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Cannabis Secondhand Smoke Exposure: Perceived Harm, Household Rules, and In-Home Cannabis Smoking

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

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Public Health (Epidemiology)

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The dissertation of Osika Tripathi is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

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ABSTRACT OF THE DISSERTATION

Cannabis Secondhand Smoke Exposure: Perceived Harm, Household Rules, and In-Home Cannabis Smoking

by

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University of California San Diego, 2023
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Background: Cannabis smoke is often perceived as not harmful[1,2] and is commonly allowed to be smoked indoors.[3–5] The prevalence of household rules to ban in-home cannabis smoking is low[6], and the prevalence of in-home cannabis smoking is high.[7] Cannabis use continues to rise in some regions of the world as cannabis use laws are liberalized.[8,9,10] There is a need to understand what drives in-home cannabis smoking, which leads to investigation of cannabis secondhand smoke (cSHS) exposure.

Methods: In Aim 1, I used cross-sectional data from the Marijuana Use and Environmental Survey to quantify the association between perceived harm of cSHS exposure and having a complete ban on in-home cannabis smoking. In Aim 2, using cross-sectional data from the Global Drug Survey 2021, I quantified the association between perceived harm of cannabis smoke exposure and in-home cannabis smoking. In Aim 3, using baseline data from Project Fresh Air, an intervention study, I i) ascertained a novel variable representing in-home cannabis smoking using air particle data and self-reported indoor particle generating events through residualization, and ii) quantified the relationship between the ascertained in-home cannabis smoking variable and urinary cannabinoids in children's urine.

Results: In Aim 1, respondents who reported cSHS exposure as "extremely harmful" had 6 times the odds (OR=6.0, 95% CI=4.9-7.2) of having a complete ban on in-home cannabis smoking as those who reported cSHS exposure as "totally safe". In Aim 2, a respondent at the 75th percentile of perceived harm of cannabis smoke had 70% higher odds (OR=1.7, 95%b CI=1.6-1.8) of having had no in-home cannabis smoking, compared to a respondent at the 25th percentile of perceived harm. In Aim 3, the odds of detectable urinary cannabinoids in children's urine were five times (OR=5.0, 95% CI = 2.4-10.4) as high in households with reported in-home cannabis smoking compared to those without any in-home cannabis smoking.

Conclusion: Perception of harm related to cannabis smoke exposure is instrumental in reducing in-home cannabis smoking through setting household rules, leading to reduced cSHS exposure at home. Advocacy and educational efforts to reduce cSHS exposure should develop tailored approaches to changing perceptions of cSHS harm.

1. Introduction

1.1. Cannabis Policy in the U.S. and Around the World

Over the last 10 years there has been an unprecedented shift in some regions of the world toward cannabis decriminalization and legalization. Other regions and nations continue to enforce or strengthen laws against cannabis use under the crucible of a war against drugs.[11–13] As of 2023, around 50 countries have legalized medical use of cannabis at a national level, with the majority of the states in the United States of America (U.S.) legalizing medical use but prohibiting cannabis use at the federal level. Eight countries have legalized cannabis for recreational use at a national level including Canada, Georgia, Luxembourg, Malta, Mexico, South Africa, Thailand, and Uruguay. In the U.S., 23 states, 3 territories, and the District of Columbia as well as the Capital Territory in Australia have legalized recreational use. Many more countries have started decriminalizing (removing penalties associated with cannabis possession) recreational cannabis use.

As research continues to show benefits and harms associated with cannabis use, and as these policies continue to shift, health advocates must ask: How can we reduce harms, to ourselves and to others around us, while taking advantages of benefits cannabis provides us?

1.2. Effect of Cannabis Laws on Cannabis Use

Several studies in the U.S. have concluded that medical cannabis laws have little or no impact on cannabis use among adolescents, but medical legalization has resulted in increase in cannabis use among adults 21 years or older.[14] Compared to studies focused on medical cannabis laws, fewer studies have evaluated the effects of legalization of recreational cannabis use. In the few studies published[14,15], findings were mixed, but do not suggest large short-term impacts, showing increased use among adolescents in some regions but no statistically significant change in adolescent cannabis use rates in others.[14,15] Studies of recreational cannabis laws have many limitations and have relied primarily on the short period following change in laws, with more research needed in more diverse populations and regions.

1.3. Methods of Cannabis Use

Cannabis is primarily used through inhalation-based methods including smoking, vaping, and dabbing.[6,16,17] In the U.S. in 2020, 16.4% adults reported smoking cannabis in the past 12 months, followed by 8.8% who reported vaping, and 2.6% who reported dabbing.[6] Of these inhalation-based cannabis users, 50.1% reported only smoking cannabis, 8.4% reported only vaping, 0.2% reported only dabbing. Additionally, 29% reported smoking and vaping and 9.8% reported using cannabis through all three methods. Of relevance to health, all three of these inhalation-based methods of cannabis use generate emissions. As smoking is the most common and most well-studied method of use, I focused on cannabis smoking for this dissertation.

1.4. Emissions from Cannabis Smoking

When cannabis products are burned or heated, they produce smoke, either mainstream or sidestream. As cannabis is burned as well as when the cannabis smoker exhales, the smoke is released into the ambient environment where others in the area could be exposed to the cannabis secondhand smoke (cSHS). The smoke emissions can suspend in the air for hours.[18] cSHS exposure of non-smokers occurs through inhalation of these combustion emissions.[19]

Cannabis smoke contains many of the same carcinogens and toxic chemicals found in tobacco smoke. In fact, some of these chemicals are found at higher concentrations in cannabis smoke than in tobacco smoke.[20] Additionally, compared to smoking tobacco, smoking a similar amount of cannabis has been shown to result in greater respiratory burden of carbon monoxide and tar.[20] In a study of systematic comparison of cannabis and tobacco smoke from similarly prepared cannabis and tobacco cigarettes, the results showed some similarities and differences in the smoke. Cannabis smoke showed higher ammonia and aromatic amines than tobacco, but cannabis smoke contained smaller concentrations of polycyclic aromatic hydrocarbons (PAHs) than tobacco smoke; PAHs and aromatic amines are known carcinogens.[20–22] Although cannabis and tobacco have similar chemical properties, one study notes that they are not equally carcinogenic. Cannabis smoke contains components that minimize some carcinogenic pathways; whereas tobacco smoke components enhance some of these carcinogenic pathways.[23] For example, cannabis downregulates the production of free radicals by promoting a Th2 immune cytokine profile and THC inhibits the enzyme needed to activate some carcinogens found in cannabis smoke.[23] Tobacco smoke, by contrast, overcomes normal cellular checkpoint protective mechanisms through respiratory epithelial cell nicotine receptors,[23] increasing the likelihood of carcinogenesis, among other mechanisms.[23]

1.5. Cannabis Use Among Parents with Children Living at Home

Cannabis use has been increasing among parents with children living at home since the early 2000s. In a study using cross-sectional data from the National Survey on Drug Use and Health (NSDUH) among 169,259 parents with children at home, past-month cannabis use increased by almost 50% (from 4.9% to 6.8%) between 2002 and 2015.[24] Additionally, between 2002 and 2015, daily cannabis use among parents with children at home doubled, with two out of every 100 parents using cannabis daily.[24] Between 2002 and 2015, cannabis use increased from 11.0% to 17.4% among cigarette-smoking parents and from 2.4% to 4.0% among non-cigarette smoking parents (p-values for trends <0.001). Another study looking at NSDUH data from 2004-2017, among adults with children living in the home, noted that cannabis use was more common in U.S. states with legalized cannabis use. Additionally, recreational use legalization increased cannabis use among adults with children living in the home across all sociodemographic variables, but the effect of medical legalization was not as homogenous.[25] Studies on parental cannabis smoking were not found. Additionally, studies on cannabis in-home and in-car smoking among parents were not available, to my knowledge.

This increase in cannabis use among parents with children living in the home is alarming as children are potentially more susceptible to environmental exposures compared to adults. Children breathe more air per kilogram of body weight than adults, and their hands frequently touch their surroundings and their mouth, all while their anatomy and physiology are rapidly developing.[26–28] Additionally, children generally spend more time indoors and have age-specific behaviors such as crawling and putting non-food times in their mouths, leading to close contact with surfaces around the home. Thus, children may be at risk for potential health consequences even at lower levels of cannabis SHS in the home.

1.6. Cannabis and Tobacco Co-Use

Cannabis use among tobacco users has also increased steadily in the U.S. since the turn of the century. In a study of 725,010 participants aged 12 years or older from NSDUH data between 2002-2014, daily cannabis use increased significantly across all tobacco users.[29] Among daily tobacco smokers, daily cannabis use increased from 4.9% to 9.0%. Among non-daily tobacco smokers, daily cannabis use increased from 2.9% to 8.0%. Among former tobacco smokers, daily cannabis use increased from 1.0% to 2.8%. Last, among never tobacco smokers, daily cannabis use increased from 0.5% to 1.1%.[29]

Another study, conducted in California between 2008 and 2018, recruited students in 6th or 7th grade and followed them for 10 years, noting that cannabis and tobacco co-use increased from 0.3% to 9.5% during that time period, with co-use higher among non-Hispanic white students compared to Hispanic or Asian students.[30] A cross-sectional study with 432 participants recruited through Amazon's Mechanical Turk, accessing clinical populations such as non-treatment seeking cannabis users, reported that cannabis and tobacco co-users were older (p=0.015), and that the years of regular cannabis use was higher for tobacco and cannabis co-users than for cannabis only user (p=0.001). There was no statistical difference between co-users and cannabis only users by sex, race/ethnicity, marital status, employment status, education level, household income, or age of first cannabis use. The study also noted that higher interrelatedness of cannabis and tobacco use was associated with greater nicotine dependence, but reasons for tobacco and cannabis co-use varied widely across the sample.[31]

Tobacco use is a leading preventable cause of cancer[32] and co-use of tobacco and cannabis is higher among groups that have higher risk of cancer—particularly, individuals with low socioeconomic status (SES), African American individuals, and males.[33] Tobacco and cannabis co-users had significantly higher levels of biomarkers of exposure to toxicants (e.g., acrylamide, fluorene, pyrene) compared to tobacco-only users, and higher levels of carcinogens (e.g., acrylonitrile) compared to cannabis-only users, indicating significantly higher smoke exposure in co-users as compared to exclusive-users of either tobacco or cannabis.[33] It is important to note that cannabis and tobacco co-use is on the rise, as co-use has been linked to various outcomes among young adults including increased delinquent behavior and heavy alcohol use,[34] driving after using cannabis,[35] academic problems,[36,37] and poorer functioning in emerging adulthood.[30]

1.7. Cannabis Use Among Other Groups

Among older adults: In a study using NSDUH data on 14,896 of adults 65 years or older from 2015-2018, past-year cannabis use increased from 2.4% to 4.2% (p=0.001), and the increase was significantly different by sex (2.6% to 5.7% among males and 1.5% to 2.9% among females).[10] In a review of cannabis use among adults 50 years or older, the greatest increase in cannabis use was seen among older adults 65 years or older compared to those who were 50 to 64 years old. The review also noted that correlates of cannabis use in older adults included being male, unmarried, using other substances such as alcohol or tobacco, and having multiple chronic diseases.[8] While cannabis use being on the rise among older adults may seem to be more benign than among parents with children at home, this behavior highlights how common and normalized cannabis use is becoming. However, normalization of a behavior without proper understanding of the potential corollaries of that normalization, such as smoking around others or leaving products lying around unsafely, may cause immediate or long-term harm.

Among young adults aged 19-22 years: The National Institute of Drug Abuse reported that, between 2014 and 2019, past-year cannabis use increased for young adults (19-22 years old) who attended college (from 34% to 43%) and who did not attend college (from 37% to 43%).[9] Daily cannabis use was three times as high among young adults not attending college compared to young adults attending college.[9] These behaviors among young adults may serve as an indicator of emerging trends that have potential for transference into the wider population in the future. The increase in cannabis use among young adults is noteworthy, especially considering the already high prevalence of cannabis use.

1.8. Perception of Harm Related to Cannabis Smoke

Cannabis smoking is perceived to be a lower risk behavior and not as harmful to health as compared to tobacco smoking.[38,39] Among those who use illicit drugs, lower perception of harm has been associated with use and the appeal of using cannabis.[38,39] Among older adults in the U.S., perceived risk associated with smoking cannabis regularly decreased from 53% to 43%, (19% relative decrease; p<0.001), between 2015 and 2019.[40] Another study, conducted in Colorado in 2003-2011 noted commercialization of cannabis was associated with lower risk perception of cannabis smoking.[41] Using data from the NSDUH from 2002-2018, another study noted that the proportion of participants perceiving cannabis smoking as low-risk nearly doubled (22.6% to 41.2%) during 2002-2014 and further increased by 16% (40.7% to 47.1%) during 2015-2018.[42] Among adolescents (12-17 years old), from the 2017 NSDUH, 80% reported that they perceived monthly cannabis use as harmful. The perception of harm was significantly associated with perception of peers using cannabis and other peer factors as well as parental monitoring.[43] Another recent study among young adults in California in 2014 and 2019-2020 reported that participants perceived cannabis as a lower harm product than any tobacco products, and while perception of harm related to e-cigarettes, hookah, and smokeless tobacco increased over time, perceived harms of cannabis did not change.[1] The same study reported that increased perception of harm related to cannabis was associated with lower odds of cannabis use among participants.[1] A separate study following adults in the U.S. between 2017 and 2021 reported similar findings: perception of daily smoking of cannabis was reported as more safe than daily smoking of tobacco and more participants in 2021 as compared to 2017 reported that daily cannabis smoking was safer.[2]

All studies described above focused on the perceived risk to those who smoke cannabis and did not discuss perceived risk to those who are exposed to cannabis smoke passively and most likely involuntarily. In a 2018 study of 4,088 U.S. adults from KnowledgePanel®, weighted to the US population, a little more than half (52%) of the participants reported that they thought cannabis SHS was harmful, but 32% reported cannabis SHS exposure as little or not at all harmful, with younger age, recent cannabis use, recent tobacco use, cannabis and tobacco co-use, and non-white race being related to increased likelihood of perceiving cannabis SHS as not harmful. The study also reported that 81% were against public cannabis smoking; those who perceived cannabis SHS as not harmful or as low harm were more likely to favor public cannabis smoking.[44] In a recent study following U.S. adults between 2017 and 2021, more participants in 2021 compared to 2017 reported secondhand cannabis smoke exposure as generally safer than secondhand tobacco smoke exposure.[2] Additionally, secondhand cannabis smoke exposure of children, pregnant women, or adults, was reported as safer than tobacco smoke exposure.[2]

Perception of harm related to health behaviors and outcomes are central to various health behavior change theories.[45] Realistic and accurate perception of harm or risk are key motivators in enacting behavioral change, and changing these preconceptions and thought processes is an effective way to amend individual behaviors.[45] Changing perception of harm related to cannabis smoke exposure could ultimately lead to reducing cannabis smoke exposure of non-smokers, especially vulnerable populations such as young children and pregnant people.

1.9. Household Rules on In-Home Cannabis Smoking

Studies of household rules on in-home cannabis smoking report cannabis smoking more often being allowed in the homes of cannabis smokers than among people who do not smoke cannabis.[3–5] Cannabis smoking was more common in homes of participants who reported they used both cannabis and tobacco than among people who use only cannabis or only tobacco.[3–5] These studies also reported that 71% of respondents from a sample of U.S. Facebook users,[4] and 59% of cannabis users from a sample of U.S. college students allowed cannabis use in their homes.[3] The high prevalence of in-home smoking and liberal household smoking rules may be attributed to the low perceived risk of cannabis use compared to cigarette use.[41,46–48]

One study among 3,464 inhalation-based cannabis users in the U.S., reported that 68.3% did not have a complete ban on in-home cannabis smoking.[6] Further, 69.6% of those who smoked cannabis did not have a complete ban compared to 55.0% of cannabis non-smokers.[6]

1.10. In-Home Cannabis Smoking

A substantial proportion of the population is exposed to cSHS. In a study conducted in 2018 with 4,088 U.S. adult participants, weighted to the U.S. population, 27% of U.S. adults reported past-week cannabis SHS exposure in indoor or outdoor public areas with 18.9% reporting exposure to outdoor cannabis SHS and 8.5% reporting indoor cannabis SHS exposure.[44] Younger adults, Black individuals, Hispanic individuals, and current cannabis or tobacco users reported significantly more cSHS exposure than their counterparts.[44] In a study in San Diego County, California with 193 households having at least one tobacco smoker and one or more children living in the home, 15% reported cannabis smoking activities in the past 7-days, with 7.3% reporting cannabis and tobacco smoking in-home.[49]

In a study with around 100,000 participants from the 2019 Global Drug Survey, assessing sentinel drug using populations from 17 countries around the world, in-home cannabis smoking was more prevalent than in-home tobacco smoking. Additionally, cannabis and tobacco co-users had higher proportions of reported in-home cannabis smoking compared to cannabis only users and tobacco only users (83% vs. 70% vs. 38%). Data from a different study similarly showed that tobacco and cannabis co-users reported higher frequency of in-home tobacco smoking as compared to cannabis only and tobacco only users (76% vs. 37% vs. 68%).[50] Another study using 2020 Global Drug Survey data reported that among 7,000 participants from the US who used cannabis in the past 12 months, 55% reported in-home cannabis smoking in the last-30-days.[7] Higher proportions of participants who used both cannabis and tobacco in the past-12-

months reported cannabis being smoked in their home in the past-30-days, compared to participants who used only cannabis in the past-12-months (59% vs. 51%). When the frequency of in-home cannabis smoking in the past-30-days was further categorized, 30% reported daily (25+ days in the last 30 days) in-home cannabis smoking; again, participants who used cannabis and tobacco reported higher frequency of daily in-home cannabis smoking than cannabis only users (33% vs. 26%).[7] Another study among 3,464 inhalation-based cannabis users in the past 12 months reported that the most common location of last cannabis smoking was at the user's own home (66%) followed by a friend's/relative's home (23%), with 65.1% reporting that someone else was around during the smoking event.[6]

In a 2017 study from Canada with around 1,000 participants, weighted to the Canadian population, 7.5% reported being exposed to cannabis smoke in their residence, before cannabis legalization in 2018. A statistically significant proportion of participants exposed to cannabis smoke in their residence were younger, used cannabis in the past 12 months, and lived in an attached home or multiple unit dwelling.[51] In a study using data from the 2019 International Cannabis Policy Study, 17% of Canadian residents who did not use cannabis or did not smoke cannabis inside their homes in the last year reported being exposed to cannabis secondhand smoke. Self-reported cannabis smoke exposure was similar in the U.S. where non-medical cannabis use was illegal, with a slightly higher proportion reporting cannabis secondhand smoke exposure in U.S. where recreational cannabis use was legal (16% vs. 21%). Additionally, across the U.S. and Canada, 20-25% of participants who lived in multiunit housing reported cannabis secondhand smoke exposure from other units or while outdoors at least once in the last month. No difference in reported cSHS exposure was seen by cannabis use legalization.[52]

1.11. Cannabis SHS Exposure Among Children

A small study of 53 children aged 0-3 years old from New York City, New York recruited at medical facilities during well-child visits or hospitalized in the pediatric unit had urine analyzed for COOH-THC, a biomarker of cannabis exposure, and found that 21% of children had detectable cannabis exposure.[53] Fifteen percent of participants reported that someone in their child's life (living in home or caring for child) smoked cannabis. Additionally, high levels of tobacco exposure, measured by cotinine, were significantly associated with COOH-THC detection. Lastly, 35% of children, living in attached housing where smoking is allowed, had detectable COOH-THC compared to 13% of children who lived in housing where smoking was not allowed.[53] Another study, among 43 young children hospitalized with bronchiolitis in Colorado, found that 16% had detectable levels of COOH-THC in their urine, with 16% of parents reporting that cannabis was smoked inside of the home or by a caregiver.[54] These studies did not explore the relationship between in-home cannabis smoking or caregiver smoking and COOH-THC detection in urine.

1.12. Cannabis Smoke Exposure Effect on Health

A systemic review of 15 experimental research articles reported not identifying any studies indicating long-term effects of cannabis SHS and thirdhand smoke (THS) exposure among adults. All 15 reports studied the immediate effects of cannabis smoke exposures in humans in a controlled environment and reported cannabinoid metabolites in bodily fluids.[55] Additional studies are needed on longer-term effects on cannabis SHS. It is important to note that regular cannabis smokers are more likely to report symptoms of bronchitis,[56] and cannabis smoking has been shown to result in greater respiratory burden of carbon monoxide and tar than even tobacco smoking.[20] One study of 159 participants from Canada reported no association between cannabis SHS exposure and perceived immediate health impacts such as headaches, coughing, chest tightness and eye irritation. Women and non-cannabis users were statistically more likely to report experiencing immediate health impacts.[57]

1.13. Cannabis Smoke Exposure Effect on Children's Health

Studies on involuntary exposure to cannabis smoke have shown associations with several health outcomes including physical and mental health outcomes, especially among children. In a study of 192 children under the age of 14, living in a home where cannabis was smoked indoors was associated with 83% higher odds of cumulative adverse health outcomes such as ED visits, ear infection, bronchitis, asthma, and skin conditions, after adjusting for child's age, education level of parent/guardian, and past 7-day child exposure to cigarette smoke.[58] Another study of 1,500 subjects sampled at a pediatric emergency department reported caregivers who used cannabis showed higher rates of viral respiratory infections compared to caregivers who did not use cannabis.[59] A few studies have studied cognitive, emotional, or mental health outcomes in association with cannabis smoke exposure of children. One study of pre- and post-natal maternal cannabis use reported that after controlling for prenatal cannabis exposure, higher maternal cannabis use when the child was an infant or toddler predicted more behavior problems at two years old.[60] Other studies focused primarily on prenatal cannabis exposure, with children prenatally exposed showing higher likelihood of reporting delinquent behavior at age 14, higher likelihood of child depressive symptoms and attention problems at age 10.[61] Among infants, at two years old, prenatal cannabis exposure has been shown to be associated with lower scores in verbal and memory domains of neurocognitive tests.[62]

Due to children's vulnerability to environmental exposures, even in low concentrations, and especially during critical periods of development leading to long term changes in their physiology, it is critical to study the cannabis smoke exposure they face and how exposure can be reduced or eliminated. With young children spending the majority of their time at home and with parental cannabis use on the rise,[24] it is important to determine how in-home cannabis smoke exposure specifically can be decreased. This might be accomplished by supplying accurate information, changing individual and communal perceptions of cannabis or cannabis smoke, implementing household rules, providing alternative venues of use outside of the home or car, or shifting to alternative, less harmful methods of use.

