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# Occupational Exposure to Secondhand Cannabis Smoke Among Law Enforcement Officers Providing Security at Outdoor Concert Events

**Douglas M. Wiegand**[1], **Mark Methner**[1], **G. Reed Grimes**[1], **James Couch**[2], **Lanqing Wang**[3], **Li Zhang**[3], **Benjamin C. Blount**[3]

[1]CDC/NIOSH Division of Field Studies and Engineering

[2]CDC/NIOSH Division of Science Integration

[3]CDC/NCEH Division of Laboratory Sciences

## Abstract

**Background:** Numerous states have legalized cannabis for medical or non-medical (recreational) use. With the increased availability and use of cannabis, occupational and environmental exposure to secondhand cannabis smoke (SHCS) raises concerns over whether non-users may be at risk for a “contact high,” impaired neurocognitive function, harm from irritants and carcinogens in smoke, or potentially failing a cannabis screening test. The extent of health effects from potential occupational exposure to SHCS is unknown. While public consumption of cannabis is illegal in the state where we did our evaluation, law enforcement officers (LEOs) anecdotally reported increased cannabis use at concerts since legalization of non-medical use in private spaces. This is a study of occupational exposures to SHCS among LEOs providing security at outdoor concerts on a college campus.

**Methods:** Investigators evaluated a convenience sample of LEOs’ exposure to SHCS and symptoms experienced while providing security during two open-air stadium rock-n-roll concerts on consecutive days in July 2018. During each event, full-shift area and LEO personal air samples were collected for Δ9-tetrahydrocannabinol (Δ9-THC), the psychoactive component of cannabis. Urine (pre- and post-event; n = 58) and blood (post-event; n = 29) were also collected and analyzed for Δ9-THC and two of its metabolites [11-nor-delta-9-tetrahydrocannabinol-9-carboxylic acid (THC-COOH) and 11-nor-hydroxy-delta-9-tetrahydrocannabinol (OH-THC)]. Urine samples were analyzed using an ultrahigh performance liquid chromatography coupled with positive electrospray ionization tandem mass spectrometry and results were compared to the Department of Transportation guidelines for urine screening for cannabis. Blood (post-event) samples were also collected and the plasma fraction was tested for Δ9-THC, THC-COOH, and OH-THC using high performance liquid chromatography coupled with mass spectrometry. LEOs also completed a medical questionnaire asking about symptoms experienced during the concerts.

**Results:** Twenty-nine LEOs participated in the evaluation. Measurable amounts of Δ9-THC were found in area (concentrations ranged from non-detectable to 330 nanograms per cubic meter [ng/

m3]) and personal air samples (53 to 480 ng/$m^3$). Small amounts (< 1.0 ng/milliliter [mL]) of a Δ9-THC metabolite (THC-COOH) were found in the post-event urine of 34% of LEOs. Neither Δ9-THC nor its metabolites were detected in any blood sample. LEOs reported experiencing non-specific symptoms during the concerts, such as burning, itchy, or red eyes (31%); dry mouth (21%); headache (21%); and coughing (21%).

**Conclusions:** Identification of Δ9-THC in the breathing zone for some LEOs indicates the potential for airborne exposure to the psychoactive component of cannabis. However, the magnitude of these exposures was small. Similarly, THC-COOH was found in the post-event urine of some LEOs at concentrations that were orders of magnitude below active use cut-points used during a cannabis screening test (50 ng/mL). Exposure to SHCS was not high enough to detect concentrations of THC, THC-COOH, to OH-THC in the blood, which could be due to differences between the limits of detection for the tests employed. The ocular and respiratory symptoms reported by LEOs may be related to irritants in SHCS. However, the health effects of SHCS remain unclear, and further research concerning occupational and environmental exposures is warranted.

### Keywords

Cannabis; Marijuana; Secondhand Smoke; Airborne Exposure; Blood Test; Urine Test; Law Enforcement; Event Security; Open-air Concert; Tetrahydrocannabinol; Δ9-THC

## Introduction

The United States Drug Enforcement Administration's Controlled Substance Act designates cannabis as a Schedule 1 drug (DEA, 2019). Despite this federal designation, cannabis has been legalized at the state level by over 30 states for either medicinal only or medicinal and recreational use. Another 15 states have decriminalized possession of small amounts (the definition of which varies by state) of cannabis (Lopez, 2019), meaning that cannabis use in public would likely result in a ticket citation, as opposed to a criminal offense that would lead to an arrest and criminal record. The changing legal landscape and the increasing social acceptance of cannabis use (Pew Research Center, 2013) may lead to more open use of cannabis in both public and private spaces.

