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Air monitoring at large public electronic cigarette events

Jona M. Johnson[a], Luke P. Naeher[a], Xiaozhong Yu[a], Stephen L. Rathbun[b], Jessica L. Muilenburg[c], Jia-Sheng Wang[a,*]

[a] Department of Environmental Health Science, College of Public Health, University of Georgia, 206 Environmental Health Science Building, Athens, GA, 30602, United States
[b] Department of Epidemiology and Biostatistics, College of Public Health, University of Georgia, 206 Miller Hall, Health Sciences Campus, Athens, GA, 30602, United States
[c] Department of Health Promotion and Behavior, College of Public Health, University of Georgia, 233 Wright Hall, Health Sciences Campus, Athens, GA, 30602, United States

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ABSTRACT

Background: Electronic cigarette (e-cigarette) conventions bring hundreds to thousands of e-cigarette users together socially regularly across the world. E-cigarette secondhand exposures to chemicals in this environment, likely the public setting with the highest concentration of e-cigarette secondhand aerosol, have not been characterized.

Methods: Air sampling for formaldehyde, acetaldehyde, acrolein, nicotine, and propylene glycol was conducted at three e-cigarette conventions and one smaller event from April 2016 to March 2017 in three states in the Southeastern United States. Volunteers attended the events as members of the public and wore backpacks containing air sampling pumps. Control sampling was conducted when venues were crowded for non-e-cigarette events. Additional control sampling was conducted in two venues when they were empty.

Results: Formaldehyde and acetaldehyde concentrations during e-cigarette events were comparable to background concentrations. The median formaldehyde concentrations during events, crowded control events, and empty control events were 12.0, 10.5, and 12.5 μg/m^3, respectively. The median acetaldehyde concentrations during events, crowded control events, and empty control events were 9.7, 15.5, and 3.5 μg/m^3, respectively. Propylene glycol and nicotine were not detected during control sampling. The median nicotine concentration during events was 1.1 μg/m^3. The median propylene glycol concentration during events was 305.5 μg/m^3.

Conclusion: Results indicate e-cigarette secondhand exposures are sources of elevated nicotine and propylene glycol exposures. Secondhand exposures to e-cigarettes did not contain consistently elevated concentrations of formaldehyde or acetaldehyde. Additional research is needed to characterize exposures via inhalation to propylene glycol at concentrations measured in this study.

1. Introduction

Electronic cigarettes (e-cigarettes) are electronic devices that deliver nicotine to a user in a manner similar to traditional cigarettes, but e-cigarettes do not burn tobacco (AIHA, 2014). E-cigarettes are rapidly increasing in popularity and are currently the most commonly used tobacco product among American youth (U.S. Department of Health and Human Services, 2016). E-cigarettes are often excluded from smoke-free laws and policies (Tobacco Control Legal Consortium, 2015).

Characterizing secondhand, or passive, e-cigarette exposures is an urgent public health priority. Passive exposures to traditional cigarettes expose bystanders to a mixture of smoke from the burning end of a cigarette and smoke exhaled by a cigarette smoker (Nelson, 2001). By contrast, e-cigarettes do not use a burning mechanism and do not produce such sidestream smoke. Passive exposures to e-cigarettes are restricted to the aerosols exhaled by the e-cigarette users and are not fully understood (Schripp et al., 2013; U.S. Department of Health and Human Services, 2016).

Research regarding secondhand e-cigarette exposures is inconsistent (Hess et al., 2016). Most studies agree nicotine, propylene glycol, and/or glycerin are present in e-cigarette aerosol. However, the available literature does not consistently report to what extent e-cigarettes produce volatile organic compounds (VOCs) (i.e. formaldehyde, acetaldehyde, and acrolein). If present in e-cigarette aerosol, these chemicals could cause adverse health effects in those exposed to secondhand

* Corresponding author.
E-mail addresses: jmogden@uga.edu (J.M. Johnson), lnaeher@uga.edu (L.P. Naeher), yuzx@uga.edu (X. Yu), rathbun@uga.edu (S.L. Rathbun), jlm@uga.edu (J.L. Muilenburg), jswang@uga.edu (J.-S. Wang).