1.14. Health Behavior Models

Many health behavior change theories are centered around risk or harm perceptions as a key factor in initiating behavioral change.[45] Changing individual perceived risk of harm related to the behavior in question is often the target of health interventions, and studies have shown that changing perceptions can change behaviors. One such theory is the Health Belief Model (HBM),[63] which posits that a person's willingness to change behaviors is due to their perceptions. Their perceptions are shaped specifically by two factors: (a) the fear of illness or disease associated with the behavior in question, which includes the desire to avoid the unhealthy outcome, and (b) belief in the effectiveness of the recommended actions to prevent the unhealthy outcome. It is important to remember that an individual's health is a function of their own behavior as well as their communal and societal systems.

The HBM and other behavior theories may be limited by failing to account for individual attitudes and beliefs, societal mores and taboos, or environmental and economic factors that may be barriers to changing behaviors. However, they do help describe some individual health information factors (perceived harm) that may be related to the desired health behavior (setting in-home rules, and in-home smoking behavior) that later affect the health of a vulnerable population such as children.

1.15. Specific Aims of This Dissertation

In the last decade more countries across the world have decriminalized or legalized cannabis use either for medical or full recreational use. In the U.S., more states continue to legalize cannabis use.[11–13] Concurrently, cannabis use has been increasing among different demographic groups including parents with children at home, older adults, college students, and non-college young adults.[8-10] Additionally, cannabis use has been increasing among tobacco smokers while tobacco smoking has been on the decline.[29] With cannabis use on the rise, it is important to note that the most common method of use is smoking,[16,17] and the most common location of cannabis use is at one's own home or a friend's/relative's home.[6] This may lead to smoke exposure of non-smokers through SHS.

The most common method of cannabis use, smoking,[16] is known to generate emissions[20–22] that are likely harmful to those exposed. Cannabis is often smoked indoors,[7] and non-smokers such as children are at risk for secondhand smoke exposure. SHS is a combination of smoke from burning and also from smoke exhaled by the smoker; it can be inhaled by non-users involuntarily while the smoke persists in the air.[19] Though those who smoke may accept the risks of smoking exposure, those exposed to SHS, especially children, are often involuntarily exposed. Children are more susceptible to environmental exposures;[26–28] therefore, preventing toxic exposures early in life is key to preventing disease later in life.

While long-term health consequences of exposure to emissions from cannabis are not yet well known,[55] cannabis smoke has a similar chemical composition to that of tobacco smoke and includes many of the same carcinogens and toxic chemicals as tobacco smoke.[20–22] A few studies have reported that cannabis secondhand smoke exposure in children, prenatally and postnatally, is associated with adverse physical, cognitive, and behavioral issues.[58–62]

Cannabis smoke is perceived as less harmful to health than tobacco smoke[1,2] and is allowed to be smoked indoors more commonly than tobacco.[3–5] Lastly, the prevalence of household rules to ban in-home cannabis smoking in homes of cannabis smokers is low,[6] and the prevalence of in-home cannabis smoking inside the home of cannabis users is high.[7]

Aim 1: Quantify the association between perceived harm of being exposed to cannabis secondhand smoke and household rules on cannabis smoking inside the home. Using data from around 22,000 participants from Marijuana Use and Environmental Survey (MUES) 2020, weighted to the US population, I described the relationship between perceived harm of being exposed to cannabis smoke and household rules on in-home cannabis smoking. I also explored effect measure modification by factors such as cannabis use, tobacco use, state cannabis legalization, and children living in home.

Aim 2: Describe the association between perceived harm of cannabis smoke exposure of non-smokers and in-home cannabis smoking in the Global Drug Survey sample. Using data from around 30,000 respondents to the Global Drug Survey (GDS) 2021 from around the world, I quantified the association between perceived harm of cannabis smoke exposure of non-smokers and in-home cannabis smoking in the last 30 days. I also explored effect measure modification by cannabis and tobacco co-use, children living in home, and cannabis legalization status.

Aim 3: Apply the residualization approach to ascertain in-home cannabis smoking using air particle data and self-reported indoor particle generating events. Quantify the relationship between in-home cannabis smoking (using existing air particle data, report of in-home cannabis smoking and the newly ascertained in-home cannabis smoking variable) and children's exposure to cannabis smoke. Using data from Project Fresh Air (PFA), a randomized controlled trial focused on reducing in-home tobacco smoking that enrolled 298 participants from households in San Diego County, I first ascertained in-home cannabis smoking using air particle data and self-reported indoor particle generating events, including both smoking and non-smoking events, using a residualization approach. Then I quantified the relationship between (1) air particle data and children's exposure to cannabis smoke, (2) reported indoor cannabis smoking and children's exposure to cannabis smoke, and (3) the ascertained in-home cannabis smoking and children's exposure to cannabis smoke. In-home cannabis smoking was measured by air particle count data and by reported indoor particle generating activities including indoor cannabis smoking; children's exposure to cannabis smoke was measured through urinary cannabis biomarkers (THC, OH-THC, COOH-THC).

2. Perception of Harm is Strongly Associated with Complete Ban on In-Home Cannabis Smoking

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2.1. Abstract

Objective: Perception of harm to health is crucial in changing behaviors like smoking. I examined the association between the perception of harm of cannabis secondhand smoke (cSHS) exposure and a complete in-home cannabis smoking ban.

Methods: Respondents were 21,381 adults from the cross-sectional Marijuana Use and Environmental Survey, a nationally representative sample of the United States population recruited from December 2019 to February 2020. Perceived harm of cSHS exposure (extremely harmful, somewhat harmful, mostly safe, or totally safe) and household rules on in-home cannabis smoking (complete ban versus no complete ban) were self-reported. Logistic regression for survey-weighted data estimated covariate-adjusted odds ratios (OR) and 95% confidence intervals (CI) for the association between perceived harm of cSHS and complete ban on in-home cannabis smoking. Stratified subgroup analyses (by cannabis smoking status, cannabis use legalization in state of residence, and children under the age of 6 living in the home) were conducted to quantify effect measure modification of the association between perception of harm and complete ban.

Results: A complete ban on in-home cannabis smoking was reported by 71.8% of respondents. Eight percent reported cSHS as "totally safe"; 20.5% "mostly safe"; 38.3% "somewhat harmful"; and 33.0% "extremely harmful". Those who reported cSHS as "extremely harmful" had 6 times the odds of having a complete ban on in-home cannabis smoking (OR=6.0, 95% CI=4.9-7.2) as those who reported it as “totally safe”. The odds of having a complete ban were higher among those who reported cSHS as “somewhat harmful” (OR=2.6, 95% CI=2.2-3.1) or “mostly safe” (OR=1.4, 95% CI=1.2-1.7). In each subgroup of cannabis smoking status, state cannabis use legalization, and children under the age of 6 living in the home, perceived harm was associated with a complete ban on in-home cannabis smoking.

Conclusions: This study demonstrates that perceiving cSHS as harmful is strongly associated with having a complete in-home cannabis smoking ban. With almost a third of US adults perceiving cSHS as at least “mostly safe”, there is strong need to educate the general population about potential risks associated with cSHS exposure to raise awareness and encourage adoption of household rules prohibiting indoor cannabis smoking.

2.2. Introduction

As of April 2023 in the United States (U.S.), 38 states had legalized medical cannabis use, 23 states had legalized recreational cannabis use,[64] and more states are pursuing legalization of cannabis use. Since the mid-2000s, cannabis use has increased among various groups, including parents with children at home, young adults, older adults, and tobacco smokers.[8–10,25,29] Combustion is the most commonly reported method of using cannabis,[16] which, like tobacco, generates emissions of toxic substances known to be harmful. Similar to tobacco SHS, cannabis secondhand smoke (cSHS) can be inhaled by non-users involuntarily while the smoke persists in the air.[19]

Cannabis is frequently allowed to be smoked indoors. In the U.S., 71% of respondents from a sample of Facebook users,[4] 59% of cannabis users from a sample of U.S. college students,[3] and 76% of Airbnb venues in Colorado[24] all reported allowing cannabis use inside their homes or venues. Fifty-five percent of U.S. cannabis users reported smoking inside their homes in the past 30 days, and 30% reported smoking cannabis daily inside of their home.[7] This suggests that cSHS exposure of non-smoking residents in the homes of cannabis users may be common.

While the health consequences of cSHS exposure are not yet well documented,[55] cannabis smoke has a similar chemical composition to that of tobacco smoke, including many of the same carcinogens and toxic chemicals.[20–22] Studies have reported that cSHS exposure in children is positively associated with adverse or problematic physical (respiratory infections and associated emergency care),[58,59] cognitive (lower scores in verbal and memory domains, attention problems), and behavioral (delinquent behaviors, depressive symptoms)[60–62] health outcomes. Therefore, even non-smokers of cannabis, especially children, may be at risk of adverse health problems from cSHS exposure.

Health-related harm perceptions are fundamental to many health behavior change theories.[45] According to current research, accurate and realistic health risk perceptions are key in motivating behavioral change, and modifying harm perceptions has been shown to effectively alter individual health behaviors.[45] Accurate perception of cSHS exposure as harmful to health could lead to the implementation of rules to ban cannabis smoking inside homes. In tobacco research, perception of tobacco smoke as harmful has been strongly associated with the voluntary adoption of a complete ban on indoor smoking.[65] Setting rules to completely ban in-home cannabis smoking could reduce the amount and frequency of cannabis smoking inside homes, ultimately leading to decreased cSHS exposure and better health outcomes. Households with no ban on indoor tobacco smoking had higher numbers of cigarettes smoked inside of homes compared to households with a complete ban,[66] and a complete ban on in-home tobacco smoking was associated with lower urinary cotinine levels among children.[67] While few data are available on the relationship between the perception of harm of cSHS exposure and health behavior, one study among young adults reported that perception of harm from cannabis smoke or vapor byproducts was inversely associated with allowing cannabis use inside of homes.[5] With only half of U.S. adults perceiving cSHS as harmful,[44] it is important to address the gaps in understanding how the perception of harm and other covariates affect household rules on in-home cannabis smoking.

In this study, I quantified the association between perceived harm of being exposed to cSHS and household rules on in-home cannabis smoking. I also evaluated effect measure modification by cannabis smoking status, tobacco smoking status, state cannabis legalization, and whether children (0-5, 6-12, 13-17 years old) resided in the home. These variables were considered as effect measure modifiers as studies have shown that recent cannabis and tobacco use[40] and permissive cannabis laws[48] are inversely associated with the perception of cSHS exposure as harmful. Also, cannabis use, tobacco use, perceived social acceptability of cannabis usage, and having children in the home are negatively related to having household rules on in-home cannabis smoking.[3,5] I hypothesized that a greater perception of harm from cSHS exposure would be associated with having household rules to ban in-home cannabis smoking.

2.3. Methods

2.3.1. Sample Selection

This cross-sectional study used data from the U.S. Marijuana Use and Environmental Survey (MUES) 2020 collected between December 2019 and February 2020.[16] MUES 2020 recruited 21,903 adult (18 years or older) respondents from the address-based and probability-based online panel, KnowledgePanel™. This panel has been used to provide representative statistics on drug use for 97% of adults in the U.S. general population in all 50 states and Washington, DC. Survey weights are provided to ensure results are representative of the U.S. general population. Patterns in missing data were assessed, but as missingness was low across variables (≤1% missing), I conducted a complete case analysis (n=21,381), excluding 522 respondents with missing data.

MUES data were de-identified, and this study was a secondary analysis of the data. Thus, this study does not constitute human subjects research and was therefore not subject to IRB review.

2.3.2. Measures

2.3.2.1. Perceived Harm. Perceived harm of cSHS was measured with the following question: "How harmful do you think it is to be exposed to *secondhand* smoke at least *3 times per* week from the following substance: Marijuana smoke?" The four response options were: "Extremely harmful", "Somewhat harmful", "Mostly safe", and "Totally safe". A similar measure has been used by the National Adult Tobacco Survey.[68]

2.3.2.2. Household Rules. Household rules on in-home cannabis smoking were measured with the following question: "Which statement best describes the rules of *smoking* marijuana *inside your home?"* A binary variable was created from four response options: complete ban ("No one is allowed anywhere") or no complete ban ("Allowed in some places", "Allowed everywhere", or "Did not make rules"). A similar measure has been used by the Global Adult Tobacco Survey.[69]

2.3.2.3. Covariates. Demographic variables were self-reported including: sex (male, female); age (continuous in years); race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic other race, non-Hispanic multiple races); marital status (married, widowed, divorced/separated, never married, living with a partner); education (less than high school, high school, some college, bachelor's degree or higher); and household income [high (>$99,999), medium ($40,000 - $99,999), low (<$40,000)]. Other covariates included: One or more residents of the participant's home was a child under the age of 6 (yes, no), 6-12 years old (yes, no), 13-17 years old (yes, no); state legalization of cannabis use at time of questionnaire (recreational and medical legalization, only medical, no cannabis legalization); frequency of cannabis smoking in the past 12 months [never smoked cannabis, did not smoke cannabis in the past 12 months (former cannabis smoker), smoked cannabis in the past 12 months (current cannabis smoker)]; frequency of cigarette smoking in past 12 months [never smoked cigarettes, did not smoke cigarettes in the past 12 months (former cigarette smoker), smoked cigarettes in the past 12 months (current cigarette smoker)]; use of any of the following drugs: opioids, amphetamines, 3,4-methylenedioxy-methamphetamine (MDMA), hallucinogens, heroin, or cocaine (never used any of these drugs; did not use any of these drugs in past 12 months; did not use any of these drugs in past 30 days; used one or more of these drugs in past 30 days).

2.3.3. Statistical Analysis

Descriptive statistics for the study sample with survey weights applied (target population) were stratified by level of perceived harm of cSHS exposure. I used multivariable logistic regression for survey-weighted data to estimate odds ratios (ORs) and corresponding 95% confidence intervals (CIs) of a complete in-home cannabis smoking ban (vs no complete ban) in association with the perceived harm of cSHS exposure. I conducted sequential modeling to examine the extent of confounding by various groups of covariates: Model 1 was an unadjusted model; the only independent variable was perceived harm. Model 2 included Model 1 and demographic variables (age, sex, race/ethnicity, marital status, highest level of education, and household income). Model 3 included Model 2 and cannabis smoking status. Model 4 included Model 3 and tobacco smoking status and use of other drugs. Model 5 included Model 4 and state cannabis legalization. Model 6 included Model 5 and children living in the home. I examined effect measure modification of the relationship between perception of harm and complete ban by cannabis smoking status (never, former, or current cannabis smoker); cigarette use (never, former, or current cigarette smoker); state cannabis legalization (recreational and medical, only medical, or no cannabis legalization); living with a child under the age of 6 (yes, no), 6-12 years old (yes, no), or 13-17 years old (yes, no) by adding statistical interaction terms in fully-adjusted logistic regression models (i.e., Model 6). Logistic regression models stratified by each statistically significant ($p<0.05$) effect modifier variable were conducted, and results for each stratum are presented. Before testing all interactions, sample sizes in all strata were confirmed to be sufficiently large (>10) to provide meaningful analysis. After weighting, all estimates were representative of the U.S. general population.

I conducted additional analyses with the original household rules variable, which had four categories as the outcome variable ("No one is allowed anywhere", "Allowed in some places", "Allowed everywhere", "Did not make rules"). The proportional odds assumption for ordinal regression was not met for any model. Therefore, a multinomial regression was run for the fully-adjusted model, with a complete ban ("No one is allowed anywhere") as the reference.

All data management was conducted in R (version 4.0.0; R Foundation for Statistical Computing, Vienna, Austria), and statistical analyses were conducted in SAS Studio (SAS Institute Inc., Cary, NC, U.S.).

2.4 Results

About half of the target population were female (51.8%), and most were non-Hispanic White (64.0%), married (56.9%), had some college education or higher (62.0%), and had middle or high income (73.7%). The average age was 48.2 (standard error=0.1 years. Less than 15% had children 0-5 years old (11.9%), 6-12 years old (14.2%), or 13-17 years old (12.7%). Approximately half had never smoked marijuana (49.9%), 33.8 % were former cannabis smokers, and 16.3% were current cannabis smokers (Table 2.1).

Most (71.4%) of the target population perceived cSHS exposure as harmful (33.0% extremely harmful and 38.4% somewhat harmful), with 28.6% reporting cSHS exposure as safe (20.5% as mostly safe; and 8.1% as totally safe) (Table 2.1).

Among the target population, 71.8% reported a complete ban on in-home cannabis smoking. The remainder (28.2%) did not have a complete ban, with 9.0% reporting allowing cannabis smoking in some places inside the home, 3.7% allowing it everywhere, and 15.6% not having any rules.

2.4.1. Sequential Modeling Results

The odds of a complete ban among those who reported cSHS as "extremely harmful" decreased from 12.1 (95% CI=10.2-14.4) to 5.0 (95% CI=5.0-7.2) after adjusting for cannabis smoking status (Table 2.2; Model 2 vs. Model 3). In the final model, after adjusting for all confounders (Model 6), respondents who reported cSHS as "extremely harmful" had statistically significantly higher odds (OR=6.0, 95%CI=4.9-7.2) of having a complete in-home cannabis smoking ban compared to those who reported it as "totally safe" (Table 2.2). In the final model, there was a dose-response relationship between level of perceived harm and having a complete ban on in-home cannabis smoking: "extremely harmful" (OR=6.0, 95%CI=4.9-7.2), "somewhat harmful" (OR=2.6, 95%CI=2.2-3.1), and "mostly safe" (OR=1.4, 95%CI=1.2-1.7); compared to those who reported cSHS exposure as "totally safe" (Table 2.2).

2.4.2. Effect Modification Results

Comparing "extremely harmful" to "totally safe" responses, statistically significant interactions ($p<0.05$) were observed between harm perception and (1) each level of respondents' cannabis smoking status, (2) each category of state cannabis legalization, and (3) presence vs. absence of children 0-5 years old living in the respondents' home—demonstrating that the strength of the perceived harm and home smoking ban relationship differed for each level of these effect measure modifiers (Figure 1). In every sub-group by cannabis smoking status, respondents who reported cSHS as "extremely harmful" had higher odds of having a complete ban on in-home cannabis smoking compared to those who reported it as “totally safe”. Among those who never smoked cannabis and among former cannabis smokers, the odds of having a complete ban on in-home cannabis smoking (vs. no complete ban) were higher than among current cannabis smokers (p-interaction=0.002); among never cannabis smokers (OR=7.3, 95%CI=5.1-10.6); among former cannabis smokers (OR=8.0, 95%CI=6.0-10.6); and among current cannabis smokers (OR=3.8, 95%CI=2.4-6.0). In each sub-group of cannabis smoking status, there was a dose-response relationship between levels of perceived harm and having a complete ban on in-home cannabis smoking.

The same pattern was observed for states’ cannabis legalization status (p-interaction = 0.022). The odds (95%CI) of having a complete ban among respondents reporting cSHS as “extremely harmful” vs. those reporting it as “totally safe” were: 7.6 (5.6-10.3) for those living in a state with only medical cannabis use legalized; 7.2 (5.1-10.1) for those in states with both medical and recreational cannabis use legalized; and 4.2 (3.0-5.8) for those in states with neither medical nor recreational cannabis use legalized (Figure 1). Both among those who reported having household members 0-5 years old and among those who did not, respondents who reported cSHS as “extremely harmful” had statistically significant higher odds of having a complete ban on in-home cannabis smoking compared to those who reported it as “totally safe” (Figure 1). However, among those who did not have household members 0-5 years old, the odds (OR=6.8, 95%CI=5.6-8.3) were significantly higher (p-interaction = 0.002) than among those who did have children 0-5 living in their home (OR=2.6, 95%CI=1.6-4.4). In both sub-groups, there was a strong dose-response relationship between levels of perceived harm and having a complete ban on in-home cannabis smoking.

2.4.3. Multinomial Analysis Results

After adjusting for all covariates, reporting any level of perceived harm increased the odds of having any level of in-home cannabis smoking rules (allowed everywhere, allowed in some places, no rules) relative to a complete ban (Table 2.3).