Although cannabis can be ingested and vaporized, inhaling smoke after combusting the plant's flowers is the most common method of consumption (Newmeyer et al., 2017; Schauer et al, 2014) and is the fastest biological uptake route of exposure for Δ9-tetrahydrocannabinol (Δ9-THC) and cannabidiol (CBD) (Grotenhermen, 2003). Smoking cannabis results in direct exposure to the smoker, as well as indirect or secondhand smoke exposure to others in the presence of the smoker. Secondhand smoke is defined as what a smoker exhales (mainstream smoke) along with the smoke from the burning product (sidestream smoke; ACS, 2019). The effects of secondhand smoke from tobacco are well documented (U.S. Surgeon General, 2014), but research on the effects of secondhand cannabis smoke (SHCS) is still being conducted. Cannabis and tobacco form many of the same toxins when burned (Moir et al., 2008), which can increase exposure (Wei et al., 2016) and lead to poor respiratory and cardiovascular health, as well as cancer and other negative health outcomes (CEPA, 2009; Cone et al., 2015a; Holitzki et al., 2017).

Exposure to SHCS has previously been assessed primarily using questionnaires. However, such data suffers from biased recall, differing sensory thresholds, and difficulties in quantifying responses. Exposure can be more accurately assessed by using selective biomarkers of exposure like urinary cannabinoids (Huestis et al., 2019). Recent improvements in analytical methods enable the sensitive and selective quantitation of Δ9-THC and its primary, long-lived metabolite (11-nor-delta-9-tetrahydrocannabinol-9-carboxylic acid; THC-COOH) (Wei et al., 2016) at the trace concentrations found in non-users with SHCS exposure (Wilson et al., 2017). A sensitive analytical method to quantify trace biomarker levels is therefore indispensable for effectively assessing SHCS exposure and attempting to link such exposures with health effects.

The pharmacokinetics of cannabis and its metabolites are complex, with Δ9-THC rapidly absorbed in the lungs and distributed throughout the body. Δ9-THC is readily absorbed in adipose tissue, the brain, the liver (metabolized to OH-THC and subsequently to THC-COOH), and the spleen [Mushoff and Madea 2006]. Δ9-THC is slowly released back into the blood, metabolized, and excreted. This resuspension coupled with THC-COOH's long half-life (approximately 140 hours) allow for Δ9-THC and metabolites to be dependably detected by routine workplace screening tests for approximately a 30-day period [Mushoff and Madea 2006]. However, the ability to detect Δ9-THC and its metabolites in blood or urine is dependent on the limits of detection for a specific testing methodology.

A number of studies have shown detectable amounts of cannabinoids in biological samples of non-cannabis smokers following exposure to SHCS (for a review, see Berthet et al., 2016). Perhaps the most frequently cited of these studies were conducted under ventilated and unventilated laboratory conditions (a specially designed 10 × 13 × 7 foot smoke exposure chamber) using cannabis strains of 5.3% to 11.3% Δ9-THC (Herrmann et al., 2015; Cone et al., 2015a, b). Non-cannabis smokers were seated in the chamber with cannabis users, who were provided with 10 cannabis cigarettes each and instructed to smoke as much and as often as desired for each of the one-hour sessions to simulate "extreme" conditions. This series of studies showed that SHCS exposure in extreme, unventilated conditions can produce detectable concentrations of Δ9-THC and THC-COOH in the blood and urine of non-cannabis smokers and can also have a statistically significant impact on post-session self-reported drug effect on non-cannabis smokers compared to baseline. Additionally, Cone et al. (2015a, b) reported that participants exposed to SHCS had considerable irritant symptoms, specifically eye irritation, during the evaluation.

While some studies have explored secondhand smoke exposure to workers (Trout et al., 1998; NIOSH 2009; Wei et al., 2016), this work has almost exclusively focused on tobacco smoke. Further work is needed to characterize occupational exposure to SHCS. In 2017, the National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation (HHE) request from the Environmental Health and Safety Office of a University in a state where cannabis is legal for both medical and recreational use. The request concerned possible exposure to SHCS among law enforcement officers (LEOs) providing security at large-scale, open-air stadium events.