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Table 1
Sampling Characteristics.

	Event 1	Event 2	Event 3	Event 4
E-Cigarette Event Details				
Location	Daytona Beach, Florida	Athens, Georgia	Chattanooga, Tennessee	Atlanta, Georgia
Date	April 2016	August 2016	October 2016	March 2017
Estimate number of attendees	1000	300	150	1500
Number of backpacks with air sampling pumps	5	7	6	4
Venue Characteristics				
Venue type	Convention	Concert	Convention	Exhibition/Tradeshow
Site (ft^2)	42,146	5100	36,000	205,000
Estimated Ceiling Height (ft)	45	35	30	13
Air Sampling[a]				
Sampling Day	Saturday	Friday	Sunday	Saturday and Sunday[b]
Sampling Hours	12:39–18:20	18:20–00:00	13:00–17:40	12:30–18:00 (Saturday) 11:30–1700 (Sunday)
Sampling duration (mean ± SD) (minutes)	313 ± 37	337 ± 8	279 ± 1	329 ± 2 (Saturday) 324 ± 16 (Sunday)
Empty Venue Control Sampling				
Sampling Month	April		December	
Sampling Day	Friday	N.A.[c]	Monday	N.A[c]
Sampling Hours	10:55–16:58		13:00–1730	
Sampling duration (mean ± SD) (minutes)	297 ± 58		262 ± 15	
Crowded Venue Control Sampling				
Estimate number of attendees	1000	800	500	1000
Sampling Month	April	October & February	December	March
Sampling Day	Saturday	Tuesday and Wednesday[d]	Sunday[e]	Saturday
Sampling Hours	12:32–18:33	19:13–22:50 (Tuesday) 19:30–22:30 (Wednesday)	12:00–17:00	12:00–17:40
Sampling duration (mean ± SD) (minutes)	355 ± 3	208 ± 11 (Tuesday) 179 ± 1 (Wednesday)	295 ± 8	333 ± 16

[a] Sampling times only reflect samples included in analysis.
[b] Sampling on Sunday was only for nicotine and propylene glycol.
[c] Not Available (N.A). – venue was not open to the public when venue was empty.
[d] Initial control sampling was on a Wednesday night. Formaldehyde and acetaldehyde control concentrations were abnormal. Researchers repeated sampling for these two chemicals on a Tuesday night.
[e] Sampling was conducted on the previous Saturday, but due to logistical difficulties, the length of the sampling was not sufficiently representative of the event. Therefore, sampling was repeated on Sunday.

e-cigarette aerosol. Formaldehyde and acetaldehyde are Group 1 (carcinogenic to humans) and Group 2 B (possibly carcinogenic to humans) carcinogens, respectively (IARC, 1999, 2006). Acrolein is a potent irritant and cardiopulmonary toxicant estimated to account for ~90% of the noncancer hazard index of tobacco smoke (ATSDR, 2007; Haussmann, 2012).

Secondhand exposures to VOCs, nicotine, and propylene glycol from e-cigarettes have been studied on a small scale (i.e. 1–10 e-cigarette users in a chamber or chamber-like environment) (Czogala et al., 2014; Long, 2014; Melstrom et al., 2017; Schober et al., 2014; Schripp et al., 2013), in a home (Ballbe et al., 2014), and using a smoking machine (Czogala et al., 2014; Geiss et al., 2015; Goniewicz et al., 2014; Kosmider et al., 2014; McAuley et al., 2012; Pellegrino et al., 2012; Schripp et al., 2013; Uchiyama et al., 2013). Research on e-cigarette secondhand exposures to these chemicals under real-use conditions in a public environment is limited.