2.5. Discussion

I demonstrate that in the U.S. adult population, the perception of cSHS harm is a key factor related to having a complete in-home cannabis smoking ban. This was true for the whole target population and, with only two exceptions, in every subgroup examined (see Figure 1). In nearly all analyses, the perception of harm of cSHS exposure at any level more than totally safe was associated with higher odds of having a complete ban on in-home cannabis smoking than of having no complete ban. One subgroup result of note is the three-fold higher odds of a complete ban on in-home cannabis smoking among current cannabis smokers who reported cSHS exposure as extremely harmful vs. totally safe.

There are very few studies, to my knowledge, that have examined the relationship between the perception of harm of cSHS exposure and a complete ban on in-home cannabis smoking. In one study among young adults (ages 18-34) in the U.S., recruited from social media websites, the likelihood of allowing cannabis use in the home was inversely but not significantly associated with the perception of harm from byproducts of cannabis smoke or vapor (beta = -0.03 (95% CI: -0.07, 0.00).[5] Similar to the estimated 28% in this study who reported cSHS exposure as totally or mostly safe, a 2018 study focused on the perception of cSHS exposure among respondents from KnowledgePanel® reported 32% of U.S. adults perceived exposure to cSHS as not at all or a little harmful,[44] with younger age, recent cannabis use, recent tobacco use, cannabis, and tobacco co-use, and non-White race/ethnicity being related to increased likelihood of perceiving cSHS exposure as not harmful.[44] In studies examining household rules, cannabis smoking was more often allowed inside the homes of young adults, cannabis smokers, tobacco smokers, and cannabis and tobacco co-users than inside the homes of non-smokers.[3,4] Additionally, in homes of young adults, peer use and perceived social acceptability of using cannabis were positively correlated with allowing cannabis use inside homes.[5]

In this study, even among current cannabis smokers, who are the most likely to put non-smoker residents of their homes at risk of cSHS exposure, the association between perceiving cSHS as harmful and having a complete ban versus not having a complete ban was fairly strong. Never cannabis smokers had eight times the odds of having a complete ban versus not having a complete ban, former smokers had seven times the odds, and current cannabis smokers had three times the odds. The differences in the relationship may be due to skewed perceptions current cannabis smokers have about harms related to cannabis smoke; cannabis smokers perceive cannabis as less addictive and a "healthier" alternative to smoking tobacco.[70] The perception of cSHS as not harmful has been associated with recent cannabis use[44] as well as regular cannabis use.[40] Additionally, current cannabis smokers are unlikely to restrict cannabis smoking inside their own homes, as they have a high (50%) prevalence of in-home cannabis smoking.[7] Even in this high-risk population, which may be more likely to expose non-smoking residents to cSHS, the perception of harm was significantly related to a complete ban on in-home cannabis smoking. Educating current cannabis smokers on the harms and risks of cannabis smoke could substantially reduce cSHS exposure, as 40% of those without a ban on in-home cannabis smoking were current cannabis smokers.

Perception of harm of cSHS exposure was strongly related to a complete ban on in-home cannabis smoking among respondents with and without children under 6 years living in the home. But unexpectedly, among these respondents, for those with children under 6 there was a weaker association than among those without children under 6 (ORs: 2.6 vs. 6.8). These differences may be due to other drivers of the behavior of parents or those with children living at home. Tobacco SHS studies show that while knowledge of risk and perception of harms are important factors, social norms (communities where the high value placed on social relationships makes changing a guest's behavior difficult and where smoking functions as a positive shared activity), gender imbalances (women's lack of agency in affecting rules and others' behavior), and structural factors (living in someone else's home, such as one's parents' house, so cannot establish household rules) are also barriers to smoke-free homes.[71] Understanding other important drivers is important for cannabis smoke-free home efforts, as decreasing or eliminating cSHS exposure of children could greatly impact children's health outcomes.[58,60–62]

This study had several noteworthy strengths. The large representative sample and low levels of missing data strengthen the external validity of the findings and allow examination of effect measure modification by important covariates. The low level of missingness in the data indicates that selection bias was unlikely, conserving the internal validity of the study findings. Limitations of this study included the cross-sectional study design, which provides no information concerning the temporal order of the associated variables, precluding inferences about causality. However, while it is plausible that the implementation of in-home rules for cannabis smoking could cause someone to perceive cSHS exposure as harmful, this seems unlikely. The self-reported nature of the data poses another limitation: participants may under-report sensitive information, such as cannabis use, rules related to cannabis use, or use of other (particularly illegal) drugs. Additionally, household rules on in-home cannabis smoking may mediate the relationship between the perception of harm of cSHS exposure and in-home cannabis smoking behavior. This study's focused, detailed look at that relationship provides a solid base for future research exploring mediation of the association by in-home cannabis smoking behavior.

2.6. Conclusion

Perceived harm from cSHS exposure was strongly associated with a complete ban on in-home cannabis smoking in this nationally representative study of U.S. adults. The odds of having a complete ban on in-home cannabis smoking increased with increases in the perception of harm from cSHS, even among current cannabis smokers. Thus, promoting a more widespread understanding that cSHS is harmful may facilitate implementation of smoke-free home policies.[72] Creating additional strategies to eliminate indoor cannabis smoking, such as identifying alternative locations outside the home for smoking, should also be explored. The most impact may be achieved through multilevel efforts: changing individual knowledge and increasing peer and community pressure and norms.[73]

Table 2.1. Descriptive Statistics of the Weighted Study Population (Target Population) Stratified by Perceived Harm of Cannabis Secondhand Smoke Exposure; MUES 2020

Characteristics	Total 21,318 n (%)	Totally safe 1,741 n (%)	Mostly safe 4,364 n (%)	Somewhat harmful 8,184 n (%)	Extremely harmful 7,029 n (%)
Complete ban on in-home cannabis smoking					
Yes	15298 (71.8)	640 (36.8)	2354 (53.9)	6056 (74.0)	6248 (88.9)
No	6020 (28.2)	1101 (63.2)	2010 (46.1)	2128 (26.0)	7819 (11.1)
Age					
Mean (Standard error)	48.2 (0.1)	41.2 (0.5)	45.9 (0.3)	48.9 (0.2)	50.5 (0.3)
Sex					
Female	11041 (51.8)	812 (46.6)	2027 (46.4)	4052 (49.5)	4150 (59.0)
Male	10277 (48.2)	929 (53.4)	2337 (53.6)	4132 (50.5)	2879 (41.0)
Race/Ethnicity					
non-Hispanic White	13649 (64.0)	1040 (59.8)	3047 (69.8)	5579 (68.2)	3983 (56.7)
non-Hispanic Black	2461 (11.5)	330 (18.9)	493 (11.3)	844 (10.3)	795 (11.3)
non-Hispanic other race	1400 (6.6)	63 (3.6)	206 (4.7)	566 (6.9)	564 (8.0)
Hispanic	3418 (16.0)	255 (14.6)	526 (12.1)	1056 (12.9)	1582 (22.5)
non-Hispanic multiple race	389 (1.8)	53 (3.1)	92 (2.1)	139 (1.7)	105 (1.5)
Marital status					
Married	12130 (56.9)	677 (38.9)	2211 (50.7)	4809 (58.8)	4433 (63.1)
Widowed	940 (4.4)	40 (2.3)	158 (3.6)	365 (4.5)	377 (5.3)
Divorced/Separated	2424 (11.4)	246 (14.1)	552 (12.6)	870 (10.6)	4433 (63.1)
Never married	4341 (20.4)	469 (27.0)	1012 (23.2)	1642 (20.0)	1218 (17.3)
Living with partner	1483 (6.9)	309 (17.7)	431 (9.9)	498 (6.1)	246 (3.5)
Highest level of education					
Less than high school	2281 (10.7)	278 (16.0)	438 (10.0)	602 (7.4)	963 (13.7)
High school	5816 (27.3)	588 (33.8)	1142 (26.2)	2058 (25.1)	2029 (28.9)
Some college	6509 (30.5)	552 (31.7)	1432 (32.8)	2539 (31.0)	1986 (28.2)
Bachelors or higher	6712 (31.5)	323 (18.5)	1352 (31.0)	2985 (36.5)	2052 (29.2)
Household income					
Low	5605 (26.3)	738 (42.4)	1095 (25.1)	1727 (21.1)	2045 (29.1)
Middle	10678 (50.1)	784 (45.0)	2281 (52.3)	4194 (51.2)	3419 (48.6)
High	5035 (23.6)	218.2 (12.5)	988 (22.6)	2263 (27.7)	1565 (22.2)
Household members aged 0 -5 years old					
Yes	2546 (11.9)	263 (15.1)	541 (12.4)	873 (10.7)	869 (12.4)
No	18772 (88.1)	1478 (84.9)	3823 (87.6)	7311 (89.3)	6160 (87.6)
Household members aged 6-12 years old					
Yes	3037 (14.2)	264 (15.2)	570 (13.1)	1070 (13.1)	1134 (16.1)
No	18281 (85.8)	1477 (84.8)	3794 (86.9)	7714 (86.9)	5896 (83.9)
Household members aged 13-17 years old					
Yes	2710 (12.7)	177 (10.2)	494 (11.3)	961 (11.7)	1079 (15.3)
No	18608 (87.3)	1564 (89.8)	3870 (88.7)	7223 (88.3)	5951 (84.6)
Cannabis legalization in state of residence					
Only medical	8419 (39.5)	656 (37.6)	1823 (41.8)	3227 (39.4)	2713 (38.6)
Medical and recreational	5988 (28.1)	450 (25.9)	1156 (26.5)	2340 (28.6)	2042 (29.0)
Not legal	6911 (32.4)	635 (36.5)	1385 (31.7)	2617 (32.0)	2274 (32.4)
Cannabis smoking status					
Never smoked cannabis	10633 (49.9)	244 (14.0)	1158 (26.6)	4050 (49.5)	5180 (73.7)
Former cannabis smoker	7204 (33.8)	598 (34.3)	1865 (42.7)	3112 (38.0)	1630 (23.2)
Current cannabis smoker	3481 (16.3)	899 (51.7)	1341 (30.7)	1022 (12.5)	219 (3.1)
Cigarette smoking status					
Never smoked cigarettes	10193 (47.8)	543 (31.2)	1528 (35.0)	3782 (46.2)	4341 (61.7)
Former cigarette smoker	8177 (38.4)	598 (34.4)	1908 (43.7)	3441 (42.0)	2230 (31.7)
Current cigarette smoker	2948 (38.3)	560 (34.4)	928 (21.3)	962 (11.8)	458 (6.5)
Drug use status					
Never used drugs	12128 (56.9)	830 (47.7)	2023 (46.4)	4495 (54.9)	4779 (68.0)
No drug use in 12 months	6498 (30.5)	565 (32.5)	1611 (36.9)	2705 (33.1)	1617 (23.0)
No drug use in past 30 days	1285 (6.0)	133 (7.6)	323 (7.4)	502 (6.1)	328 (4.7)
Used drugs in past 30 days	1407 (6.6)	213 (12.2)	407 (9.3)	482 (5.9)	305 (4.3)

Table 2.2. Sequential Modeling of the Association between Perceived Harm of Cannabis Secondhand Smoke Exposure and Complete Ban on In-Home Cannabis Smoking with "No Complete Ban" as Reference

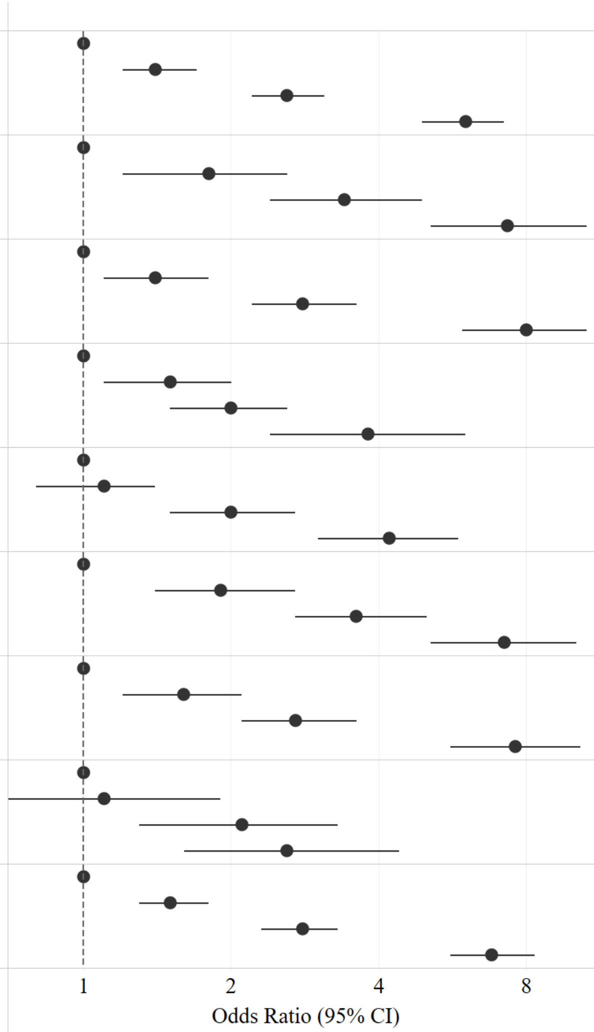
Perception of Harm	OR (95% CI)
Model 1:	
Totally safe	1.0 (ref)
Mostly safe	2.0 (1.7, 2.3)
Somewhat harmful	4.9 (4.2, 5.7)
Extremely harmful	13.8 (11.7, 16.2)
Model 2:	
Totally safe	1.0 (ref)
Mostly safe	1.8 (1.5, 2.1)
Somewhat harmful	4.2 (3.6, 4.9)
Extremely harmful	12.1 (10.2, 14.4)
Model 3:	
Totally safe	1.0 (ref)
Mostly safe	1.4 (1.2, 1.7)
Somewhat harmful	2.6 (2.2, 3.1)
Extremely harmful	6.0 (5.0, 7.2)
Model 4:	
Totally safe	1.0 (ref)
Mostly safe	1.4 (1.2, 1.7)
Somewhat harmful	2.6 (2.2, 3.1)
Extremely harmful	5.9 (4.9, 7.1)
Model 5:	
Totally safe	1.0 (ref)
Mostly safe	1.5 (1.2, 1.7)
Somewhat harmful	2.6 (2.2, 3.1)
Extremely harmful	6.1 (5.0, 7.3)
Model 6:	
Totally safe	1.0 (ref)
Mostly safe	1.4 (1.2, 1.7)
Somewhat harmful	2.6 (2.2, 3.1)
Extremely harmful	6.0 (5.0, 7.2)

Model 1: Unadjusted
Model 2: Adjusted for demographic variables (age, sex, race/ethnicity, marital status, highest level of education, and household income)
Model 3: Adjusted for Model 2 variables + cannabis smoking status
Model 4: Adjusted for Model 3 + cigarette smoking status and drug use status
Model 5: Adjusted for Model 4 + cannabis legalization
Model 6: Adjusted for Model 5 + household members aged 0-5 years, 6-12 years, and 13-17 years

Table 2.3. Multinomial Logistic Regression of the Association between Perceived Harm of Cannabis Secondhand Smoke Exposure and Household Rules on In-Home Cannabis Smoking with Complete Ban as Reference

	allowed some places vs. complete ban OR (95% CI)	Did not make rules vs. complete ban OR (95% CI)	allowed everywhere vs. complete ban OR (95% CI)	p-value
Overall Final Model				
Perceived harm				<0.001
Totally safe	1.0 (ref)	1.0 (ref)	1.0 (ref)	
Mostly safe	0.9 (0.7, 1.1)	0.7 (0.6, 0.9)	0.5 (0.4, 0.7)	
Somewhat harmful	0.5 (0.4, 0.7)	0.4 (0.3, 0.5)	0.2 (0.2, 0.3)	
Extremely harmful	0.2 (0.2, 0.3)	0.2 (0.1, 0.2)	0.1 (0.1, 0.2)	

Group	Perceived harm	OR (95% CI)
Overall target population	Totally safe	1.0 (ref)
	Mostly safe	1.4 (1.2, 1.7)
	Somewhat harmful	2.6 (2.2, 3.1)
	Extremely harmful	6.0 (4.9, 7.2)
Cannabis smoking status: Never smoked cannabis	Totally safe	1.0 (ref)
	Mostly safe	1.8 (1.2, 2.6)
	Somewhat harmful	3.4 (2.4, 4.9)
	Extremely harmful	7.3 (5.1, 10.6)
Cannabis smoking status: Former cannabis smokers	Totally safe	1.0 (ref)
	Mostly safe	1.4 (1.1, 1.8)
	Somewhat harmful	2.8 (2.2, 3.6)
	Extremely harmful	8.0 (5.9, 10.6)
Cannabis smoking status: Current cannabis smoker	Totally safe	1.0 (ref)
	Mostly safe	1.5 (1.1, 2.0)
	Somewhat harmful	2.0 (1.5, 2.6)
	Extremely harmful	3.8 (2.4, 6.0)
Cannabis use legalization: Neither medical nor recreational	Totally safe	1.0 (ref)
	Mostly safe	1.1 (0.8, 1.4)
	Somewhat harmful	2.0 (1.5, 2.7)
	Extremely harmful	4.2 (3.0, 5.8)
Cannabis use legalization: Both medical and recreational	Totally safe	1.0 (ref)
	Mostly safe	1.9 (1.4, 2.7)
	Somewhat harmful	3.6 (2.7, 5.0)
	Extremely harmful	7.2 (5.1, 10.1)
Cannabis use legalization: Only medical	Totally safe	1.0 (ref)
	Mostly safe	1.6 (1.2, 2.1)
	Somewhat harmful	2.7 (2.1, 3.6)
	Extremely harmful	7.6 (5.6, 10.3)
Household members aged 0 -5 years: Yes	Totally safe	1.0 (ref)
	Mostly safe	1.1 (0.7, 1.9)
	Somewhat harmful	2.1 (1.3, 3.3)
	Extremely harmful	2.6 (1.6, 4.4)
Household members aged 0 -5 years: No	Totally safe	1.0 (ref)
	Mostly safe	1.5 (1.3, 1.8)
	Somewhat harmful	2.8 (2.3, 3.3)
	Extremely harmful	6.8 (5.6, 8.3)



OR (95% CI) presented on logarithmic scale

Figure 2.1. Association between perceived harm of cannabis secondhand smoke exposure and complete ban on in-home cannabis smoking: overall and stratified by effect measure modifiers.

Chapter 2, in part, is currently being prepared for submission for publication of the material. Tripathi, Osika; Parada, Humberto; Shi, Y.; Matt, Georg E.; Quintana, Penelope J.E.; Liles, Sandy; Bellettiere, John. The dissertation author was the primary investigator and author of this paper.

3. Perception of Harm of Cannabis Smoke Is Strongly Associated with In-Home Cannabis Smoking

Osika Tripathi, Humberto Parada Jr., Sandy, Liles, Yuyan Shi, Georg E. Matt,

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3.1. Abstract

Objective: As countries in Europe, the Americas, and Oceania continue to re-evaluate cannabis use policies to be more lenient, perception of harm related to cannabis smoke is decreasing with many perceiving exposure to cannabis secondhand smoke as not harmful. Accurately perceiving the risk of harm is key to decreasing harmful behavior. I quantified the relationship between perception of harm from cannabis smoke exposure of non-smoking residents and in-home cannabis smoking in the last 30 days.

Methods: The analytic sample consisted of 28,154 respondents from the Global Drug Survey 2021, an annual cross-sectional survey. Perception of harm of cannabis smoke exposure of non-smoking residents and frequency of in-home cannabis smoking in the last 30 days were self-reported. Logistic regression estimated covariate-adjusted odds ratios (OR) and 95% confidence intervals (CI). Poisson regression using the continuous in-home cannabis smoking variable was used to estimate prevalence ratios (PRs) and 95% CI. Stratified subgroup analyses (by tobacco and cannabis co-use, children 5 years of age or younger living in residence, reason for THC use, cannabis legalization in country/state of residence) were conducted to quantify effect measure modification between perception of harm and in-home cannabis smoking. Country-specific logistic regressions to quantify the association between perception and in-home cannabis smoking were also run.

Results: A large percentage (61%) reported no in-home cannabis smoking in the last 30 days and the mean perception of harm of cannabis smoke on a 10-point scale was 5.2. There was a strong association between perceiving cannabis smoke exposure of non-smoking residents as harmful and not having any in-home cannabis smoking in the last 30 days. A respondent at the 75th percentile of perceived harm had 70% higher odds of no in-home cannabis smoking compared to a respondent at the 25th percentile of no in-home cannabis smoking. In each subgroup of tobacco and cannabis co-use, children 5 years or younger in residence, reason for THC use, cannabis legalization, and country, perception of cannabis smoke as more harmful was negatively associated with having any in-home cannabis smoking.

Conclusion: This study demonstrated that perceiving cannabis smoke as harmful is strongly related to not having any-in home cannabis smoking. By educating and changing perception of harm related to cannabis smoke exposure, in-home cannabis smoke and cannabis secondhand smoke exposure at home may be reduced.