The objectives of this study were to: measure the concentrations of SHCS in the stadium using area (environmental) and personal air and sampling methods; determine if exposure to SHCS results in Δ9-THC and its metabolites being present in LEOs' urine and/or blood; and describe health symptoms reported by LEOs after potential exposure to SHCS.

## Methods

### Study Setting and Participants

This study was conducted at a university football stadium during two rock-n-roll concerts, which were held on consecutive days in July 2018. The stadium was an open-air venue with a seating capacity of approximately 53,600. Because of the large size of the concert events, multiple law enforcement agencies joined forces to provide security, including the university police department, the city police, and the county sheriffs' offices. This was typical of large-scale events at the university. LEOs who participated in this study were assigned to patrol areas inside and around the stadium, and did so on foot, bicycles, and in small vehicles.

The staging area for LEOs during the concerts was an academic building directly across the street from the main gates of the stadium. Before each concert, the LEOs had a briefing meeting in a large classroom to discuss the night's activities and announcements. Study recruitment occurred in this classroom immediately following the briefing meetings. Each day, all LEOs providing security were invited to participate in the study. On the second day, LEOs were encouraged to participate if they either did not work on Day 1 or worked but did not participate in the study. No LEOs participated in the evaluation on both days. All of the law enforcement agencies have "zero tolerance" policies regarding LEO cannabis use, and therefore all LEOs were assumed to be non-cannabis users.

Once recruited, officers provided written informed consent and were given the opportunity to request their individual results. Urine samples (pre and postconcert) were collected in the lobby restroom in the academic building. Blood (postconcert) samples were collected in an enclosed area in the lobby of the academic building. This staging area was free from secondhand cannabis smoke.

### Personal Air Sampling

Personal air sampling pumps and air sampling media were attached to LEOs following their preshift briefing in the staging area. All Δ9-THC air samples were collected and analyzed using an internally-developed NIOSH contract laboratory method developed in accordance with International Organization for Standardization 17025 requirements. Each LEO's breathing zone air sample was collected on a 37-millimeter polytetrafluoroethylene filter cassette using a personal sampling pump operating at a flow rate of 3 liters per minute. Each sample was extracted using 2 milliliters (mL) of a solvent made of 80% acetonitrile and 20% water. Each sample was quantified using high-performance liquid chromatography and an ultraviolet light detector. Six field blank cassettes were handled, shipped, and analyzed along with all other samples for sampling and analysis quality control. None of the field blank samples contained Δ9-THC (limit of detection: < 50 nanograms [ng] per

field blank). We calculated the arithmetic mean for all samples for each concert day, using the minimum detectable concentration (MDC) of 40 /√2 to estimate non-detectable values (Hornung and Reed, 1990).

## Area Air Sampling

A stationary, full-shift area air sample was collected at each of the following locations during the concerts (each location had n = 2 area samples across the two concerts; each was set at approximately 4 feet from the ground): the right and left sides of the main stage; the sound stage located on the field level, in the center and approximately 180 feet in front of the main stage; and in the field house. The field house was an enclosed structure on the upper level of the west side of the stadium, adjacent to the plaza, used for vendor displays and food and beverage sales. The field house had garage-style doors at each end that were kept open to provide natural ventilation. Although the field house had a heating and cooling system for climate control, no mechanical ventilation occurred during the events.

## Urine Samples

Preconcert urine samples were collected following the LEOs preshift briefing, and postconcert urine was collected as the LEOs reported to the law enforcement staging area at the end of their shift.

Clean catch (method to prevent microbial contamination) spot urine samples were collected in sterile polypropylene specimen containers, and immediately transferred into 4 mL silanized glass vials. The vials were frozen on dry ice, stored at −70°C, and shipped to the National Center for Environmental Health's (NCEH) Tobacco Exposure Biomarkers Laboratory. Urine samples were subsequently analyzed using ultrahigh performance liquid chromatography coupled with positive electrospray ionization tandem mass spectrometry to measure the levels of Δ9-THC, and two Δ9-THC metabolites: THC-COOH and 11-nor-hydroxy-delta-9-tetrahydrocannabinol (OH-THC) (Wei et al., 2015). The limits of detection for these urine analyses were 0.005 ng per milliliter (ng/mL) for Δ9-THC, 0.015 ng/mL for THC-COOH, and 0.017 ng/mL for OH-THC.