This study aimed to characterize secondhand e-cigarette exposures in public e-cigarette conventions and events. E-cigarette conventions have been described previously as social events designed to bring together users, manufacturers, and sellers of e-cigarettes and e-cigarette accessories (Johnson et al., 2018; Williams, 2015). Hundreds to thousands of attendees come to the events and use e-cigarette devices. The thick haze of e-cigarette aerosol present inside e-cigarette events (Williams, 2015) indicate a large portion of attendees are active e-cigarette users during the events. In this study environmental samples of nicotine, propylene glycol, formaldehyde, acetaldehyde, and acrolein were collected at three e-cigarette conventions and a fourth similar but smaller event in three states across the Southeastern United States. Air sampling was conducted for a length of time representative of a work shift to simulate occupational exposures because concession workers at e-cigarette conventions and employees at e-cigarette stores/shops may have high exposures. Control sampling was also conducted on days with no e-cigarette exposures.

2. Methods

2.1. Study locations

The study was conducted at four separate e-cigarette events that occurred in Daytona Beach, Florida (Event 1), Athens, Georgia (Event 2), Chattanooga, Tennessee (Event 3), and Atlanta, Georgia (Event 4). Data collection occurred from April 2016 to March 2017. Event 1, 3, and 4 were e-cigarette conventions held in large, open venues. Event 1 and 4 had an estimated 1000–1500 attendees. Event 2 was a social gathering of an estimated 300 e-cigarette users in a concert venue. Event 3 was smaller and had an estimated 150 attendees. These events were chosen because they were within driving distance of The University of Georgia (UGA) in Athens, GA and researchers expected the events to draw a large crowd of e-cigarette users based on the events' social media presence.

2.2. Participant recruitment and selection

Study subjects were recruited from UGA students and staff or friends and family members of the researchers. All subjects gave written informed consent and completed a screening questionnaire to determine their eligibility. The UGA Institution Review Board reviewed and approved this study. Participating subjects could elect to wear backpacks containing 2–4 active air sampling pumps while attending the e-cigarette event.

2.3. Sampling methods

Air sampling was conducted at e-cigarette events using active air sampling pumps placed in backpacks worn by 21 volunteers across four events (one volunteer wore 2 backpacks). Volunteers were asked in an exit survey how they spent their time at the convention. Among volunteers that wore backpacks contain air sampling pumps, most (n = 12, 57%) sat in a designated seated area near the vendors for at least 75% of the time. Some volunteers took their backpack off but kept it near them when seated. A minority of volunteers (n = 6, 29%) visited vendor booths or stood in open vaping sections for at least 75% of the time. Three additional volunteers reportedly split the time equally between the two activities. Event characteristics, including the number of backpacks worn at each event, are provided in Table 1.

Sampling was conducted using 3 types of calibrated air sampling pumps (AirChek XR5000 & 2000, SKC Inc., Eighty Four, PA, USA; Escort Elf, Zefon International, Inc., Ocala, FL, USA). Tygon tubing connected the pumps inside the backpack to sorbent tubes affixed to backpack straps. Sorbent tubes were placed in or near the breathing zone of volunteers. All pumps were pre- and post-calibrated within 12 h of the event in the same city or neighboring city of the event. Event 1 pumps were turned on as soon as researchers entered the venue. This was logistically difficult, so Event 2–4 pumps were programmed with a delayed start (20–55 min after entrance time depending on the venue design) to allow for the time spent waiting in queues to enter the event venue. Escort Elf pumps could not be programmed and were manually operated for each event. On average, researchers sampled for approximately 5.3 h at each event (Table 1). The first event was open to the public for six hours. Sampling at later events was conducted for similar lengths of time for comparison.

2.3.1. Acrolein

Acrolein sampling was conducted at 100 mL/min in accordance with the Occupational Safety and Health Administration (OSHA) Method 52 using XAD-2 (2-hydroxymethyl Piperdine) sorbent tubes (SKC 226-118) (OSHA, 1985).

2.3.2. Nicotine

Nicotine sampling was conducted at 1000 mL/min in accordance with the National Institute for Occupational Safety and Health (NIOSH) Method 2551 using XAD-4 sorbent tubes (SKC 226-93) (NIOSH, 1998).