3.2. Introduction

The global landscape surrounding cannabis legalization and cannabis use has gone through large transformation in the recent years. Starting in the early 2000's, an increasing number of countries, specifically in Europe, the Americas, and Oceania, have revised their cannabis policies through decriminalization or legalization of medical and/or recreational use.[12,13] According to the World Drug Report 2023, the prevalence of cannabis use globally is 4.3%, with the highest prevalence estimates in North America (17.4%), Australia and New Zealand (12.2%), and Western and Central Europe (7.8%).[74] With smoking being the most common method of cannabis use,[16] in-home cannabis smoking merits careful examination due to the potential for cannabis secondhand smoke (cSHS) exposure, especially for non-smokers. One study noted that 63% of cannabis users from an international sample reported in-home cannabis smoking in the last 30 days with 23% reporting daily in-home cannabis smoking.[7] Another study among cannabis users in the United States (US) reported that the most common locations of cannabis smoking were at home and the homes of friends or family with others around at time of smoking.[6] These statistics indicate that there may be substantial cannabis smoke exposure of non-smokers.

cSHS exposure may pose adverse health risks,[55] particularly to vulnerable populations such as children and pregnant individuals. Cannabis smoke contains known carcinogens and toxic chemicals[20–22] and has been associated with various adverse respiratory outcomes.[75] Pre-natal and post-natal cannabis exposure have been associated various physical and cognitive health problems during childhood and adolescence.[60–62,76] Other studies have shown that cSHS exposure among children has been associated with higher odds of adverse health effects[58] and viral respiratory infections.[59] Despite all this evidence of harm related to cannabis exposure, perceived risk associated with smoking cannabis has been decreasing in the U.S.[40,42] Additionally, a substantial proportion of the U.S. population reported that cSHS exposure resulted in little harm or was not harmful at all.[44,77] Recent studies have also reported that adults in the US perceive cSHS exposure as safer than tobacco secondhand smoke exposure, and this perception is increasing.[2]

Perception of harm is a critical determinant of health behavior and is often targeted in interventions to change behaviors.[45] In order to decrease in-home cannabis smoking and related harms due to cSHS exposure of non-smokers, it is important to understand the factors that motivate cannabis use behavior, one of which may be perception of harm. Despite the increase in prevalence of cannabis use worldwide, there is paucity of research exploring factors that influence in-home cannabis use behaviors, especially in international settings. By focusing on how individual perception of harm is related to in-home cannabis smoking, I aim to find spaces where educational efforts or public policy may be able to help intervene to reduce cSHS exposure.

In this international study with respondents from 21 countries, I aimed to quantify the relationship between perception of harm of cannabis smoke exposure of non-smoking residents and past 30-days in-home cannabis smoking. I hypothesized that individuals who perceive cannabis smoke to be more harmful would have a lower likelihood of having cannabis smoking in the home compared to individuals who perceive cannabis smoke to be less harmful. I explored possible effect measure modification of this association by: the respondent's cannabis and/or tobacco use in the past 30 days; children 5 years of age or younger living in respondent' home (yes/no); the respondent's reason(s) for cannabis use; and cannabis legalization status in the country/state where the respondent resided. Lastly, I also provide country-specific estimates of the association in question as I expected that other unmeasured factors such as culture at a national level may affect the relationship between perception and in-home cannabis smoking behavior.

3.3. Methods

3.3.1. Study Design and Participants

Cross-sectional analyses of data from Global Drug Survey (GDS) 2021, collected between December 2020 and March 2021, was conducted.[78] The GDS is the largest annual anonymous online survey of people from around the world who use licit and/or illicit drugs.[78] The survey was designed by substance use experts and is optimized to study drug use patterns and behaviors among a large sample of drug-using populations around the world. The GDS data are from a non-probability sample and thus findings are not representative of a wider population. As such, drug use is significantly higher among the GDS sample compared to the general population. A high proportion of the GDS sample tends to be young, white, and employed, with high levels of education and experience with illicit drug use. Full details about the GDS methods are published elsewhere.[79]

The GDS 2021 was distributed in over 20 countries and translated into 11 languages (German, English, French, Dutch, Hungarian, Spanish, Finnish, Portuguese, Danish, Romanian and Italian) to recruit a convenience sample of people who use recreational drugs. A total of 50,000 respondents initiated the online survey. For consistency with previous GDS analyses, following GDS advisory, respondents who were aged under 16 years or didn't provide an age, who didn't report a gender or responded to the drug screen items or reported using a 'fake drug' "phantazine"(n=16,780), and respondents from countries with less than 100 respondents (n=1,198) were excluded from analysis (as country is treated as a random effect). Furthermore, those with missing data on key variables were also excluded as follows: in-home cannabis smoking (n=127); perceived harm of cannabis smoke (n=1,922); and covariates of interest (n=1,819). The final analytic sample consisted of 28,154 respondents. (Figure 1)

Ethical approval was obtained The University College London (11671/001), which was registered at RMIT University (2020-23913-11758) and The University of Queensland (2017001452).

3.3.2. Measures

3.3.2.1. Perception of Harm of Cannabis Smoke Exposure. Perceived harm of cannabis smoke exposure was assessed by the question: “In your opinion, how harmful to non-smoking residents do you think smoking cannabis is?” The responses were on a 10-point scale, with 10 being extremely harmful and 1 being completely harmless. For analyses, the units of this continuous variable were scaled by dividing by its inter-quartile range (IQR) (4), which effectively compares a respondent at the 75% percentile of cannabis perception of harm to a respondent at the 25th percentile of cannabis perception of harm.

3.3.2.2. In-Home Cannabis Smoking. In-home cannabis smoking in the last 30 days was assessed by the question: “In the last 30 days, on how many days was cannabis smoked inside your home? (do not include vaping or e-cigarette use).” Responses ranged from 0 to 30 days. Responses were coded into a binary variable (yes/no) with “yes” indicating one or more days of cannabis being smoked inside the home and “no” indicating zero days of in-home cannabis smoking in the last 30 days.

3.3.2.3. Covariates. Respondents self-reported their demographic characteristics as follows: gender (man, woman, or non-binary/transgender/intersex); age (years); education, (<high school, high school, trade or college certificate, undergraduate degree or more, don’t

know); race/ethnicity, (White, Hispanic/Latino, multiple race, other); frequency of going clubbing in past 12 months (never, once every 3 months or less, 1-2 times a month, one or more times a week); and past-year use of the five most common illicit substances reported by 2021 GDS respondents (excluding cannabis: MDMA, Cocaine, Amphetamines, LSD, Psilocybin). Other covariates included: cannabis and tobacco co-use in the last 30 days (cannabis only, tobacco only, both cannabis and tobacco, didn't use cannabis or tobacco); children five years of age or younger living in the residence (yes, no); reason for cannabis (tetrahydrocannabinol, THC) use in the past 12 months (haven't used THC in past 12 months, exclusively for recreational reasons, mostly for recreational reasons, mostly for medical reasons, exclusively for medical reasons); cannabis legalization in country/state of residence (recreational and medical use legal, only medical use legal, not legal). Cannabis legalization categorization took into account the varying legalities of states in the U.S., as well as the recreational and medical use legalized in the Australian Capital Territory compared to the medical only legalization in the rest of Australia.

3.3.2.4. Statistical Analyses. Descriptive statistics for all covariates were examined stratified by perception of harm quartiles (Q1: 1-3, Q2: 4-5, Q3: 6-7, Q4: 8-10). I conducted restricted cubic spline regressions to test for non-linear associations[80] between perceived harm of cannabis smoke exposure and in-home cannabis smoking. Since tests indicated the relationship was linear (Supplementary Figure 1), I used logistic regression to estimate odds ratios (ORs) and corresponding 95% confidence intervals (CIs) of no in-home cannabis smoking in the last 30 days (vs. any in-home cannabis smoking in the last 30 days) in association with perceived harm of cannabis smoke exposure of non-smoking residents, adjusting for all covariates and the respondent's country as a random effect.

I examined the effect measure modification of the relationship between perceived harm of cannabis smoke exposure of non-smoking residents and in-home cannabis smoking by the following variables: cannabis and tobacco co-use in last 30 days, children 5 or younger living in residence, reason for cannabis (THC) use in the past 12 months, and cannabis legalization in country/state of residence. Statistical interaction was tested for each variable and logistic regression models were conducted, stratified by each statistically significant effect modifier variable ($p<0.05$). The results of each stratum are presented separately and all strata were confirmed to be sufficiently large ($n>10$), ensuring meaningful analysis. Logistic regression was also conducted stratified by each country and for the US stratified by cannabis use law in each state of residence, adjusting for all other covariates. Statistical interactions by country of residence were also tested.

I also conducted a Poisson regression with the continuous in-home cannabis smoking in the last 30 days, adjusting for all covariates and the respondent's country as a random effect. The coefficients were exponentiated to estimate prevalence ratios (PRs) and corresponding 95% CIs, to quantify how many days of in-home cannabis could be reduced by changing harm perception.

All data management and statistical analyses were conducted in R (version 4.0.0; R Foundation for Statistical Computing, Vienna, Austria).

3.4. Results

The mean age of respondents was 33.3 (SD: 12.8), 90.4% were white, 62.3% were men, and 46.8% had an undergraduate degree or higher (Table 3.1).

The mean perceived harm of cannabis smoke on a 10-point scale was 5.2 (SD: 2.9) (Table A.2 in Appendix A). A large proportion (60.9%) reported no in-home cannabis smoking in the last 30 days (Table 3.1). A little more than a third (39.9%) reported not using cannabis or tobacco in the last 30 days, with another 33.2% reporting using both cannabis and tobacco in the last 30 days. Only 9.0% reported having children 5 or younger living in the residence. Almost half (43.8%) reported not using cannabis products with THC in the past 12 months, and 28.1% reported using THC exclusively for recreational reasons. Most of the respondents (80.9%) lived in countries/states which have legalized medical cannabis use only (Table 3.1).

After adjusting for all confounders, a respondent at the 75^{th} percentile of perceived harm had 70% higher odds (OR=1.7, 95% CI=1.6-1.8) of having had no in-home cannabis smoking in the last 30 days compared to a respondent at the 25^{th} percentile (Table 3.2).

The number of days cannabis was smoked inside of the home in the last 30 days was 16% (PR=0.84, 95% CI=0.83-0.84) lower among a respondent at the 75^{th} percentile of perceived harm, compared to a respondent at the 25^{th} percentile (Table 3.3).

Statistically significant interactions ($p<0.05$) were observed between perceived harm and (1) cannabis and tobacco use status, (2) whether children 5 years old or younger lived in respondents' home, (3) reason for THC use in the past 12 months, and (4) cannabis legalization in country/state of residence. Among every sub-group of tobacco and cannabis co-users in the last 30 days, a respondent at the 75^{th} percentile of perceived harm had higher odds of not having any in-home cannabis smoking in the last 30 days compared to a respondent at the 25^{th} percentile: among cannabis only users (OR=2.2, 95%CI=1.9-2.5); among tobacco only users (OR=1.4, 95%CI=1.2-1.6); among respondents who used both cannabis and tobacco (OR=1.5, 95%CI=1.3-1.6); and among those who didn't use cannabis or tobacco (OR=2.0, 95%CI=1.7-2.2) (Table 3.2).

Among those with children 5 or younger living in the home, a respondent at the 75^{th} percentile of perceived harm had higher odds (OR=2.1, 95%CI=1.7-2.5) of having had no in-home cannabis smoking compared to a respondent at 25^{th} percentile than among those without children 5 or younger living in the home (OR=1.7, 95%CI=1.6-1.8) (p-interaction=0.01) (Table 3.2).

In each sub-group of reasons for cannabis (THC) use in past 12 months, a respondent in the 75^{th} percentile of perceived harm had higher odds of no one having smoked cannabis in their home in the last 30 days compared to a respondent in the 25^{th} percentile (p-interaction<0.001): among those who had not used THC in past 12 months (OR=1.8, 95%CI=1.6-2.0); among those who used THC mostly for medical reasons (OR=2.5, 95%CI=1.9-3.2); among those who used THC mostly for recreational reasons, (OR=1.7, 95%CI=1.4-1.9); among those who used THC exclusively for recreational reasons (OR=1.6, 95%CI=1.5-1.8); and among those who provided no reason for THC use (OR=1.6, 95%CI=1.4-1.8) (Table 3.2).

In each category of recreational/medical cannabis use legalization in the country/state of respondent residence, a respondent in the 75^{th} percentile of perceived harm had higher odds of no in-home cannabis smoking compared to a respondent in the 25^{th} percentile (p-interaction<0.001): among those who lived in a country/state where recreational and medical cannabis use was legal (OR=1.8, 95%CI=1.5-2.2); among those who lived in a country/state where only medical cannabis use was legal (OR=1.8, 95%CI=1.7-1.9); among those who lived in a country/state where cannabis use was not legal (OR=1.4, 95%CI=1.2-1.6) (Table 3.2).

In all 21 countries, the analysis revealed that a respondent in the 75th percentile of perceived harm of cannabis smoke had higher odds of no in-home cannabis smoking in the last 30 days, compared to a respondent in the 25^{th} percentile (p-interaction<0.01) with the highest odds in the following countries: Sweden (OR=3.9; 95% CI=1.5-11.9), Mexico (OR=2.0; 95%

CI=1.4-3.0), Australia (OR=2.0; 95% CI=1.6-2.4), and the USA (OR=1.8; 95% CI=1.5-2.2) (Supplementary Table 3.2).

3.5. Discussion

In this convenience sample of 28,154 international respondents from the GDS 2021, the findings suggest a strong and statistically significant relationship between perceiving cannabis smoke exposure as harmful and not having any in-home cannabis smoking. Overall, as well as among every subgroup, with one exception, with increasing perception of cannabis smoke exposure as harmful, the number of days cannabis was smoked inside homes was also lower. One of the strongest associations between perception of harm and in-home cannabis smoking was seen among respondents who used cannabis only in the last 30 days, where respondents in the 75th percentile of perceived harm had 2.7 higher odds of no in-home cannabis smoking in the last 30 days and the number of days cannabis was smoked inside the home was 36% lower than among participants in the 25th percentile of perceived harm. Similarly, respondents with children 5 years of age or younger living in the home had higher odds of no in-home cannabis smoking in the last 30 days than respondents without resident children 5 years of age or younger. Lastly, the respondents were from 21 different countries, and I observed relatively consistent associations with some notable exceptions. The odds ranged from almost four times higher odds of not having any in-home cannabis smoking in the last 30 days in Sweden, where only medical cannabis use was legalized, to much lower odds in jurisdictions where cannabis use was not legal: Denmark (1.3), Hungary (1.3), Italy (1.3) and US (1.3).

To date, the association between perceived harm of cSHS exposure and in-home cannabis smoking remains understudied. But perception of harm has been shown to be a key factor in changing health behaviors and is central to many health behavior change theories.[45] Studies show that perception of harm related to cannabis smoke exposure seems to be decreasing,[2,40,42] with many adults reporting cSHS exposure as not harmful.[44,77] As in-home cannabis is prevalent in homes of cannabis users,[7,50] it is important to understand the strength of the relationship between perception of harm and in-home cannabis smoking in order to eliminate or reduce cSHS. While some studies have examined the relationship between perceived harm and household rules on in-home cannabis smoking,[5,77] no studies, to my knowledge, have examined the relationship between perceived harm and in-home cannabis smoking behavior.

Household rules may be viewed as a mediator of the relationship between perceived harm and in-home cannabis smoking, or less so, as a proxy variable for in-home cannabis smoking. One such study among young adults recruited from social media reported that the likelihood of allowing cannabis use in the home was inversely associated with the perception of harm of cannabis smoke or vapor byproducts (beta = -0.03; 95% CI: -0.07-0.00).[5] In another study of the US general adult population, perceiving harmfulness of cSHS exposure at any level higher than totally safe was associated with higher odds of having a complete ban on in-home cannabis smoking, with the highest odds seen among those who reported cSHS exposure as extremely harmful as compared to totally safe (OR=6.0; 95% CI=5.0-7.2).[77] While in the current study I report a smaller effect, the direction of the association between perceived harm and no in-home cannabis smoking is positive and statistically significant. The differences in the magnitudes of the effects in this study and previously reported estimates could be due to the multiple factors, such as perception of harm in the two studies being measured differently or the two study samples being sourced very differently; the current study analyzes an international drug using convenience sample, while a nationally representative sample of the US general population was analyzed in the prior study.

The current study included respondents from 21 countries, representing variations in both cannabis use laws and cultural views on cannabis. A majority of the countries had legalized medical cannabis use only. The main analysis showed that the relationship between perceived harm and no in-home cannabis smoking was significantly lower, but still positive (OR: 1.4; p-interaction = 0.001), where cannabis use was not legal. The strongest and the least strong association were both seen in countries where only medical cannabis use is legal [Denmark (OR:1.3) and Sweden (OR:3.9)]; this may be attributed to other national or cultural factors. Among countries where cannabis use is not legal, the association also varied (1.3 in Hungary to 2.0 in Romania). A study including adolescent respondents from 32 European countries noted that individual level factors such as perception of cannabis availability, harm, and peer cannabis use were more strongly associated with cannabis use and frequency of use than with country level factors, but social context and country level norms were associated with cannabis use behavior as well.[81] So, changing individual perceptions may not have the same impact on behavior change in all settings—it is necessary to look into other factors and take a multi-pronged approach in order to effect change in health behavior such as in-home cannabis smoking.

The US presents a unique case where cannabis use has not been legalized nationally and state laws vary. However, the strength of the association by cannabis legalization status in the US mirrors what is seen in other countries, with the least strong and non-significant associations (OR=1.3) seen in states were cannabis use is not legalized and stronger and significant associations in states where medical cannabis use is legalized (OR=2.4) and where recreational and medical use is legalized (OR=1.8). In a similar study of the relationship between perception of harm of cSHS exposure and complete ban on in-home cannabis smoking among the US general adult population, similar results were seen where respondents living in states where cannabis use was not legal had the least strong relationship (OR=4.2) compared to those who lived in states where recreational and medical cannabis use was legal (OR=7.2) and states where only medical use was legal (OR=7.6).[81] The variability in the results of the relationship observed in the current study may be due to differences in cannabis policies and legislations. Legalization may encourage open dialogue without taboo of the subject or fear of prosecution, but societal stigmas of cannabis hold strong and intersect with other areas of social inequity.[82] In the current study, I categorized countries' cannabis legalization as not legal, medical only legal, or recreational and medical legal. However, policies and how they are enforced vary significantly by country and may explain some of the variation in odds ratios seen in different countries. Secondly, while legal policies are important, social and cultural norms concerning how cannabis is viewed are also important, as norms inform perception of harm and what behavior is culturally acceptable. Thus, cultural factors specific to each country could influence beliefs about the potential harm related to cannabis smoke exposure and smoking behavior.

Eliminating in-home cannabis smoking would be optimally beneficial but is likely unfeasible. However, we may be able to reduce cSHS exposure by decreasing the number of days cannabis is smoked inside the home, which could result in reduced health issues. This is important, as smoking cannabis or being exposed to cannabis smoke has been associated with various health risks, similar to tobacco smoke,[20–23] including respiratory issues, cardiovascular problems and potential cognitive effects, especially in children and pregnant women.[20,56,58–62] Taking preventive measures to reduce health issues associated with cannabis smoke exposure may reduce impacts on individuals and the burden on healthcare systems. Increasing perception of harm in an effort to reduce in-home cannabis smoking should also help prevent normalization of smoking, cannabis or otherwise, within residential settings.[83] This may in turn discourage cannabis use initiation and reduce social pressures on young individuals or others who may be more susceptible to initiating cannabis use.[83] Lastly, these results may inform development of evidence-based public health policies and regulation related to cannabis use, including implementing smoke-free policies for indoor spaces, designing educational campaigns to raise awareness about risk of cSHS exposure, and targeting interventions to protect vulnerable populations. Further research is needed to better understand the factors influencing the behavior of smoking indoors to inform advocacy efforts aimed at promoting informed decision-making and responsible cannabis use.

This study has limitations. The GDS is an online survey and may exclude those who cannot readily access the internet. The survey may be susceptible to bots or inaccurate responses by respondents, but this has been curbed by excluding responses that don't match GDS exclusion rules (i.e., missing information on country, sex, or age; if age >80 years; if responded endorsed using a fake drug [Phantazine]; if they did not complete drug use screening questions; or if respondent didn't confirm they were 16 years of age or older). The GDS does not provide any incentive for participation so no benefit is provided to those who provide fake feedback or use bots. The GDS recruits respondents using non-random opportunistic sampling, leading to a sample that is non-representative of a general population, and as such there may be inherent differences between participants and non-participants. The GDS tends to recruit a younger, more educated, more involved drug-using sample (in the last 12 months, 26% used MDMA, 23% used cocaine, 20% used amphetamines), and respondents who predominantly identify as "white", indicating lack of racial/ethnic diversity in the data. Another limitation is that the independent variable was not specific enough and didn't clarify the perception of harm to non-smoking residents from in-home cannabis smoking or from cSHS exposure. Despite these limitations, the GDS provides valuable data for exploring relationships between aspects of drug use and associated harms as well as for identifying trends. It is important to note that the findings may not be representative of the broader population and caution should be exercised when drawing conclusions from the overall and the country-specific results. Additionally, this is a cross-sectional study, therefore conclusions about causality should be drawn with caution. Lastly, a substantial proportion of the sample is from Germany (38%) and as such, the estimates could be driven by German respondents. To reduce any bias due to the large sample size from Germany, I adjusted for the random effect of country for all analyses and estimated country-specific results. Many of the country specific estimates remained consistent with results from Germany, with variations noted in a few countries.