Urine results were compared to standard workplace cannabis screening (50 ng/mL) and confirmation (15 ng/mL) thresholds. For standard workplace testing, the screening threshold uses an immunoassay method to identify a broad group of Δ9-THC, THC-COOH, and OH-THC. If a urine sample exceeds the screening threshold, it is re-analyzed using a gas chromatography-mass spectrometry test that specifically measures the level of THC-COOH (Swotinsky, 2015). These threshold values are the minimum concentrations that must be present in a urine specimen for it to be considered a positive result. Urine thresholds are used as markers of exposure and not as markers of health effects.

Urine specimens were also analyzed for creatinine, which is an indicator of the degree of urine dilution. All urine samples were creatinine-corrected to measure changes in urine concentration over the shift. The change of THC-COOH concentration measured in the urine from preconcert to postconcert was calculated to determine if THC-COOH levels changed. A Spearman's rank correlation statistic was calculated to determine the relationship of

THC in personal air sampling to postconcert creatinine-corrected THC-COOH. Statistical analyses were performed using SPSS version 18.

### Blood Samples

Blood was collected postconcert as the LEOs reported to the law enforcement staging area at the end of their shift. Each blood sample was drawn into a 6-mL lavender top ethylenediaminetetraacetic acid (EDTA) tube and centrifuged to separate the plasma from the other blood constituents. From each sample, 1.5 mL of plasma was removed and placed into a separate cryovial. These blood plasma samples were then frozen on dry ice and shipped to a laboratory (NMS Labs, Willow Grove, Pennsylvania) that used high performance liquid chromatography coupled with mass spectrometry to detect Δ9-THC, THC-COOH, and OH-THC. The limits of detection for the blood plasma analyses were 0.5 ng/mL for Δ9-THC, 5.0 ng/mL for THC-COOH, and 1.0 ng/mL for OH-THC.

Blood plasma results were compared to a threshold used by some law enforcement agencies during for cause (reasonable suspicion) drug testing, which is 5 ng/mL of Δ9-THC in the whole blood (Governors Highway Safety Association, no date). Similar to urine testing, blood results could not be compared to OELs because none exist. Like urine, blood thresholds are generally used as markers of firsthand exposure.

### Medical Questionnaire

LEOs completed a postconcert questionnaire asking about demographic information and whether (yes, no, or unsure) they experienced any symptoms or sensations consistent with cannabis intoxication during their work shift (APA, 2013; DEA, 2017; NIDA, 2018). The Fisher's exact test statistic was used to determine whether reported symptoms (yes/no) were associated with detectable amounts (yes/no) of THC-COOH in postconcert urine. These tests were two-tailed, and statistical significance was set at $P < 0.05$.

LEOs were asked, "On a scale from 0 (not at all) to 10 (very much), how would you rate your perception of experiencing a 'contact high' from exposure to secondhand cannabis smoke during tonight's concert?" Responses of 0–3 indicated a low perception of cannabis intoxication, 4–6 indicated a moderate perception of cannabis intoxication, and scores of 7 or greater indicated a high perception of cannabis intoxication. Logistic regression was performed to see if perceived cannabis intoxication was associated with a detectable level of THC-COOH in postconcert urine.

LEOs were also asked to rate their perceived level of SHCS exposure during the past 30 days (none, mild, moderate, or severe) and whether they lived with a cannabis user (yes/no).

## Results

### Study Participants

On the first day, 93 LEOs worked security, and 14 (15%) participated in the study. On the second day, 83 LEOs worked security, and 15 different LEOs (18%) participated. Our total sample size was 29 LEOs.

Most (86%) LEOs were male, with a median age of 39 years (range 23–64 years) and a median length of tenure in law enforcement of 10 years (n = 25; range < 1–41 years). Most LEOs were on duty from approximately 3:00 p.m.–11:30 p.m.

## Personal Air Sampling

Over two days, nineteen of 29 (66%) full-shift personal air samples had measurable amounts of Δ9-THC (Table 1). Ten samples were considered not detected (ND) because they were below the MDC of 40 nanograms per cubic meter (ng/$m^3$) of air. On Day 1, Δ9-THC concentrations ranged from ND to 330 ng/$m^3$, with an arithmetic mean of 125 ng/$m^3$ (n = 14; SD = 116 ng/$m^3$). On Day 2, concentrations ranged from ND to 290 ng/$m^3$, with an arithmetic mean of 104 ng/$m^3$ (n = 15; SD = 87 ng/$m^3$).