2.3.3. Formaldehyde and acetaldehyde

Formaldehyde and acetaldehyde sampling was conducted in accordance with EPA Compendium Method TO-11A (EPA, 1999) using Sep-Pak DNPH-silica plus short cartridges (Waters Corporation, WAT037500). Sampling was conducted at Event 1 at a flow rate of 800 mL/min for 120 min before sorbent tubes were replaced. Data from this event revealed larger air volumes could be collected without saturating a sorbent tube. The front and back of each sorbent tube were analyzed separately to verify no breakthrough occurred. Therefore, sampling was conducted at a flow rate of 800 mL/min on one sorbent tube per pump during remaining events. Sep-Pak Ozone Scrubbers (Waters Corporation, WAT054420) were included on the sampling chain after Event 1. These were added to prevent ozone concentrations from affecting formaldehyde concentrations.

2.3.4. Propylene glycol

Propylene glycol sampling was conducted in accordance with the NIOSH Method 5223 on XAD-7 OVS sorbent tubes (SKC 226-57) (NIOSH, 1996). This method recommends a maximum volume of 60 L. Event 1 samples were collected at 1000 mL/min for a total volume of 60 L before sorbent tubes were replaced. Event 1 data indicated larger volumes could be sampled without saturating the sorbent tube. Event 2 and 3 samples were collected at a flow rate of 800 mL/min using one sorbent tube per pump. Propylene glycol samples were collected at Event 4 at a flow rate of 1000 mL/min. A second-day sampling of the event was conducted at 800 mL/min.

2.4. Control sampling

For each event, control sampling was conducted in the venue to establish typical background concentrations of the chemicals. Sampling was conducted both when the venue was empty ("empty control sampling") and when a crowded, non-e-cigarette event occurred in the venue ("crowded control sampling").

Control sampling was conducted prior to the event in venues for Events 1 & 4 and after the event in venues for Events 2 & 3. Two venues (Event 1 & 3) were open to the public when the venue was empty. Pumps were placed in backpacks or bags worn on a shoulder during crowded control sampling or were stationary during empty control sampling. Shoulder bags were more appropriate than bookbags for two of the crowded control events (Event 2 & Event 4). Researchers were not allowed in the exact room where the convention was held when the rooms were empty but were allowed in neighboring corridors for times and durations reflective of the event (Table 1). Empty control sampling was not feasible for Events 2 and 4.

Crowded control sampling for Events 1, 3, and 4 was conducted on the same day of the week for similar durations (± 45 min) at similar times of the day as the e-cigarette event. Control sampling was conducted during two crowded concerts lasting three hours on a weeknight in the Event 2 venue.

2.5. Air sample analysis

Samples and field blanks were shipped overnight on ice (~5 °C) within one week to Veritas Laboratory in Novi, Michigan, USA for analysis. Nicotine samples were analyzed in accordance with NIOSH Method 2551 using gas chromatography with a nitrogen phosphorus detector (reporting limit [RL]: 0.1 μg/sample). In accordance with EPA Compendium Method TO-11A, formaldehyde and acetaldehyde samples were analyzed using high performance liquid chromatography (RLs: acetaldehyde, 0.5 μg/sample; formaldehyde, 0.1 μg/sample). Propylene glycol samples were analyzed in accordance with NIOSH Method 5523 using gas chromatography with a flame ionization detector (RL: 20 μg/sample). Acrolein samples were analyzed in accordance with OSHA Method 52 using gas chromatography and a nitrogen phosphorus detector (RL: 2.0 μg/sample).

2.6. Data analysis

Geometric means, medians, and ranges across events and control days were calculated for formaldehyde, acetaldehyde, nicotine, acrolein, and propylene glycol. OSHA recommends air pump pre- and post-calibrations have no more than 5% discrepancy (OSHA, 2014). This study includes formaldehyde/acetaldehyde data from 4 samples that exceed this range because data points from these pumps were the same or very similar to the data from pumps within recommended ranges. Exceptions are noted in Table 2. Data below the Bureau Veritas Laboratory RL is indicated by " < " followed by the RL concentration based on sample volume collected. One-half of the RL concentration for a chemical was used to calculate a geometric mean and median when the chemical was detected below the RL. All acrolein samples (n = 13, 6 at e-cigarette events) were below the RL (2.0 μg/sample) and are not presented here. SAS® University Edition. (SAS, 2015) and Microsoft Excel 2011 were used to make Tables 1 and 2.