3.6. Conclusion

In this international sample, perceived harm of cSHS exposure was strongly positively associated with no in-home cannabis smoking. There was a linear dose-response relationship—as perception of harm increased, the odds of no in-home cannabis smoking in the last 30 days increased. Changing individual perception of harm related to cannabis smoke through education and interventions may be a key way to reduce or eliminate in-home cannabis smoking and cSHS exposure at home. Future studies should investigate how perceptions may vary across certain demographics as well as other factors that may affect decision making, which can help tailor interventions to specific populations to optimally reduce in-home cannabis smoking. There is also a need to explore the role of peers and social dynamics and norms that influence perception of harm to provide insights on how attitudes are reinforced or challenged.

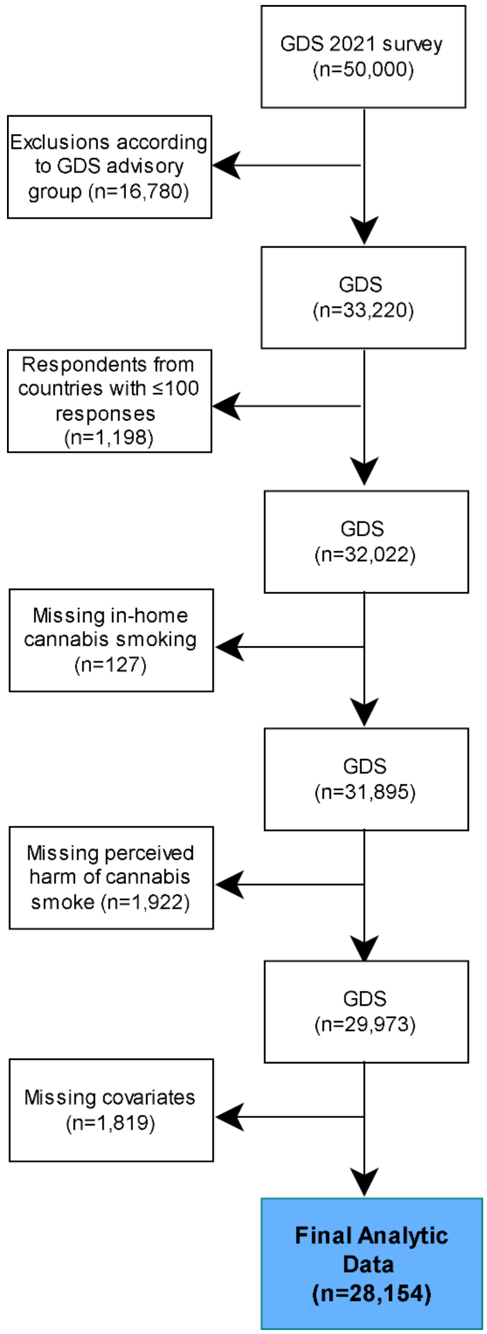

Figure 3.1. Exclusion criteria for study.

Table 3.1. Descriptive Statistics of all Global Drug Survey 2021 Respondents Stratified by Perception of Harm Quartiles

Characteristics	Total (n=28154) n (%)	Q1* (n=9812) n (%)	Q2* (n=6191) n(%)	Q3* (n=5220) n (%)	Q4* (n=6931) n (%)
In-home cannabis smoking					
Yes	11001 (39.1%)	5391 (54.9%)	2654 (42.9%)	1715 (32.9%)	1241 (17.9%)
No	17153 (60.9%)	4421 (45.1%)	3537 (57.1%)	3505 (67.1%)	5690 (82.1%)
Tobacco and cannabis co-use in last 30 days					
Cannabis only	3750 (13.3%)	1674 (17.1%)	974 (15.7%)	594 (11.4%)	508 (7.3%)
Tobacco only	3828 (13.6%)	1262 (12.9%)	837 (13.5%)	737 (14.1%)	992 (14.3%)
Both tobacco and cannabis	9334 (33.2%)	4459 (45.4%)	2215 (35.8%)	1487 (28.5%)	1173 (16.9%)
Didn't use cannabis or tobacco	11242 (39.9%)	2417 (24.6%)	2165 (35.0%)	2402 (46.0%)	4258 (61.4%)
Children 5 or younger living in residence					
No	25615 (91.0%)	9172 (93.5%)	5688 (91.9%)	4716 (90.3%)	6039 (87.1%)
Yes	2539 (9.0%)	640 (6.5%)	503 (8.1%)	504 (9.7%)	892 (12.9%)
Reason for cannabis (THC) use in the past 12 months					
Have not used THC in past 12 months	12334 (43.8%)	2633 (26.8%)	2289 (37.0%)	2569 (49.2%)	4843 (69.9%)
Exclusively for recreational reasons	7924 (28.1%)	3465 (35.3%)	1981 (32.0%)	1419 (27.2%)	1059 (15.3%)
Mostly for recreational reasons	3171 (11.3%)	1499 (15.3%)	797 (12.9%)	500 (9.6%)	375 (5.4%)
Mostly for medical reasons	858 (3.0%)	442 (4.5%)	178 (2.9%)	110 (2.1%)	128 (1.8%)
Exclusively for medical reasons	107 (0.4%)	46 (0.5%)	20 (0.3%)	17 (0.3%)	24 (0.3%)
No reason provided for THC use	3760 (13.4%)	1727 (17.6%)	926 (15.0%)	605 (11.6%)	502 (7.2%)
Cannabis Legalization in country/state of residence					
Recreational and medical use legal	1601 (5.7%)	733 (7.5%)	420 (6.8%)	246 (4.7%)	202 (2.9%)
Only medical use legal	22771 (80.9%)	7717 (78.6%)	4986 (80.5%)	4240 (81.2%)	5828 (84.1%)
Not legal	3782 (13.4%)	1362 (13.9%)	785 (12.7%)	734 (14.1%)	901 (13.0%)
Age					
mean (sd)	33.3 (12.8)	29.9 (11.7)	31.6 (11.8)	33.7 (12.2)	39.3 (13.5)
median (range)	30.0 [16.0, 80.0]	27.0 [16.0, 80.0]	29.0 [16.0, 80.0]	31.0 [16.0, 80.0]	38.0 [16.0, 80.0]
Gender					
Women	9649 (34.3%)	2850 (29.0%)	1930 (31.2%)	1851 (35.5%)	3018 (43.5%)
Men	17541 (62.3%)	6575 (67.0%)	4018 (64.9%)	3197 (61.2%)	3751 (54.1%)
Non-binary/transgender/Intersex	964 (3.4%)	387 (3.9%)	243 (3.9%)	172 (3.3%)	162 (2.3%)
Education					
Less than highschool	2319 (8.2%)	1137 (11.6%)	546 (8.8%)	290 (5.6%)	346 (5.0%)
High school	4435 (15.8%)	1885 (19.2%)	979 (15.8%)	734 (14.1%)	837 (12.1%)
Trade or college certificate	7940 (28.2%)	2915 (29.7%)	1795 (29.0%)	1426 (27.3%)	1804 (26.0%)
Undergraduate or higher	13186 (46.8%)	3743 (38.1%)	2809 (45.4%)	2729 (52.3%)	3905 (56.3%)
Don't know	274 (1.0%)	132 (1.3%)	62 (1.0%)	41 (0.8%)	39 (0.6%)
Race/ethnicity					
White	25463 (90.4%)	8707 (88.7%)	5545 (89.6%)	4804 (92.0%)	6407 (92.4%)
Hispanic/Latino	1012 (3.6%)	374 (3.8%)	232 (3.7%)	158 (3.0%)	248 (3.6%)
Mixed race	675 (2.4%)	312 (3.2%)	173 (2.8%)	94 (1.8%)	96 (1.4%)
Other	1004 (3.6%)	419 (4.3%)	241 (3.9%)	164 (3.1%)	180 (2.6%)
Went clubbing in the last 12 months					
Never in past 12 months	15083 (53.6%)	4734 (48.2%)	3050 (49.3%)	2754 (52.8%)	4545 (65.6%)
Once every 3 months or less	10186 (36.2%)	3782 (38.5%)	2444 (39.5%)	1986 (38.0%)	1974 (28.5%)
1-2 times a month	2284 (8.1%)	1005 (10.2%)	549 (8.9%)	385 (7.4%)	345 (5.0%)
One or more times a week	601 (2.1%)	291 (3.0%)	148 (2.4%)	95 (1.8%)	67 (1.0%)
MDMA use in last 12 months					
No	20863 (74.1%)	6442 (65.7%)	4359 (70.4%)	4005 (76.7%)	6057 (87.4%)
Yes	7291 (25.9%)	3370 (34.3%)	1832 (29.6%)	1215 (23.3%)	874 (12.6%)
Cocaine use in last 12 months					
No	21691 (77.0%)	6881 (70.1%)	4621 (74.6%)	4130 (79.1%)	6059 (87.4%)
Yes	6463 (23.0%)	2931 (29.9%)	1570 (25.4%)	1090 (20.9%)	872 (12.6%)
Amphetamines use in last 12 months					
No	22540 (80.1%)	7157 (72.9%)	4881 (78.8%)	4286 (82.1%)	6216 (89.7%)
Yes	5614 (19.9%)	2655 (27.1%)	1310 (21.2%)	934 (17.9%)	715 (10.3%)

Table 3.1. Descriptive Statistics of all Global Drug Survey 2021 Respondents Stratified by Perception of Harm Quartiles (continued)

Characteristics	Total (n=28154) n (%)	Q1* (n=9812) n (%)	Q2* (n=6191) n(%)	Q3* (n=5220) n (%)	Q4* (n=6931) n (%)
LSD use in last 12 months					
No	23580 (83.8%)	7558 (77.0%)	5037 (81.4%)	4490 (86.0%)	6495 (93.7%)
Yes	4574 (16.2%)	2254 (23.0%)	1154 (18.6%)	730 (14.0%)	436 (6.3%)
Psilocybin use in last 12 months					
No	23845 (84.7%)	7697 (78.4%)	5112 (82.6%)	4535 (86.9%)	6501 (93.8%)
Yes	4309 (15.3%)	2115 (21.6%)	1079 (17.4%)	685 (13.1%)	430 (6.2%)

* Q1 = Q1 and lower (1-3); Q2 = higher than Q1 and lower than or equal to the Median (4-5); Q3 = Greater than the Median but lower than or equal to Q3 (6-7); Q4 = Greater than Q3 (8-10)

Table 3.2. Logistic Regressions for In-Home Cannabis Smoking in the Last 30 Day by 4 Unit Increment in Perception of Harm (Referent: Yes, In-Home Cannabis Smoking in Last 30 Days)

Perception of harm (4 units)	OR (95% CI)	p-interaction
Overall	1.7 (1.6, 1.8)	-
Stratified Results		
Tobacco and cannabis co-use in last 30 days		<0.001
Cannabis only	2.2 (1.9, 2.5)	
Tobacco only	1.4 (1.2, 1.6)	
Both	1.5 (1.4, 1.6)	
Didn't use cannabis or tobacco	2.0 (1.7, 2.2)	
Children 5 or younger living in residence		0.01
No	1.7 (1.6, 1.8)	
Yes	2.1 (1.8, 2.5)	
Reason for cannabis (THC) use in the past 12 months		<0.001
Have not used THC in past 12 months	1.8 (1.6, 2.0)	
Exclusively for recreational reasons	1.6 (1.5, 1.8)	
Mostly for recreational reasons	1.7 (1.5, 1.9)	
Mostly for medical reasons	2.5 (1.9, 3.2)	
Exclusively for medical reasons	NA*	
No reason provided for THC use	1.6 (1.4, 1.8)	
Cannabis Legalization in country/state of residence		0.001
Recreational and medical use legal	1.8 (1.5, 2.2)	
Only medical use legal	1.8 (1.7, 1.9)	
Not legal	1.4 (1.2, 1.6)	

Overall model is adjusted for gender, education, race/ethnicity, clubbing, cocaine use, amphetamine use, psilocybin use, LSD use, cannabis and tobacco co-use, children 5 or younger living in residence, reason for cannabis use, and cannabis legalization in country/state of residence and the random effect of country.
All other models report results for stratified logistic regression for categories of each effect modifier variable, adjusting for all co-variates except for stratification/effect modification variable in question.
***Model did not converge due to small cell sizes.**

Table 3.3. Poisson Regression for Number of Days Cannabis Was Smoked Inside of Home in the Last 30 Day by 4 Unit Change in Perception of Harm

Perception of harm (4 units)	Coefficient (95% CI)	p-interaction
Overall	0.8 (0.8, 0.8)	-
Stratified Results		
Tobacco and cannabis co-use in last 30 days		<0.001
Cannabis only	0.7 (0.7, 0.7)	
Tobacco only	0.9 (0.9, 0.9)	
Both	0.9 (0.9, 0.9)	
Didn't use cannabis or tobacco	0.6 (0.5, 0.6)	
Children 5 or younger living in residence		<0.001
No	0.9 (0.8, 0.9)	
Yes	0.7 (0.7, 0.8)	
Reason for cannabis (THC) use in the past 12 months		<0.001
Have not used THC in past 12 months	0.8 (0.7, 0.8)	
Exclusively for recreational reasons	NA*	
Mostly for recreational reasons	0.9 (0.9, 0.9)	
Mostly for medical reasons	0.7 (0.7, 0.7)	
Exclusively for medical reasons	NA*	
No reason provided for THC use	0.9 (0.9, 0.9)	
Cannabis Legalization in country/state of residence		<0.001
Recreational and medical use legal	0.8 (0.8, 0.8)	
Only medical use legal	NA*	
Not legal	0.9 (0.9, 0.9)	

Overall model is adjusted for gender, education, race/ethnicity, clubbing, cocaine use, amphetamine use, psilocybin use, LSD use, cannabis and tobacco co-use, children 5 or younger living in residence, reason for cannabis use, and cannabis legalization in country/state of residence and the random effect of country.
All other models report results for stratified Poisson regression for categories of each effect modifier variable, adjusting for all co-variates except for stratification/effect modification variable in question.
***Model did not converge due to small cell sizes.**

Chapter 3, in part, is currently being prepared for submission for publication of the material. Tripathi, Osika; Parada, Humberto; Liles, Sandy; Shi, Yuyan; Matt, Georg E.; Quintana, Penelope J. E.; Ferris, Jason; Winstock, Adam; Bellettiere, John. The dissertation author was the primary investigator and author of this paper.

4. The Air Our Children Breathe: In-Home Cannabis Smoking Increases Secondhand Smoke Exposure in Children's Urine

Osika Tripathi, Humberto Parada Jr., Georg E. Matt, Penelope J.E. Quintana, Yuyan Shi, Sandy Liles, Ben Nguyen, John Bellettiere

4.1. Abstract

Objective: I examined the relationship between in-home cannabis smoking by parent/guardian and urinary cannabinoid levels in children.

Study Design and Participants: I used baseline data from Project Fresh Air, a randomized controlled trial aimed at reducing fine particulate matter levels among households in San Diego County having a tobacco smoker and at least one child living in the home. Parent/guardian and youngest child (median=3 years old) from each household were enrolled. Of 298 enrolled households, 275 were included in the analyses.

Outcome Variable: Children's spot urine samples were analyzed for three cannabis exposure biomarkers: Δ9-tetrahydrocannabinol (THC) and its two major metabolites, 11-hydroxy-Δ9-tetrahydrocannabinol and 11-nor-9-carboxy-Δ9-tetrahydrocannabinol. The molar equivalents of each biomarker were summed to create one variable representing total THC equivalents (TTE) in urine.

Independent Variables: In-home cannabis smoking was measured: by parent/guardian report of in-home cannabis smoking (yes/no); by the air particle geometric mean count and by the number of air-particle-determined daily smoking events; by geometric mean counts uniquely attributed to in-home cannabis smoking and by number of daily smoking events uniquely attributed to in-home cannabis smoking—each ascertained through residualization with adjustment for tobacco smoking, air particle generating, and ventilating activities.

Statistical Analysis: I conducted two modeling procedures to quantify associations of each of the two residualization-ascertained in-home cannabis smoking variables with urinary TTE in children: (i) logistic regression where the outcome was urinary cannabinoids (detectable/undetectable), and (ii) linear regression where the outcome was the quantity of TTE in children with detectable urinary cannabinoids.

Results: Households averaged 2.9 daily cannabis smoking events and 10.6% reported in-home cannabis smoking; 27.3% of children had detectable urinary cannabinoids. The logistic regression showed the odds of detectable TTE in children's urine were five times [odds ratio (OR)=5.0, 95%CI=2.4-10.4] as high in households with reported in-home cannabis smoking as in households without any reported in-home cannabis smoking; the odds increased by a factor of 2.5 (95%CI=1.6-3.9) for each additional daily smoking event uniquely attributed to in-home cannabis smoking; and by a factor of 1.8 (95%CI=1.3-2.3) for each standard deviation increase in geometric mean particle counts uniquely attributed to in-home cannabis smoking. The linear regression results showed that, for children with a detectable level of urinary TTE, the quantity of TTE in their urine was non-significantly higher among those with reported in-home cannabis smoking.

Conclusion: I found a strong association between both reported and ascertained measures of in-home cannabis smoking and children's exposure (yes/no) to cannabis as measured by urinary cannabinoids. As young children spend most of their time at home, reducing in-home cannabis smoking could substantially reduce their exposure to cannabis smoke.

4.2. Introduction

The most common method of cannabis use, smoking,[16] is known to generate emissions[20–22] that are likely harmful to those exposed. Cannabis is often smoked indoors,[7] and non-smokers such as children are at risk for exposure, especially with cannabis use on the rise among parents with children living at home.[24,25,29] While the long-term health consequences of exposure to cannabis smoke are not yet well known,[55] cannabis smoke contains carcinogens, respiratory irritants, and other harmful chemicals.[20–22] Cannabis smoking also emits large amounts of $PM_{2.5}$ (fine particulate matter with aerodynamic diameters ≤ 2.5 µm), which is strongly associated with adverse cardiovascular and pulmonary health[84] and correlates with respiratory burden of carbon monoxide and tar.[20] Cannabis secondhand smoke (cSHS) is a combination of smoke directly from burned cannabis and from smoke exhaled by the smoker.

While those who smoke cannabis may choose to take on risks from smoking, those exposed to cSHS are often involuntarily exposed and may be especially vulnerable to adverse outcomes. Children in particular are more susceptible to harmful environmental exposures.[26–28] One study found that reported indoor cannabis smoking was associated with 83% higher odds of cumulative adverse health outcomes such as emergency department visits, ear infections, bronchitis, asthma, and skin conditions compared to children with no exposure to indoor cannabis smoke.[58] Another study found that children with caregivers who smoked cannabis had a higher rate of viral respiratory infections.[59] A few studies have shown a positive association of adverse or problematic cognitive, emotional, or mental health outcomes with pre- and post-natal cannabis smoke exposure.[60–62] Given children's vulnerability to environmental exposures, it is important to study their level of exposure to cannabis smoke and how it can be decreased.

The principal psychoactive constituent of cannabis is *(-)-trans*-Δ9-tetrahydrocannabinol (THC). In the human body, THC is metabolized to 11-hydroxy-Δ9-tetrahydrocannabinol (OH-THC), and OH-THC is further metabolized to 11-nor-9-carboxy-Δ9-tetrahydrocannabinol (COOH-THC).[85] All three cannabinoids, THC, OH-THC and COOH-THC can be measured in urine and can be used as biomarkers for cannabis exposure.

While a few studies described COOH-THC in children's urine and parental report of cannabis smoking around the children,[53,54] they did not quantify the relationship between in-home cannabis smoking and cannabis analyte detection in urine. Additionally, the only measure of cannabis exposure in these studies was urinary COOH-THC, a common biomarker to measure THC consumption, but the amount of cannabis smoke exposure reported may be underestimated due to not measuring THC and its primary metabolite OH-THC.

This study assessed the relationship between in-home cannabis smoking by parent/guardian and urinary cannabinoid levels (THC, OH-THC, and COOH-THC) found in children to estimate cSHS exposure.

4.3. Methods

4.3.1. Study Design

I used data from Project Fresh Air (PFA), a two-group randomized control intervention aimed at reducing in-home tobacco secondhand smoke (SHS) and fine particulate matter ($PM_{0.5-2.5}$) levels through real-time feedback and coaching in San Diego County, CA.[86,87] The data included in this study were collected during the approximately 7-day pretest period at the beginning of the baseline phase of the trial. I capitalized on the abundance of data collected by PFA, encompassing questionnaire responses, urine data, air particle data, and air nicotine data, by using the baseline variables to understand the relationship between in-home cannabis smoking and cannabis smoke exposure of children.

4.3.2. Study Participants

Between 2012 and 2015, participants were recruited through various sources, including community events, organizations such as the Women, Infants, and Children (WIC) nutrition programs, advertisements in local papers, and referrals from healthcare professionals. Inclusion criteria for the study were being a parent or guardian 18+ years of age or older, having an adult tobacco smoker living in the home, having at least one child under 14 years old living in the home, and having no plans of moving for three months. A total of 298 families were enrolled—specifically, one parent or guardian and the youngest child from each household were selected for participation in the study. Additional details of participant recruitment and enrollment procedures are reported elsewhere.[86]

Study procedures for PFA were approved by the San Diego State University Institutional Review Board (#770080) in October 2011. Prior to study participation, parents or guardians provided written informed consent and children above the age of 6 provided written informed assent.

Of 298 households enrolled, 10 were excluded for not having urine samples, two were excluded for missing data on all three cannabis analytes due to assay issues, ten were excluded for missing air particle data, and one was excluded due to very high values for cannabis biomarkers (THC= 8.0 ng/ml, OH-THC= 168.0 ng/ml, COOH-THC= 331.0 ng/ml) implicating primary exposure to cannabis. The final analytic sample size was 275 households (Figure 1).