On Day 1, the highest concentrations were measured on LEOs who worked at the east stadium gates and on the field level. On Day 2, the highest concentrations of Δ9-THC were found on air samples from LEOs working in the plaza and the field house (220 to 290 ng/m3) as well as on the field level (140 ng/m3). The Δ9-THC concentrations for LEOs working at other locations, on both days, were below the MDC.

## Area Air Sampling

All area air sampling results showed measurable air concentrations of Δ9-THC. These ranged from 53 to 390 ng/$m^3$ on Day 1, with an arithmetic mean of 198 ng/$m^3$ (n = 4; SD = 142 ng/$m^3$). Day 2 ranged from 150 to 480 ng/$m^3$ on Day 2, with an arithmetic mean of 269 ng/$m^3$ (n = 4; SD = 144 ng/$m^3$). (Table 2). The sound stage had the highest area air concentration measured on Day 1 (390 ng/$m^3$), and the sample inside the field house had the highest (480 ng/$m^3$) on Day 2.

## Urine Samples

Fourteen LEOs participated in pre- and postconcert urine testing on Day 1 and 15 participated on Day 2, leading to a total of 58 urine samples. Δ9-THC or OH-THC were not detected in any of the 58 urine samples. However, small amounts of THC-COOH were detected in the urine of 10 of 29 (34%) LEOs. A summary of THC-COOH values (ng/mL) and the creatinine-corrected results (μg/g) are shown in Table 3. Detectable THC-COOH levels, all below 1.0 ng/mL, were detected in 15 of 58 (26%) urine samples from the 10 individuals with detectable levels. All THC-COOH levels were well below any screening (50 ng/mL) or confirmation (15 ng/mL) thresholds used for workplace drug testing. Levels of THC-COOH were detected in the urine more frequently in samples collected on Day 2 (14 of 15 detectable results from 9 LEOs) than on Day 1.

Nearly all LEOs (9 of 10; 90%) with detectable levels of THC-COOH in their urine had levels that increased across their work shift. These across-shift increases were small, ranging from < 0.01 to 0.082 μg/g of creatinine.

### Blood Samples

Fourteen LEOs participated in blood plasma testing on Day 1 and 15 on Day 2, leading to a total of 29 blood plasma samples. None of the samples contained detectable amounts of Δ9-THC, THC-COOH, or OH-THC.

### Medical Questionnaire

Twenty-nine questionnaires were completed and analyzed. Table 4 shows the frequency of responses to whether the LEOs perceived experiencing any symptoms or sensations of cannabis intoxication during their work shift. The most commonly reported symptoms were burning, itchy, or red eyes (n = 9; 31%); dry mouth (n = 6; 21%); headache (n = 6; 21%); and coughing due to lung irritation (n = 6; 21%). There were no statistically significant differences in the reporting of these symptoms between those with detectable and non-detectable THC-COOH concentrations in postconcert urine.

The average rating of perceived cannabis intoxication was 1.6 (range 0–9), indicating low perceptions by LEOs. On the basis of individual perceived cannabis intoxication ratings, 24 (83%) indicated a low level of perceived cannabis intoxication, 4 (14%) indicated a moderate level of perceived cannabis intoxication, and 1 (3%) indicated a high level of perceived cannabis intoxication. There were no statistically significant associations between perceived cannabis intoxication and detectable levels of THC-COOH in postconcert urine.

Concerning past potential exposure to SHCS, 19 (66%) LEOs reported no exposure to secondhand cannabis, and 10 (34%) reported mild exposure to SHCS in the past 30 days. No LEOs reported moderate or severe secondhand exposure in the past 30 days. One LEO reported living with a regular cannabis user.

### Trend Analysis

The air sampling and biological data were visually examined to determine whether any patterns emerged, but none were found. For example, there were instances where LEOs were working in areas where Δ9-THC was detected in the air, but the LEOs' blood plasma and urine results did not contain THC-COOH. Conversely, in stadium areas where Δ9-THC was not detected in the air, urine results from some LEOs showed detectable amounts of THC-COOH. A Spearman's rank correlation statistic that examined the relationship between postconcert THC-COOH levels and personal air sampling results (when Δ9-THC detected) was not statistically significant ($n = 7$; $\rho = 0.4$; $p = 0.4$).

