use. All differences significant at $p < 0.05$.

practitioners can use information from this study to inform patients about the health effects associated with cannabis use and and SHCS exposure on respiratory issues (to themselves and others in their homes). This may be especially relevant for practitioners prescribing cannabis for medicinal uses, as combusted canabis use is common. (Berey et al., 2022) Policymakers could use these findings to underscore the need to reduce the likelihood of SHCS exposure in public spaces via indoor and outdoor smoke-free laws that include both tobacco and cannabis use. These findings may inform public health messaging raising awareness about the potential harms of SHCS exposure, especially among cannabis users, who have lower perceptions of cannabis-related harm. Finally, research on longer-term health effects are warranted among those experiencing SHCS exposure. The extent to which cannabis smoke exposure leads to serious pulmonary and other health problems remains unknown. (Tashkin and Roth, 2019; Huang et al., 2015) Future research should focus on assessing the temporal sequence of respiratory issues following acute and longer-term SHCS exposure across a variety of combustible cannabis products.

This study has several limitations. Causal interpretations cannot be made due to the cross-sectional nature of the data. Objective assessments of respiratory functioning (e.g., spirometry reading) and biomarkers of cannabis exposure were not included in this study. Degree of smoke exposure and respiratory distress will differ between combustible and non-combustible cannabis use. Data were collected after medical cannabis use was legalized in Oklahoma, and thus we cannot determine whether rates of SHCS exposure increased following legalization or whether findings would generalize to individuals living in states where cannabis is not legal. Almost a third of the sample (30 %) reported current cannabis use, which is higher than state and national estimates. (Substance Abuse and Mental Health Services Administration, 2021; Substance Abuse and Mental Health Services Administration, 2021) This may be due to how we queried about cannabis (asking about both medical and recreational use), or because of an unmeasured self-selection bias. Similarly rates of current cigarette smoking were higher than state estimates, and may have influenced reports of respiratory symptom severity. Because of the potential for misclassification and mismeasurement of tobacco SHS for cannabis SHS, it is difficult to conduct an observational study demonstrating the uniqe impact of SHCS exposure on respiratory symptoms in current cigarette smokers. More intensive and accurate methods of tobacco versus cannabis smoke exposure are needed. Only in a group of non-cigarette smokers and non-cannabis users can we have the most accurate measurement of how SHCS exposure impacts physical health outcomes. Data were collected during COVID-19, and cannabis use may have increased during this time as dispensaries remained open.

6. Conclusion

In comparison to secondhand tobacco smoke exposure, which is considered a prevantable cause of morbidity and mortality (US Department of Health and Human Services, 2006; Centers for Disease Control and Prevention, 2014), cannabis smoke is comprised of similar toxicants and carcinogens, and has higher levels of fine particulates. (Moir et al., 2008; Nguyen and Hammond, 2022) Nearly half of the

respondents in this study reported SHCS exposure in the past month and, notably, even non-cannabis users reported SHCS exposure and endorsed higher levels of respiratory symptoms compared to non-users who were not exposed. Some of the most vulnerable groups of individuals reported an increased likelihood of being exposed to cannabis smoke, including those who were younger, identified as a racial or ethnic minority, used cannabis and cigarettes in the past 30-days, and endorsed lower cannabis harm perceptions. To combat the effects of SHCS exposure, limitations on both indoor and outdoor cannabis smoking should be implemented to ensure the safety of all those in the area. Public health messaging about the risks of cannabis use, SHCS exposure, and subsequent potential respiratory issues may also be warranted to reduce potential long-term health effects.

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CRediT authorship contribution statement

Amy M. Cohn: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Brittany Zaring-Hinkle:** Writing – original draft. **Joshua D. Catino:** Writing – original draft. **Sarah J. Ehlke:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation. **Kali Ware:** Writing – review & editing, Resources. **Adam Alexander:** Writing – review & editing, Supervision, Investigation, Formal analysis. **Michael A. Smith:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Data curation. **Sheri Jewell-Fleming:** Writing – review & editing, Supervision. **Lurdes Queimado:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Darla E. Kendzor:** Writing – review & editing, Writing – original draft, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102835.

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