4.3.3. Study Procedures

After study enrollment, trained project staff installed a Dylos DC1700 (Dylos, California, USA) air particle monitor, in the room nearest where the most tobacco smoking occurred as reported by the participants.[88] The monitors continuously count fine air particles (0.5-2.5 μm in diameter), average every 10 seconds, and save locally on the device. Passive nicotine dosimeters were also placed within 2 feet of the air particle monitor to measure air nicotine. Approximately seven days after installing the air particle monitor, project staff returned to administer a face-to-face computer-assisted interview with the enrolled parent/guardian to assess participant household characteristics, use of cannabis and tobacco, and other air particle generating activities that occurred in the past 7 days.

After interviewing the enrolled parent/guardian, project staff provided the parent/guardian with a urine collection kit which included verbal, written, and pictorial instructions on how to collect urine samples from the enrolled child. Urine samples were collected by the parent/guardian during the visit or within 24 hours of the visit and were transported by project staff to the biosafety laboratory. Contaminated samples (e.g., feces or baby powder) were discarded, and parents were asked to collect another sample. Valid urine samples were stored in the lab freezers at or below -20°C. Samples were sent frozen to the Centers for Disease Control and Prevention (CDC) Tobacco Laboratory and analyzed for cannabis exposure biomarkers.

4.3.4. Measures of In-Home Cannabis Smoking

In-home cannabis smoking was measured using data from air particle monitoring and interview report of in-home cannabis smoking in the last 7 days, which corresponded with the air particle monitor data collection period. The air particle data was the most objective and sensitive data that I had on smoking and other air particle generating activities in the home but did not identify the source of air particles. Report of in-home cannabis smoking may have false negatives potentially leading to underestimation of the true relationship. Due to these aspects, I used the residualization approach to ascertain in-home cannabis smoking using both air particle data and report of in-home cannabis smoking (Detailed in Statistical Analyses).

1. The report of in-home cannabis smoking was collected from parent/guardians via the question: “How often in the past 7 days did anyone smoke medicinal or recreational marijuana in your home?” The responses were coded as “never” if answers were “0” and as “one or more days” if answers were 1-3 times, 4-6 times, 7-9 times, or 10+ times.
2. Geometric mean particle counts were computed to summarize air particle concentrations.
3. The number of daily smoking events was calculated based on particle counts from the air monitors, using a previously validated algorithm.[87] Monitors counted particles irrespective of their source, e.g., smoking cigarettes, smoking cannabis, burning toast, cooking with oil, burning incense. Daily smoking events were identified if in a 5-minute period the maximum particle count was $\geq$15,000 counts/0.01 ft^3.
4. Geometric mean of the number air particle counts uniquely attributed to in-home cannabis smoking was calculated using the residualization approach (Detailed in Statistical Analyses).
5. Number of daily smoking events uniquely attributed to in-home cannabis smoking was calculated using the residualization approach (Detailed in Statistical Analyses).

4.3.5. Measures of Cannabis Exposure

At the CDC Tobacco Laboratory, a panel of three cannabis biomarkers (THC, OH-THC, and COOH-THC) were measured by a validated isotope-dilution liquid chromatography/tandem mass spectrometry method using a modification of the method of Wei et al. (2015).[89] The limit of detection (LOD) for each biomarker was 0.005 ng/ml.

The molar equivalents of THC, OH-THC and COOH-THC were summed to create a new variable named total THC equivalents (TTE). Values below the LOD were estimated as half LOD (0.0025 ng/ml). A binary variable for TTE was also calculated, where those with undetectable LOD for all three biomarkers were considered "not detected". For each biomarker, a binary variable was also created to identify children who were detectable for that analyte (Yes/No). Binary variables were created for each of the 3 biomarkers and for their summed composite (TTE), in which instances of non-detection were coded as "0" and detectable values were coded as "1".

4.3.6. Covariates

Covariates included variables from the questionnaire, urine sample assays, and nicotine dosimeter assays.

Questionnaire data

1. *Demographics*

   The questionnaire included questions on the sex of the child (male or female), age of the child (years), parent/guardian's education (years), family income (increments of $10,000), race/ethnicity (Black, White, Hispanic, or other), and type of home (apartment/condominium, detached house, or other).

2. *Report of in-home tobacco smoking*

   Parents/guardians were asked to report whether cigarettes, cigars, pipe tobacco, hookah or e-cigarettes were smoked inside the home in the past 7 days (Yes/No, for each product).

3. *Report of particle-generating activities*

   For each in-home *particle-generating* activity in the past 7 days, parents/guardians were asked the number of times incense was burned; food was burned; participants fried food with oil; gas or propane appliances were used to cook or heat the home; aerosol spray products were used; participants vacuumed, dusted, or swept; and anything else that generated air particles.

   Participants were also asked about burning of wood and using of any gas/space/wall-mounted heating device in the past 7 days. For each activity 3 factors were measured: (1) number of days each activity was conducted in home, (2) average number of hours per day each activity was conducted, and (3) intensity of activity [1(low), 2(medium), 3(high)]. The responses from each factor were multiplied to create an overall assessment of the total impact of wood burning or use of heater in the past 7 days (Activity Impact Score). Each of these composite variables is unitless.

4. *Report of particle ventilating activities*

   Parents/guardians were asked about the frequency of engaging in in-home ventilation activities during in-home particle generating activities in the past 7 days: Questions were asked about opening a window, opening an interior door, opening an exterior door, use of air purifier, use of exhaust fan, use of ceiling fan, use of window fan or AC, and use of central HVAC system, during particle generating activities (cooking, cleaning or smoking). The responses for these activities (cooking, cleaning, smoking) were coded as: during all three of the activities [3], during two of three activities [2], during only one activity [1], and during none of the activities [0] (Table B.2 in Appendix B).

Additionally, participants were asked about central HVAC use, air purifier use, exhaust fan use, and window fan or AC use in the last 7 days. For each activity 3 factors were measured: (1) number of days each activity was conducted in home, (2) average number of hours per day each activity was conducted, and (3) intensity of activity [1(low), 2(medium), 3(high)]. The responses from each factor, for each activity, were multiplied to create an overall assessment of the total impact of these ventilating activities in the past 7 days (Activity Impact Score). Each of these composite variables is unitless.

Nicotine Dosimeter: Average air nicotine concentration ($\mu g/m^3$) was estimated via nicotine dosimeter assays conducted using liquid chromatography/tandem mass spectrometry with electro-spray ionization. This captures information about in-home tobacco smoking and e-cigarette use that may not have been caught through the questionnaire.

4.3.7. Statistical Analysis

Descriptive statistics of the 275 households included in this study were computed. Missingness in reported variables and air nicotine data were highest for report of in-home cannabis smoking (77/275; 28%), followed by report of in-home cigarette, cigar, pipe, hookah, e-cigarette smoking (34/275; 12%), family income (28/275; 10.2%), and air nicotine (12/275;4.4%). To minimize bias due to missing data in key variables, I used multiple imputation by chained equations generating 30 imputations each with 50 iterations using the MICE package in R.[90,91] All analyses after calculating descriptive statistics used multiple imputed data.

Multiple variables that estimate in-home cannabis smoking were used in the analyses since none of them alone provides an optimal estimate. This is why the residualization approach[92,93] (details below) was used to create a variable that benefits from the specificity of reported in-home cannabis smoking and the sensitivity of the objective air particle data.

4.3.7.1. In-Home Cannabis Smoking Variable Ascertainment by Use of Residualization Approach. To calculate and partition out how much of the objective air particle data was related to reported in-home cannabis smoking, I conducted linear regression with number of daily smoking events as the dependent variable, and with all reported in-home tobacco smoking variables, reported in-home air particle generating and ventilation activities, and air nicotine as the independent variables. The residuals from this model (Model A) provided information on how much of the variance in the air particle data is not due to the variables specified in Model A (Table B.1 in Appendix B). Subsequently, a second model (Model B) was estimated with the addition of reported in-home cannabis smoking to the model. The residuals from Model B provided information on variance in the air particle data not due to all air particle generating behaviors specified in the model. The difference in the residuals from the two models (residuals of Model A – residuals of Model B) equal the variance in the number of daily smoking events that are uniquely attributed to reported in-home cannabis smoking. This estimate was used as an explanatory variable in the main analyses. This process was replicated using geometric mean particle counts as the dependent variable. Table B.1 (Appendix B) provides a detailed guide on the computation of number of daily smoking events that are uniquely attributed to in-home cannabis smoking, and geometric mean particle counts that are uniquely attributed to in-home cannabis smoking.

The residualization process led to some negative values in the residuals, due to the linear regression used for residualization, so values were adjusted by adding the mean of the dependent variable (number of daily smoking events or geometric mean particle counts) to each residual. Doing this preserved the distance between all values.

4.3.7.2. Main Analyses: Association Between In-Home Cannabis Smoking and Urinary Cannabinoids in Children. To model the relationship between in-home cannabis smoking and urinary cannabinoids, two models (for all five of the independent variables) were examined: a logistic regression model was used to estimate the odds of cannabis biomarkers being detected in the urine, and a linear regression model was used among those with detectable cannabis biomarkers to quantify total TTE. For the linear regression model, the outcome variable was natural log transformed. The regression models were conducted separately for each independent variable, adjusting for child and parent/guardian demographic variables.

4.3.7.3. Sensitivity Analyses. Values below the LOD (0.005 ng/ml) were imputed in two ways to compare results with the main analyses: (1) the LOD/sqrt(2) (0.0035 ng/ml); and (2) zero. All linear regression models were also run with these alternative LOD values to describe the cannabinoid levels.

4.4. Results

For the 275 children included in this study, the median age was 3.0 years (range: 0.0, 14.0) and 52.4% were male. Almost half of the children were Hispanic (48.0%) and 18.9% were non-Hispanic White. One-fifth of the households had an annual family income <$10,000 and the average level of education of the parents/guardians was 13.2 years (SD: 3.3). Almost half

(43.3%) reported living in a detached home, while 41.5% reported living in an apartment/condominium (Table 4.1).

On average, there were 2.9 (SD: 5.0) daily smoking events. Ten percent of parents/guardians reported that cannabis was smoked inside the home, and 27.3% of children had detectable cannabis analytes in their urine (Table 4.1). The average TTE was 0.0127 nmol/L (SD: 0.04224).

After mean adjustment of residuals variables with negative values, there were on average 2.9 (SD:0.5; median: 2.8; range: 1.7, 4.7) daily smoking events uniquely attributed to reported in-home cannabis smoking in the last 7 days. After mean adjustment, the average geometric mean particle count/0.01 ft^3 uniquely attributed to reported in-home cannabis smoking in the last 7 days was 3281.9 (SD:124.6; median:3249.4; range: 3016.8, 3707.8) (not presented in table).

4.4.1. Report of In-Home Cannabis Smoking

The odds of cannabis biomarkers being detected in children's urine in households that reported in-home cannabis smoking in the last 7 days were 5.0 (95% CI: 2.4, 10.4) times the odds of detectable cannabis biomarkers in households that did not report in-home cannabis smoking. Among those with detectable urinary cannabinoids, the TTE levels were greater, but not statistically significant, by 86.1% (95% CI: -1.4%, 251.4%) among those with report of in-home cannabis smoking in the last 7 days compared to those without.

4.4.2. Number of Daily Smoking Events

The odds of cannabis biomarkers being detected in children's urine increased significantly by 10% (OR=1.1; 95% CI: 1.0, 1.2) for every daily smoking event. Among those with detectable urinary cannabinoids, for every daily smoking event, the TTE levels increased, but not statistically significantly, by 4.7% (95% CI: -0.4%, 10.2%).

4.4.3. Number of Daily Smoking Events Uniquely Attributed to In-Home Cannabis Smoking

For every daily smoking event uniquely attributed to in-home cannabis smoking, the odds of cannabis biomarkers being detected in the children's urine increased statistically significantly by a factor of 2.5 (95% CI: 1.6, 3.9). Among those with detectable urinary cannabinoids, for every daily smoking event uniquely attributed to in-home cannabis smoking, the TTE levels increased, but not statistically significantly, by 35.7% (95% CI: -7.1%, 98.2%).

4.4.4. Geometric Mean Air Particle Count

For every standard deviation increase in the geometric mean air particle count, the odds of cannabis biomarkers being detected in the children's urine significantly increased by a factor of 1.9 (95%CI: 1.3, 2.7). Among those with detectable levels of cannabis biomarkers, for every standard deviation increase in the geometric mean air particle count, the TTE levels increased significantly by 48.5% (95% CI: 7.3%, 105.5%).

4.4.5. Number of Geometric Mean Air Particle Count Uniquely Attributed to In-Home Cannabis Smoking

For every standard deviation increase in the geometric mean air particle count uniquely attributed to a report of in-home cannabis smoking, the odds of cannabis biomarkers being detected in the children's urine significantly increased by a factor of 1.8 (95%CI: 1.3, 2.2). Among those with detectable levels of cannabis biomarkers, for every standard deviation increase in the geometric mean air particle count attributed to in-home cannabis smoking, the TTE levels increased, but not were statistically significant, by 28.2% (95% CI: -5.8%, 74.5%).

4.4.6. Sensitivity Analyses Results

Results were similar to main analyses results, with slightly stronger estimates when undetectable results were entered as zero than when undetectable results were entered as LOD/sqrt(2) (Table 4.2, Table B.3 in Appendix B).

4.5. Discussion

In this study of 275 households in San Diego County I investigated the association between in-home cannabis smoking and children's exposure to cannabis smoke, as measured by the summed urinary concentrations of THC, OH-THC, and COOH-THC. Using three THC biomarkers instead of just one (COOH-THC) increased the number of children with detectable cannabinoids in their urine from 22.5% (n=62) to 27.3% (n=75), increasing the accuracy of number of children who were exposed to cannabis smoke. The results showed that reported in-home cannabis smoking had the strongest association (OR: 5.0) with detectable TTE compared to air monitoring data. This was expected as the air particle data is not able to differentiate between sources of smoke or particles. But via the residualization process, the air particle data was used to parse out how much of detectable TTE might be due to in-home cannabis smoking, leading to stronger associations seen using the newly ascertained air particle data. The linear regression results showed a positive, though statistically insignificant, relationship between reported in-home cannabis smoking and the quantity of TTE in urine.

To my knowledge, this study is the first to quantify the relationship between in-home cannabis smoking and cannabinoid biomarkers in children's urine. One study among 43 young children hospitalized with bronchiolitis in Colorado found that 16% had detectable levels of COOH-THC (0.015 ng/ml) in their urine, with 16% of parents reporting that cannabis was smoked in the home or by a caregiver.[54] Another study examined 53 young children who visited a hospital for well-child visits or were hospitalized in the pediatric unit and found that 20.8% had detectable urinary COOH-THC levels (0.015 ng/ml), with 15% of parents reporting that cannabis was smoked in the home or by a caregiver.[53] These studies did not explore the relationship between in-home or caregiver smoking and detectable urinary cannabinoids, likely due to limited sample size. In the current study, 11% of parents/guardians reported that cannabis was smoked inside the home, and 22.6% of the sample had detectable levels of COOH-THC (≥0.005 ng/mol). Using all three cannabinoid biomarkers, 27.3% had detectable levels of TTE.

The findings from the first step (logistic) regression revealed a strong and statistically significant relationship (OR: 5.0) between reported in-home cannabis smoking and the detectability of urinary TTE. All associations tested during the first step of the two-step modelling were statistically significant and positive. The second step (linear) regression showed a positive but statistically insignificant relationship between in-home cannabis smoking and quantity of urinary TTE among those with detectable TTE. There was a positive trend for all different measurements of in-home cannabis smoking; meaning that as the level of in-home cannabis smoking increased, the amount of cannabis exposure of children also tended to increase, albeit not statistically significantly.

This study offers unique contributions and novel approaches to examining the relationship between the report of in-home cannabis smoking and an objective measurement of children's exposure to cannabis. A summary variable (TTE) was created from 3 urinary cannabis biomarkers (THC, OH-THC, and COOH-THC), providing a more sensitive assessment of children’s exposure to cannabis smoke than would measurement of a single biomarker. Furthermore, the diversity of the measures of in-home cannabis smoking was leveraged to develop a novel variable that integrated objective air particle data and questionnaire-reported information on in-home cannabis smoking. This approach of incorporating air particle data alongside self-reports allowed for a more robust analysis by enabling me to partition out the portion of air particle data due to reported in-home cannabis smoking. To further enhance the depth of this investigation, I employed a two-stage modeling approach. This provided insights into the likelihood of detectability of TTE and enabled the examination of the quantity of TTE in those with detectable TTE, adding granularity to the understanding of the relationship between in-home cannabis smoking and cannabis smoke exposure of children.

This study had several limitations. Data collection by personal interviews may introduce report bias, such as social desirability bias; report of in-home cannabis smoking could be under-reported due to the taboo associated with cannabis, particularly at the time the data were collected when cannabis was not yet recreationally legalized in California. Underreporting of in-home cannabis smoking could lead to underestimation of the association between in-home cannabis smoking and urinary cannabinoids in children. And while I was not able to address the underreporting, the residualization approach partitioned the objective but non-specific air particle data to determine how much was uniquely due to reported in-home cannabis smoking. Further, PFA inclusion criteria required the household to have a tobacco smoker living in the home, which may have made the sample less representative of the general population, and tobacco smokers are more likely to use cannabis.[29,94] Additionally, this was a convenience sample from San Diego County, which largely consisted of low-income individuals and was almost 50% Hispanic, limiting the generalizability of the findings. Data collection occurred before legalization of adult cannabis use in California, when pressure to keep illicit drug use clandestine may have favored smoking indoors, potentially increasing child exposure. Missing data in reported in-home cannabis smoking posed a challenge, as some households were not administered questions about in-home cannabis smoking due to being enrolled in the PFA when cannabis questions had not yet been approved by the IRB or due to being in the Navy. The missingness in all variables was mitigated through multiple imputation and ascertainment of in-home cannabis smoking through the residualization approach in the multiple imputed dataset to reduce bias in the estimates. Lastly, though cSHS was likely primarily responsible for the measured urinary cannabinoid levels, thirdhand cannabis smoke may also have contributed to those levels. Unfortunately, we did not have an assessment of thirdhand cannabis smoke. A fortunate strength of this study is that COOH-THC has a half-life of around 6-7 days, longest of the THC metabolites, and that urine samples were collected on the last day of the pretest week.[85,95] Parent report of in-home cannabis smoking during the past 7 days also occurred on that day, and air particle monitoring and air nicotine measures were assessed only for the duration of the pretest week, resulting in temporal correspondence of all measures.

4.6. Conclusion

The findings from this study suggest a strong and significant relationship between in-home cannabis smoking and cSHS exposure of children in the home. Future studies should investigate cannabis smoke and tobacco smoke co-exposure. Approaches to decrease in-home cannabis smoking, especially in households with children, should also be tested. While this study shows that participant reports of in-home cannabis smoking can be used to estimate cSHS in the home, employing biomarker analysis or environmental monitoring may lead to a more accurate estimate of cSHS exposure. Further, as cannabis legalization continues to evolve across the U.S., it is essential to investigate the impact of changing regulatory environments on patterns of in-home smoking and potential increases in cSHS exposure of children. Lastly, more studies are needed on the long-term effects of cSHS exposure of children to provide a comprehensive understanding of the risks associated with cannabis smoke exposure.

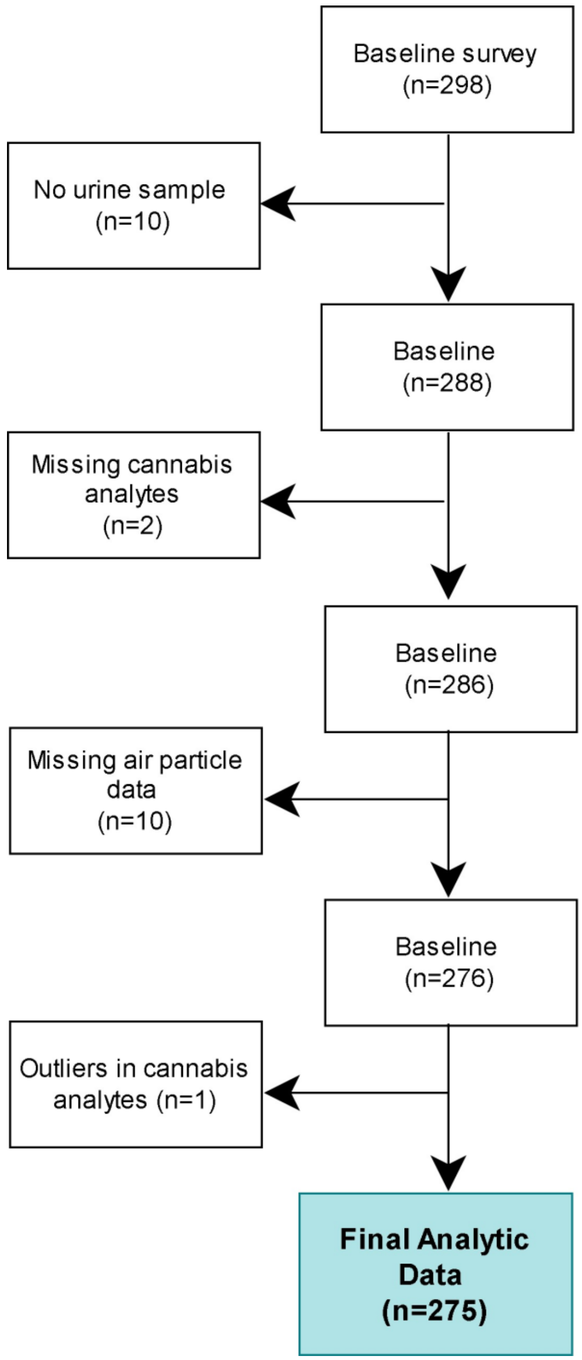

Figure 4.1. Exclusion criteria for analyses.