## Discussion

To the authors' knowledge, this evaluation is the first to assess work exposures to Δ9-THC from SHCS for LEOs following efforts to legalize cannabis in the United States. This evaluation utilized an assessment of airborne exposures through area and personal breathing zone samples, coupled with measurements of biological uptake of Δ9-THC and resulting metabolites, and a survey of potential health effects that may result from a "contact high" associated with SHCS.

Evaluating work exposure to Δ9-THC and its metabolites is difficult due to the lack of occupational exposure limits (OELs) in the U.S. Establishment of OELs is particularly important for workers in cannabis production and processing, as these workers routinely interact with cannabis material, both in raw and processed forms. However, additional concerns exist for environmental exposures to Δ9-THC, as is seen in SHCS, and OELs could be utilized to prevent hazardous exposures during events with high intensity exposure. Continued research is necessary to establish OELs for Δ9-THC.

Our assessment of air exposures revealed higher concentrations of Δ9-THC in some areas of the stadium compared with other areas. Personal Δ9-THC air exposures of officers working around the east gates, the field house, and the field level areas were generally higher than those working in the vendor area, the main gate, bike patrol, backstage, and headquarters (a building located across the street from the stadium), among others. Concentrations of Δ9-THC in the air differed by locations with each day. These differences were likely multifactorial, and may be due to variations in the magnitude and direction of wind currents and also the amount of cannabis smoked in these areas.

Both area and personal Δ9-THC air sample results serve as indicators that the potential exists for exposure to Δ9-THC on the days sampled. Δ9-THC concentrations ranged from ND to 330 ng/$m^3$ for personal air sampling, while area samples ranged from 40 to 480 ng/$m^3$. Despite this seemingly low level of exposure among LEOs inside a venue such as the one studied here (open air), it appears prudent to assess other types of venues (e.g. indoor arena) where LEOs may work to determine if the potential for exposure is any different.

Potential exposures to Δ9-THC from SHCS not only exists for LEOs, but other professions that come in contact with combusted cannabis routinely. These professions include home healthcare, where aids enter homes where cannabis may be actively used for medicinal purposes, and in the cannabis production and processing industry, where heat may be applied to the raw plant and potential combustible products released into the air (Iglesia et al. 2018). Burning either tobacco or cannabis generates significant microgram quantities of harmful smoke chemicals such as the respiratory irritant acrolein or the carcinogen acrylonitrile (Moir et al. 2008). Secondhand exposure to tobacco smoke has been studied extensively, and is known to cause numerous adverse health effects (U. S. Surgeon General 2014). Similar duration and intensity of exposure to SHCS is likely to also increase risk to adverse health effects.

Combustion of cannabis not only leads to the release of Δ9-THC in the air, but results in the inhalation and biological uptake of Δ9-THC. Levels of Δ9-THC and subsequent metabolites can be quantified in the bodily fluids of exposed individuals, where research has shown the concentration of Δ9-THC smoked in the area is weakly related to the levels of metabolites found in the blood or urine (Cone et al., 2015a,b; Holitzki et al., 2017). The intensity of this relationship may be related to a number of factors, including the volume of air where cannabis is smoked, ventilation within the area of combustion, the amount of cannabis smoked, the number of smokers in the area, and individual differences, including metabolism (Holitzki et al., 2017). Our evaluation revealed that one metabolite, THC-COOH, was found in the urine of many LEOs. Though levels were quantified in

minute amounts, they were identified shortly after LEOs worked a shift with definable Δ9-THC concentrations in the air. The levels of urinary THC-COOH were all below 1.0 ng/mL, which is well below any routinely used workplace tests for screening or confirmation of use. Even in the context of a zero-tolerance workplace cannabis use policy, these levels would not be reported as a positive drug test indicating prior cannabis use. The concentrations of THC-COOH identified in our evaluation indicates that though exposure was present and Δ9-THC was metabolized as a result of this exposure, levels in this environment would not approach levels requiring action during workplace drug testing procedures. Additional data are needed to better characterize potentially harmful exposures to SHCS, especially in occupational settings.

A correlation between air sampling and biological data was not established during our evaluation. After inhalation of cannabis, Δ9-THC is detectable in the blood within 3–10 minutes after smoking, urinary OH-THC and THC-COOH can take hours or days to reach a peak [Mushoff and Madea 2006]. As Δ9-THC is metabolized to OH-THC and THC-COOH, it is distributed throughout the body and eliminated in the feces and urine. In the course of this evaluation, there were instances where officers were working in areas where Δ9-THC was detected in the air, but the officers' blood plasma and urine results did not contain the Δ9-THC, THC-COOH, or OH-THC. Conversely, in stadium areas where Δ9-THC was not detected in the air, urine results from some officers showed detectable amounts of this THC metabolite. This may be due to the low concentrations of Δ9-THC found in both the air, and metabolites identified in the urine. The quantities often approached the limit of detection, which could have resulted in low level of identification in one substrate where the limit of detection was substantially more sensitive, while simultaneously being not detected in the other.

Nearly all individuals (9 of 10) with detectable levels of THC-COOH in urine had creatinine-corrected levels that increased across the shift. Such a finding indicates that exposure was occurring during these concerts. Some LEOs (n = 5) that participated on Day 2 of this study had worked the concert the day before (but had not participated in the Day 1 study). Of these, three (60%) had detectable THC-COOH in their preconcert urine. These LEOs could have been exposed to SHCS on the first day that could have resulted in a detectable THC-COOH level in the urine on the second day (e.g., carryover effect). This may have contributed to the substantially larger number of LEOs having detectable levels of THC-COOH in the urine on Day 2 (9) than Day 1 (1), and is consistent with the half-life of THC-COOH in the urine [Mushoff and Madea 2006].

This evaluation was subject to several limitations. First was the inability to determine the exact time periods during the concerts that LEOs experienced exposure to Δ9-THC. Because Δ9-THC in the blood plasma is highest within minutes of an exposure while urine levels peak within hours of exposure, it is possible that an exposure early in the concert would decline in the plasma matrix, but would not result in sufficient metabolism of Δ9-THC to be detected in the urine [Mushoff and Madea 2006]. Second, 15%–18% of on-duty LEOs participated in this study. This limited participation and small sample size restricts how generalizable the findings are to the entire group of LEOs working at this or other similar events. Lastly, the questionnaire responses were based on self-report, which may

have been impacted by recall bias and/or a desire to give socially desirable responses, and the symptoms described were nonspecific and could be explained by other environmental conditions (e.g., tobacco smoke, allergens, etc).

## Conclusion

This study showed that LEOs were exposed to Δ9-THC in air during these open-venue concert venues, but the magnitude of these exposures was low. Similarly, very low levels of a metabolite of Δ9-THC, THC-COOH, was found in the urine of some LEOs. Given this scenario, coupled with the absence of OELs, drawing definitive conclusions about exposure and biomonitoring data are challenging. As one of the first studies examining occupational exposure to SHCS in a real-world setting, this area of research will need continued attention given the changing laws regarding cannabis consumption and potential for occupational and environmental exposures.

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**Table 1.**

Results of full-shift * personal air samples for Δ9-THC

| | Participant's work location | Concentration (ng/m$^3$) |
|---|---|---|
| Day 1 | East gates 2,5,6 | 300 |
| | East gates 2,5,6 | 180 |
| | East gates 7,8,9 | 240 |
| | Southwest gates 2,3 | [51] † |
| | Field level | 330 |
| | | 290 |
| | | [94] |
| | | [81] |
| | Plaza/Field house | ND ‡ |
| | | ND |
| | Roving outside stadium, in vendor area | [49] |
| | Roving west side of stadium | ND |
| | Bike patrol outside stadium | ND |
| | Directed operations (Headquarters building) | ND |
| Day 2 | Plaza/Field house | 220 |
| | | 250 |
| | Field level, gate 13 | 290 |
| | Field house, gate 6 | [120] |
| | Field house, gate 6 | [90] |
| | Field house, gate 6 | [64] |
| | Field level | [99] |
| | | 140 |
| | Roving east side of stadium, rooftop | [41] |
| | Roving field level, concourse | [92] |
| | Bike patrol outside stadium | ND |
| | East ramp behind stage (fixed location) | ND |
| | Backstage | ND |
| | Main entry gate | ND |
| | Directed operations (Headquarters building) | ND |
| Minimum detectable concentration (MDC) § | | 40 |
| Minimum quantifiable concentration (MQC) ¶ | | 140 |

* Sampling times ranged from 343 minutes to 501 minutes.