Table 4.1. Descriptive Statistics for Demographic Variables; Project Fresh Air

	Baseline (n=275)	
Characteristics	n	%
Cannabis reported smoked inside home in last 7 days		
No	169	61.5%
Yes	29	10.5%
Missing	77	28.0%
Number of daily smoking events		
mean (sd)	2.9 (5.0)	
median (range)	0.9 (0.0, 33.6)	
Geometric Mean Particle Count /0.01 ft^3		
mean (sd)	3281.9 (3578.8)	
median (range)	2089.5 (536.5, 27342.2)	
Total THC Equivalents$_{a,b}$ (nmol/L)		
Not detected	200	72.7%
Detected	75	27.3%
mean (sd) [half LOD]$_c$	0.1 (0.4)	
median (range) [half LOD]	0.2 (0.2, 0.5)	
THC		
Not detected	251	91.3%
Detected	24	8.7%
OH-THC		
Not detected	218	79.3%
Detected	54	19.6%
Missing	3	1.1%
COOOH-THC		
Not detected	209	76.0%
Detected	62	22.5%
Missing	4	1.5%
Age of child		
mean (sd)	3.6 (3.6)	
median (range)	3.0 (0.0, 14.0)	
Sex of child		
Female	131	47.6%
Male	144	52.4%
Race/ethnicity of child		
Black	38	13.8%
White	52	18.9%
Hispanic	132	48.0%
Other	53	19.3%
Family Income (annual)		
less than $10,000	53	19.3%
$10,000 - $19,999	44	16.0%
$20,000 - $29,999	46	16.7%
$30,000 - $39,999	32	11.6%
$40,000 - $49,999	26	9.5%
$50,000 - $59,999	12	4.4%
$60,000 - $69,999	9	3.3%
$70,000 - $79,999	10	3.6%
$80,000 - $89,999	4	1.5%
$90,000 - $99,999	2	0.7%
$100,000 or more	8	2.9%
Missing	29	10.5%

Table 4.1. Descriptive Statistics for Demographic Variables; Project Fresh Air (continued)

Characteristics	Baseline (n=275) n	%
Years of education of parent		
mean (sd)	13.2 (3.3)	
median (range)	13.0 (0.7, 22.0)	
Home Type		
Apartment/Condo	114	41.5%
Detached House	119	43.3%
Other	42	15.3%

a Each biomarker (ng/ml) was divided by its molecular weight (ng/nmol) to yield nmol/ml, and the 3 values were summed. TTE = [THC (ng/ml)/314.5 (ng/nmol)] + [OH-THC (ng/ml)/330.5 (ng/nmol)] + [COOH-THC (ng/ml)/344.4 (ng/nmol)]

b For the categorization of TTE, those with undetectable LOD for all three biomarkers were considered 'not detected'

c half LOD = 0.0025 ng/ml

Table 4.2. Estimates of Two Modelling Procdures: Logistic Regression for Total THC Equivalents in Urine of Children (n=275). Linear Regression for Total THC Equivalents among those with Detectable Urinary Cannabinoids (n=75) with Cannabis Biomarkers <LOD Treated as Half of LOD (0.0025 ng/ml)

	Logistic (n=275)		Linear (log outcome) (n=75)	
Measures	OR	95% CI	%	95% CI
In-home cannabis smoking in past 7 days				
M1	5.4	2.7, 10.6	80.8	-0.4, 228.3
M2	4.9	2.3, 10.0	76.4	-4.1, 224.5
M3	5.0	2.4, 10.4	86.1	-1.4, 251.4
Number of daily smoking events				
M1	1.1	1.1, 1.2	6.6	2.1, 11.2
M2	1.1	1.0, 1.2	4.9	-0.1, 10.1
M3	1.1	1.0, 1.2	4.7	-0.4, 10.2
Number of daily smoking events uniquely attributed to reported in-home cannabis smoking in past 7 days				
M1	2.3	1.5, 3.6	20.4	-15.8, 72.2
M2	2.5	1.6, 3.9	32.1	-8.6, 90.8
M3	2.5	1.6, 3.9	35.7	-7.1, 98.2
Scaled Geometric Mean Particle count				
M1	2.0	1.4, 2.8	63.1	24.5, 113.7
M2	1.8	1.3, 2.6	48.7	9.4, 102.1
M3	1.9	1.3, 2.7	48.5	7.3, 105.5
Scaled Geometric Mean Particle count uniquely attributed to reported in-home cannabis smoking in past 7 days				
M1	1.7	1.3, 2.2	16.3	-13.1, 55.7
M2	1.7	1.3, 2.3	25.4	-7.1, 69.2
M3	1.8	1.3, 2.3	28.2	-5.8, 74.5

M1: unadjusted
M2: M1 + demographic variables
M3: M2 + type of home

Chapter 4, in part, is currently being prepared for submission for publication of the material. Tripathi, Osika; Parada, Humberto; Matt, Georg E.; Quintana, Penelope J.E.; Shi, Yuyan; Liles, Sandy; James O’Neill, Nguyen, Ben; Bellettiere, John. The dissertation author was the primary investigator and author of this paper.

5. Discussion

5.1. Summary of Key Findings

Findings from this dissertation contribute to the body of work surrounding perceptions of harm, cannabis smoking behaviors, and exposure to cannabis secondhand smoke. Chapter 2 focused on the relationship between perceived harm of cannabis secondhand smoke exposure and complete ban on in-home cannabis smoking in the general U.S. population. Chapter 3 focused on the association between perceived harm of in-home cannabis smoking and cannabis smoke exposure of household residents in a global sample from 21 countries. Lastly, Chapter 4 focused on the relationship between in-home cannabis smoking in the last 7 days and urinary cannabinoid levels in children. The results from these three chapters can be used by policy makers and government bodies to promote a more accurate view of cannabis smoke and cSHS as harmful to health that might change perceptions of the harm of cSHS. Results from this study suggest that these promotions or educational movements should include suggesting bans on in-home cannabis smoking and strategies to eliminate in-home cannabis smoking, through identifying alternative locations outside of the home for smoking, with the goal to eliminate cSHS exposure at home.

In Chapter 2, I used data from Marijuana Use and Environmental Survey (MUES) 2020 collected between December 2019 and February 2020 to examine how perception of harm of cSHS was associated with household rules on in-home cannabis smoking. Data from 21,2381 participants from the U.S. weighted to the U.S. general population were used. Multivariable logistic regression for survey-weighted data revealed that perceiving cSHS at any level more than totally safe was strongly associated with higher odds of having a complete ban on in-home cannabis smoking. Even in households with current cannabis smokers, perception of cSHS as harmful was highly associated with having a complete ban on in-home cannabis smoking. Additionally, almost a third of the U.S. population reported cSHS exposure as totally or mostly safe with more than two-thirds of current cannabis smokers perceiving cSHS exposure as totally or mostly safe. Another study noted similar proportions of respondents perceiving cSHS exposure as not at all or little harmful, with younger age, recent cannabis use, recent tobacco use, tobacco and cannabis co-use, and non-White race/ethnicity associated with a higher likelihood of perceiving cSHS exposure as not harmful.[44] Educating the general population and specifically cannabis smokers, who may be more likely to expose non-smoking residents to cSHS, on the harms of cannabis smoke could lead to setting in-home cannabis smoking rules to reduce cSHS to non-smokers.

In Chapter 3, I used data from the Global Drug Survey 2021, collected between December 2020 and March 2021, of 28,154 respondents from 21 countries to examine the association between perception of harm of cannabis smoke exposure of non-smoking residents and in-home cannabis smoking in the last 30 days. Logistic regression results indicated that a respondent at the 75th percentile of perceived harm had 70% higher odds of having had no in-home cannabis smoking compared to a respondent at the 25th percentile. A Poisson regression analysis showed that a respondent at the 75th percentile of perceived harm had 16% fewer days during which cannabis was smoked inside the home, compared to a respondent at the 25th percentile. Examining country-specific results, there were relatively consistent associations between perception of harm and in-home cannabis smoking, with some notable exceptions. The strongest and the least strong odds of in-home cannabis smoking were both seen in countries where only medical cannabis was legalized (Denmark: 1.3, Sweden: 3.9). Across all 20 countries, there was a statistically significant positive association between perceiving cannabis smoke exposure of non-smoking residents as harmful and having had no in-home cannabis smoking in the last 30 days. Changing perception of harm of cannabis smoke exposure may play a pivotal role in reducing or eliminating in-home cannabis smoking altogether. Through reduction or elimination of in-home cannabis smoking, cSHS exposure of non-smokers, especially children and pregnant people, could be reduced.

Chapter 4 used data from Project Fresh Air (PFA), a two-group randomized control intervention aimed at reducing indoor smoking through real-time feedback and coaching in San Diego County, California. Between 2012 and 2015, households with at least one child under 14 years of age and one adult tobacco smoker were recruited. The study presented in Chapter 4 relied on data collected at baseline before any intervention started among the 298 households. I conducted a two-step modeling approach: Results from the logistic regression analysis indicated that the odds of cannabis biomarkers being detected in children's urine were five times higher in households with reported in-home smoking, almost three times higher for each additional daily smoking event uniquely associated with reported in-home cannabis smoking, and almost two times higher for each standard deviation increase in geometric mean particle count uniquely associated with reported in-home cannabis smoking. Among those with detectable urinary cannabinoids, the levels of urinary cannabinoids were 86.1% greater, albeit not statistically significant, among those with report of in-home cannabis smoking, 35.4% greater for every daily smoking event uniquely associated with report of in-home cannabis smoking, and 24.2% greater for every standard deviation increase in the geometric mean air particle count uniquely associated with report of in-home cannabis smoking. These findings provide evidence of a strong relationship between in-home cannabis smoking and exposure of children to cannabinoids. As cannabis use among parents with children at home continues to increase,[24,25] and with in-home cannabis smoking so strongly associated with cannabinoids detected in children's urine, action needs to be taken to educate adults, especially those with children living at home, about the potential harms of cSHS exposure of vulnerable populations such as children during critical periods in their development. Educating, changing perception of harm, providing solutions on how to decrease cSHS exposure (e.g., setting rules not allowing in-home smoking, providing alternate spaces to smoke such as backyard, outside in the garage, etc.) may reduce in-home smoking and reduce cannabis smoke exposure of children.

5.2. Contribution to Research and Implications

The original work in this dissertation advances the literature surrounding cannabis secondhand smoke exposure; all 3 studies presented in Chapters 2– 4 include novel contributions to understanding relationships among perceived harm, household rules, in-home cannabis smoking and cannabis smoke exposure of children. These chapters also explored whether these relationships vary among different groups such as cannabis smokers and those with children living at home as well as whether the relationships were different by state/country cannabis use policies. The results from this dissertation can be used to inform targeted educational programs aimed at fostering greater awareness of harm associated with cSHS exposure. Governmental and other authorities can also promote the fostering of public awareness and support the adoption of household rules to completely ban in-home cannabis smoking. The results can be used to support the need for strengthening policies and regulations to deter in-home cannabis smoking, through local ordinances or parental responsibility laws. All these actions and more can help in creating cannabis smoke-free homes for the safety of population health, especially vulnerable populations. This is needed in the current environment where (1) Cannabis use laws are being liberalized,[11–13] (2) Cannabis use continues to increase among many different demographic groups,[8–10] especially those with children living at home,[24,25] and (3) in-home cannabis smoking is prevalent.[7,50]

Understanding how cannabis smoke exposure is perceived is important, as perceptions can influence public opinion and subsequently public health policies. Inaccurate perception of harm or perception of harm as not harmful can also lead to making personal decisions due to the individual not being aware of the risk not only to themselves but to their families, especially those who are vulnerable to the effects of smoke exposure such as children and pregnant people. [58,59,62] This work adds to the currently limited literature and attempts to bridge that gap by quantifying the impact that different levels of perceived harm of cannabis smoke have on decision making about cannabis smoking at home. Although, my work on this dissertation addresses only one factor, perception of harm, that may lead to making decisions on in-home smoking, it is the first of its kind and can be used to inform policymaking (e.g., policies to restrict smoking in-homes especially in multi-unit housing, strengthening existing smoke-free housing regulations), educational (e.g., public awareness campaigns through social media, TV, radio etc.; educational programs in schools K-12 as well as in colleges), interventional (e.g., targeted studies among household with cannabis users or smokers to reduce in-home smoking or to quit using altogether) efforts to reduce cSHS exposure.

A specific advancement of the literature is illustrated by the results of effect modifiers in Chapters 2 and 3, showing that even among current cannabis smokers or users, perception of cSHS exposure as harmful was related to having a complete ban on in-home cannabis smoking or having had no in-home cannabis smoking recently. Thus, even among this high-risk population, who may be more likely to expose non-smokers to cSHS, changing perception of harm may influence changing or setting of household rules and in-home smoking behavior--

experimental studies are needed to test this hypothesis. Educating current cannabis smokers or users and making sure that misinformation is challenged are especially important for this group as current cannabis smokers bring risk to any home they may smoke in—if their perceptions can be changed, their decisions on where they choose to smoke may also be changed.

Household rules or restriction on in-home cannabis smoking may be a mediator of the relationship between perceived harm and in-home smoking. It could also be viewed as a proxy for in-home cannabis smoking behavior. But having household rules or restrictions is not equivalent to actual reduction in the behavior of in-home smoking; rules are not always followed, and exceptions may be made for family or friends, as has been shown in tobacco research.[71] So, Chapter 3 results provide a first attempt to understand how perception of harm may be associated with actual behavior of in-home cannabis smoking as opposed to household rules. As hypothesized, perception of cSHS exposure as harmful was related to not having had any in-home cannabis smoking, although the strength of this association (OR:1.7; Chapter 3) was lower in magnitude than the association between perception and rules (OR: 6.0; Chapter 2). This was expected as setting rules is likely easier than enforcing them. The results from Chapter 3 also suggest that changing perception of harm could lead to reducing the frequency with which cannabis is smoked inside. Reducing in-home smoking could reduce health issues associated with cSHS exposure. Both the smoking of cannabis and exposure to cSHS have been associated with various adverse respiratory, cardiovascular, and potential cognitive issues, especially in children.[20,56,58–62] Effectively addressing such health issues would help alleviate both individual health burden and the burden on health care systems.

Changing individual perceptions through education or interventions should not be the only action taken to decrease in-home cannabis smoking. There is a need to change social or cultural norms surrounding cannabis, which may drive users to in-home smoking over out-door smoking as cannabis is viewed as a social taboo, even in legal settings. The results from Chapter 3 also show that in some countries perception of harm has a stronger association with no in-home cannabis smoking. In the U.S., the association was also stronger in states where only medical use is legalized. Educational and interventional campaigns should be tailored to demographics for optimal reduction of in-home cannabis smoking.

Cannabis use policies impact cannabis use perceptions and behaviors. In the U.S., in states where cannabis use has been legalized, many states' policies have not prioritized consumer awareness of cannabis products and the associated health considerations.[13] Some states have focused on commercial models to incentivize market outcomes, such as increased sales and consumption, which are at odds with public health goals of reducing adverse health outcomes related to cannabis use or dependence, or preventing cSHS exposures to non-smokers. State cannabis use policies also differ in many areas including where cannabis use is allowed and how cannabis is advertised. In most U.S. states where recreational cannabis use is legalized, cannabis use has effectively only been legalized in very narrow margins such as those who own their own home or properties which allow smoking, as cannabis use is illegal in public spaces, even in spaces where tobacco use is allowed. For example, landlords (which include private as well as public housing) generally ban cannabis use on property through use of fines or eviction.[13,96] In the context of a legalized product which is virtually illegal to use in all private and public areas, consumers may be compelled to use cannabis within the confines of their residences. In the case of consumers who rent their residence, they may be willing to expose themselves to potential repercussions should their landlords or property management become aware of their cannabis use on property or inside home. These inherent limitations in government regulation necessitate a multifaceted approach, through amending the prohibition of outdoor cannabis use, but retaining strong smoke-free indoor rules, for example possibly allowing use in cannabis establishments, which have stand-alone buildings to allow use for patrons, or allowing use in outdoor areas of cannabis establishments where employees and non-smoking patrons would not be exposed to cSHS.[96]

Lastly, an indoor smoking ban, no in-home smoking, or increasing indoor ventilation only consider the harms related to secondhand smoke exposure which may be ineffective or limited against cannabis thirdhand smoke (cTHS) exposure.[97] cTHS may already be present in the environment from years of unregulated indoor smoking practices and it can be transported (e.g., through moving of furniture) to a previously smoke-free environment. For past cTHS pollution, remediation requires identifying reservoirs, followed by cleaning or removing them to avoid continued cTHS exposure.[97] There needs to an effort to achieve true smoke free indoor environments through addressing and remediating reservoirs of pollutants and limiting or preventing transportation of items polluted with THS.[97]

To try to solve the problem of new or future cSHS and cTHS exposure, specifically for personal environments such as homes or cars, advocating for smoking outside the home may be the only viable strategy. But to suggest outdoor cannabis smoking, legal policies on outdoor smoking would need to be revised so there are legal outdoor spaces to smoke cannabis, which would also decrease cSHS exposure.

Chapter 4 was the first study to examine the relationship between in-home cannabis smoking and cannabinoid exposure of children. While a few studies have described the detectability of COOH-THC in the children's urine,[53,54] these studies did not explore the relationship of in-home cannabis smoking or caregiver cannabis smoking to detectable urinary cannabinoids in children. The current study revealed a strong relationship between in-home cannabis smoking and detectability of urinary cannabinoids in children. The Chapter 4 study was also the first to use multiple urinary biomarkers to provide a more sensitive measure of THC exposure of children. A last unique contribution from Chapter 4 was use of a residualization approach leveraging the diversity of available measures related to in-home cannabis smoking to ascertain patterns and mean levels of household air particle concentrations uniquely associated with reported in-home cannabis smoking. This method developed novel variables that integrated objective air particle data and parent reported in-home cannabis smoking information. These new measures provide us with a more accurate and nuanced understanding of the relationship as well as allowing for more robust analysis through partitioning out the objective but not specific air particle data.

Finally, the results from Chapter 4 underline the need to reduce in-home cannabis smoking, especially in homes where children reside. Recalling results from Chapter 2 and 3, there is a need to change perception of harm related to cannabis smoke, as well as a need to investigate other key factors that may affect parental decision making on in-home cannabis smoking.

5.3. Limitations

There are a few limitations to note for Chapters 2, 3, and 4. Except for air particle, air nicotine, and urinary cannabinoid data in Chapter 4, most of the data used in all three chapters were self-reported, very likely resulting in under-reporting of some variables. Data for Chapters 2 and 3 were collected anonymously online and so reporting bias may be less of a concern. However, Chapter 4 data were collected through personal interviews before cannabis use was legalized, so report of in-home cannabis could be severely under-reported.

Limitations for all three chapters also included the cross-sectional study design, which precludes any causal inferences, as the information about the temporality of the associated variables is not available.

An important limitation of Chapter 3 was the nature of the GDS. The GDS is an online survey and may exclude those who cannot access the internet. The survey may also be susceptible to bots, but this has been curbed by excluding responses that report using a 'fake drug' ("phantazine"). The GDS also tends to recruit a convenience sample of younger, more educated, more involved drug-using respondents who predominantly identify as "white", making this sample non-representative of a general population and lacking in racial/ethnic diversity. The perception of harm variable was not carefully worded, and failed to make clear whether the harm to non-smoking residents was due to in-home cannabis smoking or to cSHS exposure. Lastly, a large proportion of the GDS sample resides in Germany, which may have led to estimates driven by German respondents. To reduce control for any such potential bias, random effect of country was adjusted for all analyses and country-specific results were also calculated.

Chapter 4 also had a few limitations. The PFA was a convenience sample from San Diego County, California largely consisting of low-income household with almost 50% being of Hispanic/Latino ethnicity. PFA inclusion criteria included requiring households to have at least one tobacco smoker living in the home. The sampled households were not representative of the general population, limiting the generalizability of the findings. Lastly, a limitation was the missing data in the survey, particularly for reported in-home cannabis smoking. This was mitigated through implementation of multiple imputation and ascertainment of in-home cannabis smoking through the residualization approach in the multiple imputed dataset to reduce bias.

5.4. Recommendations for Future Research

All three Chapters together tell a story of cSHS exposure and indicate that changing perception of harm of cSHS or cannabis smoke exposure may be a key factor in (i) encouraging setting household rules on in-home smoking, (ii) reducing in-home cannabis smoking, and (iii) through setting household rules and reducing in-home smoking reducing cSHS exposure of vulnerable populations, such as children.

Future research is needed to understand other modifiable factors that influence setting of household rules and in-home cannabis smoking behavior. Some of these factors may be the role of peers and social dynamics. Relating to perception of harm of cSHS exposure, additional research is needed to provide insights on how attitudes or perceptions related to cannabis are being challenged or re-enforced, Additional studies should be conducted with a focus on toxicants or carcinogens measured in urine or other biological samples among those exposure to cSHS, which would open the path in the search of long-term health effects of cSHS exposure. Additional research is also needed to understand the impact of changing regulatory environments on patterns of in-home cannabis smoking and the potential increases of cSHS and tobacco SHS exposure in children. While there are a few studies on the health effects of cannabis smoke exposure in children, there needs to be more research on the long-term effects of cSHS exposure—of children and of adults—to provide a comprehensive understanding of the risks associated with cSHS exposure.

Lastly, similar research on in-home cannabis vaping and perception of harm related to cannabis vaping exposure should be completed. Vaping is increasingly popular and may be likely to be used in-home or indoor venues because it is easy to disguise.

5.5. Concluding Remarks

This dissertation showed: (i) perceiving cSHS as harmful is associated with having a household ban on in-home cannabis smoking in the U.S., (ii) perceiving cSHS as harmful is associated with not having had in-home cannabis smoking in 21 countries, (iii) in-home cannabis smoking is associated with cannabis smoke exposure of children. This work provides important insights to inform advocacy surrounding reduction of cSHS exposure: it can be used to tailor educational campaigns, create effective messaging and develop strategies to effectively and accurately communicate the risks associated with cSHS exposure. By changing minds and behavior, harm related to cSHS exposure can be reduced.

Appendix A. Supplementary Materials to Chapter 3

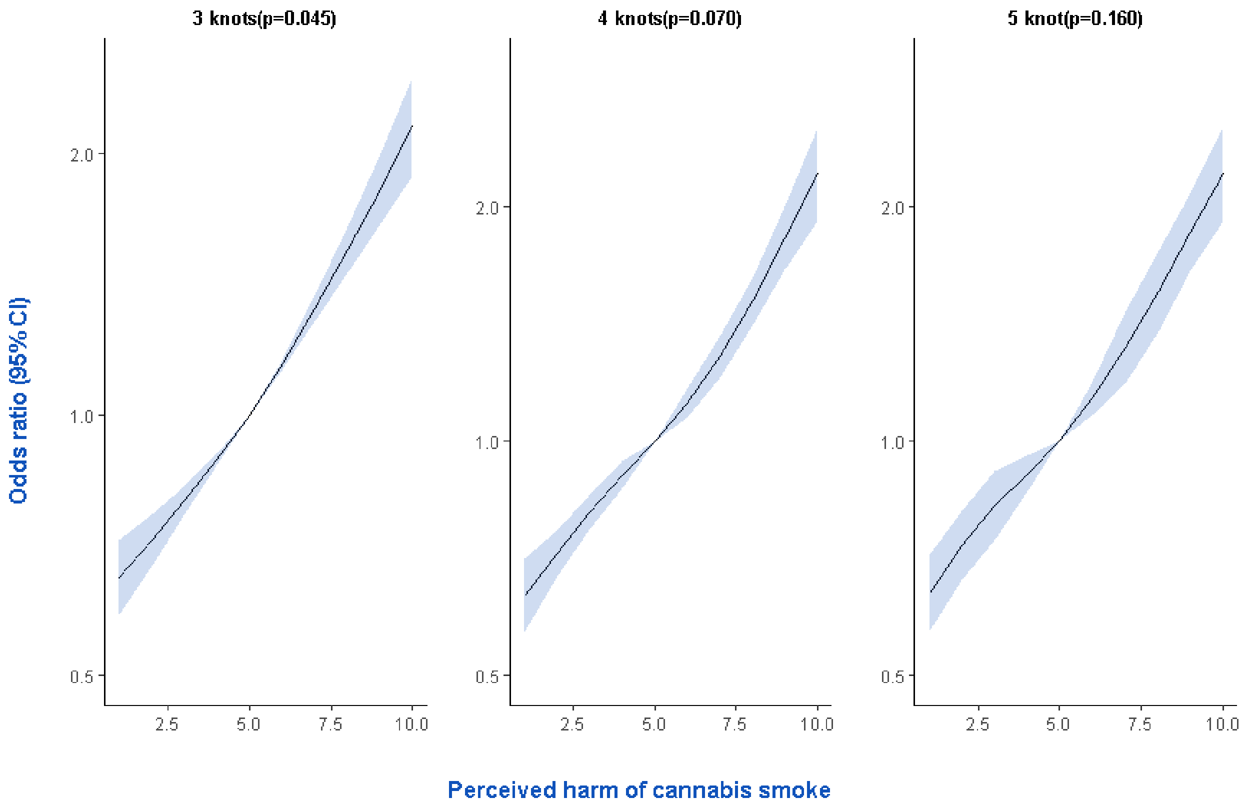

Figure A.1. Supplementary Figure 1. Restricted cubic spline regression between perceived harm of cannabis smoke and in-home cannabis smoking

Table A.1. Descriptive Statistics of Country of Residence by In-Home Cannabis Smoking and Logistic Regression for In-Home Cannabis Smoking in the Last 30 Day by 4 Unit Increment in Perception of Harm by Country of Residence (Reference: Yes, In-Home Cannabis Smoking in Last 30 Days)

Perception of harm (4 units)	n	% with no in-home cannabis smoking	OR (95% CI)	p-value
Recreational and medical cannabis use legal				
Canada	388	53.9	1.8 (1.2, 2.6)	<0.001
Mexico	510	27.6	2.0 (1.4, 3.0)	<0.001
Only medical cannabis use legal				
Australia	1501	60.0	2.0 (1.6, 2.4)	<0.001
Brazil	731	46.8	1.4 (1.0, 1.9)	<0.001
Denmark	814	54.8	1.3 (1.0, 1.7)	<0.001
Finland	756	61.9	1.7 (1.3, 2.1)	<0.001
Germany	10793	63.0	1.8 (1.7, 2.0)	<0.001
Ireland	825	60.8	1.6 (1.2, 2.0)	<0.001
Italy	162	58.0	1.3 (0.7, 2.7)	0.07
Netherlands	966	60.4	1.8 (1.4, 2.2)	<0.001
New Zealand	3164	78.4	2.3 (2.0, 2.7)	<0.001
Poland	173	53.2	1.7 (0.8, 3.7)	0.08
Sweden	181	76.8	3.9 (1.5, 11.9)	<0.001
Switzerland	966	42.7	1.6 (1.3, 2.0)	<0.001
United Kingdom	1196	62.1	1.5 (1.2, 1.9)	<0.001
Cannabis use not legal				<0.001
Austria	1190	52.8	1.4 (1.1, 1.8)	<0.001
Belgium	418	67.2	1.6 (1.1, 2.4)	<0.001
Hungary	1146	66.1	1.3 (1.0, 1.6)	<0.001
Romania	414	60.6	1.6 (1.1, 2.3)	<0.001
Spain	207	61.4	2.0 (1.1, 3.9)	<0.001
Australia	1501	60.0	2.0 (1.6, 2.4)	<0.001
Recreational and medical use legal	35	65.7	NA*	
Cannabis use not legal	1466	59.8	2.0 (1.6, 2.5)	<0.001
United States of America	1653	46.0	1.8 (1.5, 2.2)	<0.001
Recreational and medical use legal	668	47.0	1.8 (1.3, 2.4)	<0.001
Only medical use legal	578	44.5	2.4 (1.7, 3.4)	<0.001
Cannabis use not legal	407	46.7	1.3 (0.9, 2.0)	<0.001

Each country has been marked with cannabis use legalization status at time of survey. US and Australia respondents are divided into cannabis use law categories depending on the law of the U.S. state or Australian territory they resided in.

*Model did not converge due to small sample size

Table A.2. Descriptive Statistics of all Global Drug Survey 2021 Respondents Stratified by In-Home Cannabis Smoking in the Last 30 Days

Characteristics	Total (n=28154) n (%)	No, in-home cannabis smoking (n=17153) n (%)	Yes, in-home cannabis smoking (n=11001) n (%)
Perceived harm of cannabis smoke			
Mean (sd)	5.15 (2.9)	5.85 (2.9)	4.07 (2.5)
Median (range)	5.00 [1.00, 10.0]	6.00 [1.00, 10.0]	4.00 [1.00, 10.0]
1 (completely harmless)	3128 (11.1%)	1255 (7.3%)	1873 (17.0%)
2	3353 (11.9%)	1504 (8.8%)	1849 (16.8%)
3	3331 (11.8%)	1662 (9.7%)	1669 (15.2%)
4	2582 (9.2%)	1419 (8.3%)	1163 (10.6%)
5	3609 (12.8%)	2118 (12.3%)	1491 (13.6%)
6	2588 (9.2%)	1669 (9.7%)	919 (8.4%)
7	2632 (9.3%)	1836 (10.7%)	796 (7.2%)
8	2528 (9.0%)	1945 (11.3%)	583 (5.3%)
9	1293 (4.6%)	1076 (6.3%)	217 (2.0%)
10 (extremely harmful)	3110 (11.0%)	2669 (15.6%)	441 (4.0%)
Tobacco and cannabis co-use in last 30 days			
Cannabis only	3750 (13.3%)	1423 (8.3%)	2327 (21.2%)
Tobacco only	3828 (13.6%)	3317 (19.3%)	511 (4.6%)
Both tobacco and cannabis	9334 (33.2%)	1875 (10.9%)	7459 (67.8%)
Didn't use cannabis or tobacco	11242 (39.9%)	10538 (61.4%)	704 (6.4%)
Children 5 or younger living in residence			
No	25615 (91.0%)	15299 (89.2%)	10316 (93.8%)
Yes	2539 (9.0%)	1854 (10.8%)	685 (6.2%)
Reason for cannabis (THC) use in the past 12 months			
Have not used THC in past 12 months	12334 (43.8%)	11233 (65.5%)	1101 (10.0%)
Exclusively for recreational reasons	7924 (28.1%)	3235 (18.9%)	4689 (42.6%)
Mostly for recreational reasons	3171 (11.3%)	928 (5.4%)	2243 (20.4%)
Mostly for medical reasons	858 (3.0%)	307 (1.8%)	551 (5.0%)
Exclusively for medical reasons	107 (0.4%)	57 (0.3%)	50 (0.5%)
No reason provided for THC use	3760 (13.4%)	1393 (8.1%)	2367 (21.5%)
Cannabis Legalization in country/state of residence			
Recreational and medical use legal	1601 (5.7%)	687 (4.0%)	914 (8.3%)
Only medical use legal	22771 (80.9%)	14232 (83.0%)	8539 (77.6%)
Not legal	3782 (13.4%)	2234 (13.0%)	1548 (14.1%)
Age			
Mean (sd)	33.3 (12.8)	35.4 (13.5)	30.0 (10.8)
Median (range)	30.0 [16.0, 80.0]	33.0 [16.0, 80.0]	27.0 [16.0, 80.0]
Gender			
Women	9649 (34.3%)	6463 (37.7%)	3186 (29.0%)
Men	17541 (62.3%)	10213 (59.5%)	7328 (66.6%)
Non-binary/transgender/Intersex	964 (3.4%)	477 (2.8%)	487 (4.4%)
Education			
Less than highschool	2319 (8.2%)	1112 (6.5%)	1207 (11.0%)
High school	4435 (15.8%)	2443 (14.2%)	1992 (18.1%)
Trade or college certificate	7940 (28.2%)	4336 (25.3%)	3604 (32.8%)
Undergraduate or higher	13186 (46.8%)	9116 (53.1%)	4070 (37.0%)
Don't know	274 (1.0%)	146 (0.9%)	128 (1.2%)
Race/ethnicity			
White	25463 (90.4%)	15813 (92.2%)	9650 (87.7%)
Hispanic/Latino	1012 (3.6%)	597 (3.5%)	415 (3.8%)
Mixed race	675 (2.4%)	248 (1.4%)	427 (3.9%)
Other	1004 (3.6%)	495 (2.9%)	509 (4.6%)
Went clubbing in the last 12 months			
Never in past 12 months	15083 (53.6%)	10200 (59.5%)	4883 (44.4%)
Once every 3 months or less	10186 (36.2%)	5588 (32.6%)	4598 (41.8%)
1-2 times a month	2284 (8.1%)	1086 (6.3%)	1198 (10.9%)
One or more times a week	601 (2.1%)	279 (1.6%)	322 (2.9%)

Table A.2. Descriptive Statistics of all Global Drug Survey 2021 Respondents Stratified by In-Home Cannabis Smoking in the Last 30 Days (continued)

Characteristics	Total (n=28154) n (%)	No, in-home cannabis smoking (n=17153) n (%)	Yes, in-home cannabis smoking (n=11001) n (%)
MDMA use in last 12 months			
No	20863 (74.1%)	14128 (82.4%)	6735 (61.2%)
Yes	7291 (25.9%)	3025 (17.6%)	4266 (38.8%)
Cocaine use in last 12 months			
No	21691 (77.0%)	14479 (84.4%)	7212 (65.6%)
Yes	6463 (23.0%)	2674 (15.6%)	3789 (34.4%)
Amphetamines use in last 12 months			
No	22540 (80.1%)	14978 (87.3%)	7562 (68.7%)
Yes	5614 (19.9%)	2175 (12.7%)	3439 (31.3%)
LSD use in last 12 months			
No	23580 (83.8%)	15468 (90.2%)	8112 (73.7%)
Yes	4574 (16.2%)	1685 (9.8%)	2889 (26.3%)
Psilocybin use in last 12 months			
No	23845 (84.7%)	15541 (90.6%)	8304 (75.5%)
Yes	4309 (15.3%)	1612 (9.4%)	2697 (24.5%)

Appendix B. Supplementary Materials to Chapter 4

Table B.1. Models for Addressing Variance In Air Particle Data Due to Various Particle Generating Activities

Model	Relation expressed	Output	Action
Model A	*Number of daily PGEs (>= 15,000 counts/0.01ft^3 over 5 minutes)* = air nicotine + reported tobacco smoking + reported other indoor particle generating activities + reported ventilation activities during indoor particle generating activities	Residual(Model A) for each participant	Residual (Model A) - Residual(Model B) = Number of daily smoking events uniquely attributed to in-home cannabis smoking, for each participant
Model B	*Number of daily PGEs (>= 15,000 counts/0.01ft^3 over 5 minutes)* = air nicotine + reported indoor tobacco smoking + reported other indoor particle generating activities + reported ventilation activities during indoor particle generating activities + **reported in-home cannabis smoking**	Residual(Model B) for each participant	
Model C	*Geometric Mean Particle count* = air nicotine + reported tobacco smoking + reported other indoor particle generating activities + reported ventilation activities during indoor particle generating activities	Residual(Model C) for each participant	Residual(Model C) - Residual(Model D) = Mean particle count uniquely attributed to in-home cannabis smoking, for each participant
Model D	*Geometric Mean Particle count* = air nicotine + reported indoor tobacco smoking + reported other indoor particle generating activities + reported ventilation activities during indoor particle generating activities + **reported in-home cannabis smoking**	Residual(Model D) for each participant	

Table B.2. Descriptive Statistics for Reported Air Particle Generating Events; Project Fresh Air

	Baseline (n=275)	
Characteristics	n	%
Air nicotine (ug/m^3)		
mean (sd)	0.4 (1.6)	
median (range)	0.0 (0.0, 15.7)	
Missing	12	4.4%
HVAC use Impact Score		
mean (sd)	22.8 (67.0)	
median (range)	0.0 (0.0, 504.0)	
Air Purifier Use Impact Score		
mean (sd)	14.0 (64.0)	
median (range)	0.0 (0.0, 504.0)	
Exhaust Fan Use Impact Score		
mean (sd)	13.7 (50.1)	
median (range)	2.0 (0.0, 504.0)	
AC Use Impact Score		
mean (sd)	62.6 (141.9)	
median (range)	0.0 (0.0, 504.0)	
Burning Wood Impact Score		
mean (sd)	2.3 (12.0)	
median (range)	0.0 (0.0, 105.0)	
Gas Heater Use Impact Score		
mean (sd)	4.7 (23.0)	
median (range)	0.0 (0.0, 252.0)	
Number of times incense burned used in past 7 days		
mean (sd)	5.4 (17.0)	
median (range)	0.0 (0.0, 168.0)	
Number of times food burned used in past 7 days		
mean (sd)	1.6 (4.0)	
median (range)	0.0 (0.0, 30.0)	
Number of times oil fried in past 7 days		
mean (sd)	17.0 (24.4)	
median (range)	9.0 (0.0, 196.0)	
Number of times gas/propane appliance used in past 7 days		
mean (sd)	22.6 (30.2)	
median (range)	14.0 (0.0, 147.0)	
Number of times electric appliance used to cook/heat in past 7 days		
mean (sd)	44.6 (59.3)	
median (range)	28.0 (0.0, 700.0)	
Number of times aerosol spray products used in past 7 days		
mean (sd)	20.3 (58.0)	
median (range)	4.0 (0.0, 672.0)	

Table B.2. Descriptive Statistics for Reported Air Particle Generating Events; Project Fresh Air (continued)

Characteristics	n	Baseline (n=275) %
Number of times vacuumed/dusted/swept in past 7 days		
mean (sd)		17.8 (23.5)
median (range)		9.0 (0.0, 147.0)
Number of times do anything else that generates particles in past 7 days		
mean (sd)		4.9 (20.7)
median (range)		0.0 (0.0, 196.0)
Number of times do anything else that generates particles in past 7 days		
mean (sd)		2.3 (19.3)
median (range)		0.0 (0.0, 245.0)
Cigarettes smoked inside home in last 7 days		
No	192	69.8%
Yes	49	17.8%
Missing	34	12.4%
Cigar smoked inside home in last 7 days		
No	230	83.5%
Yes	11	4.0%
Missing	34	12.4%
Pipe tobacco smoked inside home in last 7 days		
No	238	86.5%
Yes	3	1.1%
Missing	34	12.4%
Hookah smoked inside home in last 7 days		
No	238	86.5%
Yes	3	1.1%
Missing	34	12.4%
e-cigarette smoked inside home in last 7 days		
No	203	73.8%
Yes	38	13.8%
Missing	34	12.4%
Did anyone open windows to room with cooking, cleaning, or smoking		
No	36	13.1%
1	36	13.1%
2	133	48.4%
3 (during all three activities)	70	25.4%
Missing	0	0.0%

Table B.2. Descriptive Statistics for Reported Air Particle Generating Events; Project Fresh Air (continued)

Characteristics	Baseline (n=275) n	%
Did anyone close interior doors to room with cooking, cleaning, or smoking		
No	133	48.3%
1	72	26.2%
2	53	19.3%
3 (all three activities)	17	6.2%
Missing	0	0.00%
Did anyone open exterior doors to room with cooking, cleaning, or smoking		
No	36	13.1%
1	35	12.7%
2	111	40.4%
3 (all three activities)	93	33.8%
Missing	0	0.0%
Did anyone use air purifier with a fan in the room with cooking, cleaning, or smoking		
No	257	93.5%
Yes	13	4.7%
Missing	5	1.8%
Did anyone use exhaust fan in the room with cooking, cleaning, or smoking		
No	113	41.0%
1	103	37.5%
2	44	16.0%
3 (all three activities)	15	5.5%
Missing	0	0.0%
Did anyone use a ceiling fan in the room with cooking, cleaning, or smoking		
No	103	37.5%
1	49	17.8%
2	93	33.8%
3 (all three activities)	30	10.9%
Missing	0	0.0%
Did anyone use a window fan or AC in the room with cooking, cleaning, or smoking		
No	218	79.3%
Yes	54	19.6%
Missing	3	1.1%
Did anyone use a central HVAC system in the room with cooking, cleaning, or smoking		
No	221	80.4%
Yes	49	17.8%
Missing	5	1.8%

Table B.3. Linear Regression for Total THC Equivalents among those with Detectable Urinary Cannabinoids (n=75) with Cannabis Biomarkers <LOD Treated as LOD/sqrt(2), and as Zero

	LOD/sqrt(2)		<LOD as zero	
	linear (log outcome)		linear (log outcome)	
	%	95% CI	%	95% CI
In-home cannabis smoking in past 7 days				
M1	77.5	-0.3, 215.8	91.2	-1.6, 271.4
M2	73.2	-3.9, 212.4	86.1	-5.2, 265.2
M3	82.4	-1.3, 237.3	97.3	-2.5, 299.1
Number of daily smoking events				
M1	6.3	2.1, 10.8	7.3	2.3, 12.4
M2	4.8	-0.1, 9.8	5.3	-0.3, 11.1
M3	4.6	-0.4, 9.8	5.2	-0.6, 11.2
Number of daily smoking events uniquely attributed to reported in-home cannabis smoking in past 7 days				
M1	19.7	-15.3, 69.1	22.4	-17.8, 82.2
M2	30.7	-8.5, 86.6	36.2	-9.3, 104.7
M3	34.2	-7.0, 93.6	40.1	-7.9, 113.3
Scaled Geometric Mean Particle count				
M1	60.7	23.8, 108.6	71.2	26.6, 131.3
M2	47.4	9.5, 98.3	52.9	8.7, 115.0
M3	47.0	7.3, 101.2	48.5	7.3, 105.5
Scaled Geometric Mean Particle count uniquely attributed to reported in-home cannabis smoking in past 7 days				
M1	15.8	-12.6, 53.4	17.89	-14.8, 63.0
M2	24.3	-7.0, 66.1	28.6	-7.7, 79.2
M3	27.0	-5.8, 71.2	31.6	-6.5, 85.3

M1: unadjusted
M2: M1 + demographic variables
M3: M2 + type of home

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