† Values in brackets were between the MDC and MQC. More uncertainty is associated with these values.

‡ ND = none detected, below the MDC of 40 ng/m$^3$.

§ The MDC was calculated by dividing the analytical limit of detection of 50 ng per sample by an average air sample volume of 1.25 m$^3$.

¶ The MQC was calculated by dividing the analytical limit of quantification of 170 ng per sample by an average air sample volume of 1.25 m$^3$.

**Table 2.**

Results of full-shift * area air samples for Δ9-THC, in ng/m$^3$

| Sample location | Concentration, Day 1 | Concentration, Day 2 |
|---|---|---|
| Main stage, left | 180 | 150 |
| Main stage, right | [53] † | 260 |
| Sound stage | 390 | 190 |
| Field house | 170 | 480 |
| Minimum detectable concentration (MDC) ‡ | 40 | |
| Minimum quantifiable concentration (MQC) § | 140 | |

* Sampling times ranged from 260 minutes to 397 minutes.

† Values in brackets were between the MDC and MQC. More uncertainty is associated with these values.

‡ The MDC was calculated by dividing the analytical limit of detection of 50 ng per sample by an average air sample volume of 1.25 m$^3$.

§ The MQC was calculated by dividing the analytical limit of quantification of 170 ng per sample by an average air sample volume of 1.25 m$^3$.

**Table 3.**

THC-COOH in urine samples, by day

| | THC-COOH concentration in ng/mL (range) | THC-COOH concentration in µg/g creatinine (range) | Percent detected (number)[#] |
|---|---|---|---|
| Day 1 (n = 28) | ND[*]–0.015 | ND[*]–0.019 | 3.5% (1) |
| Preconcert urine (n = 14) | ND | ND | 0% (0) |
| Postconcert urine (n = 14) | ND–0.015 | ND–0.019 | 7% (1) |
| Day 2 (n = 30) | ND–0.92 | ND–0.44 | 47% (14) |
| Preconcert urine (n = 15) | ND–0.92 | ND–0.44 | 33% (5) |
| Postconcert urine (n = 15) | ND–0.70 | ND–0.22 | 60% (9) |
| Total (n = 58) | ND–0.92 | ND–0.44 | 26% (15) |

[*]ND = not detected, below the limit of detection of 0.015 ng/mL.

[†]ND = not detected, below the limits of detection of 0.015 ng/mL for THC-COOH and 1.1 mg/deciliter for creatinine.

[#]Among the total urine samples represented in the Table row, the percent (number) in which THC-COOH was detected.

**Table 4.**

Self-reported symptoms and sensations associated with cannabis intoxication (n = 29)

| Symptom/Sensation* | % Yes (n) | % No (n) | % Not sure (n) |
|---|---|---|---|
| Burning, itchy, or red eyes | 31 (9) | 69 (20) | 0 (0) |
| Dry mouth† | 21 (6) | 76 (22) | 0 (0) |
| Headache† | 21 (6) | 75 (21) | 3 (1) |
| Coughing due to lung irritation | 21 (6) | 79 (23) | 0 (0) |
| Increased appetite | 14 (4) | 83 (24) | 3 (1) |
| Rapid heartbeat | 10 (3) | 86 (25) | 3 (1) |
| Euphoria or feeling “high” | 3 (1) | 93 (27) | 3 (1) |
| Anxiety | 3 (1) | 97 (28) | 0 (0) |
| Sensation of slowed time | 3 (1) | 97 (28) | 0 (0) |
| Lightheadedness | 3 (1) | 97 (28) | 0 (0) |

*We asked about additional symptoms/sensations, which were not reported by any LEOs. These included impaired coordination, impaired judgement, social withdrawal, altered senses, inappropriate or excessive laughter, feelings of superiority or invincibility, feeling “sluggish” or lazy, impaired short-term memory, difficulty with thinking and problem-solving, mood changes, paranoia, increased sociability, shallow breathing, cold or hot hands and/or feet, increased introspection or self-reflection, slurred speech, feeling a loss of control or panic, and confusion.

†n = 28