3. Results

3.1. Venue characteristics

Secondhand e-cigarette exposures at four large e-cigarette events

Table 2
Sampling Results.

CHEMICAL	VALUE	LOCATION											
		EVENT 1 (FLORIDA)				EVENT 2 (GEORGIA)[a]		EVENT 3 (TENNESSEE)			EVENT 4 (GEORGIA)		
		Empty (control)	Crowd (control)	EVENT (individual samples)	EVENT (TWAs)	Crowd (control)[b]	EVENT	Empty (control)	Crowd (control)	EVENT[c,d]	Crowd (control)	EVENT[e]	OVERALL (events only)[f]
Nicotine	Geometric Mean (μg/m^3)			**0.81**	**0.81**		**1.4**					**1.8**	**0.79**
	Median (μg/m^3)			**0.85**	**0.85**		**1.5**					**1.9**	**1.1**
	Range (μg/m^3)	< 0.29	< 0.28	**0.65–0.95**	**0.65–0.95**	< 0.56	**1.1–1.5**	< 0.37	< 0.34– < 0.36	**< 0.36– < 0.37**	< 0.29– < 0.34	**1.3–2.2**	**< 0.36–2.2**
	Sample Size	1	3	**4**	**4**	1	**4**	2	2	**5**	2	**6**	**19**
Formaldehyde	Geometric Mean (μg/m^3)	10.9	11.0	**7.5**	**7.7**	10.5	**10.5**	16.1	9.0	**12.5**	31.5	**40.8**	**15.2**
	Median (μg/m^3)	11.0	11.0	**7.8**	**8.1**	10.5	**10.0**	16.5	9.1	**12.5**	33.5	**42.5**	**12.0**
	Range (μg/m^3)	9.9–12	10–12	**4.5–9.6**	**6.5–8.8**	10–11	**10–12**	13–20	9.0–9.1	**12–13**	22–45	**29–59**	**6.5–59**
	Sample Size	2	2	**9**	**3**	2	**4**	2	2	**2**	2	**4**	**13**
Acetaldehyde	Geometric Mean (μg/m^3)	2.0	12.0	**6.6**	**7.1**	29.0	**9.8**	4.1	4.6	**5.4**	18.5	**15.9**	**9.6**
	Median (μg/m^3)	2.1	12.0	**7.9**	**7.0**	29.0	**9.9**	4.2	4.6	**5.5**	18.5	**16.0**	**9.7**
	Range (μg/m^3)	< 2.7-2.9	11–13	**< 7.2–8.8**	**6.7–7.7**	29–29	**9.4–10**	4.1–4.2	4.3–4.9	**5.3–5.6**	18–19	**14–18**	**5.3–18**
	Sample Size	2	2	**9**	**3**	2	**4**	2	2	**2**	2	**4**	**13**
Propylene Glycol	Geometric Mean (μg/m^3)			**251.5**	**264.7**		**233.7**			**226.3**		**422.5**	**299.8**
	Median (μg/m^3)			**272.5**	**305.5**		**235.0**			**230.0**		**410.0**	**305.5**
	Range (μg/m^3)			**< 300–440**	**< 331.3–366.5**	< 140	**210–260**	< 91– < 92	< 84– < 85	**210–240**	< 73	**380–490**	**210–490**
	Sample Size	0	0	**14**	**3**	2	**2**	2	2	**3**	2	**5**	**13**

[a] Most Event 2 calibrations were performed on the same sorbent tubes used to sample at the event. Based on control concentrations from all other control sampling, this would have only impacted formaldehyde and acetaldehyde concentrations. To address possible formaldehyde and acetaldehyde contamination, an exercise tested how much contamination was added to the tubes when they under went pre/post calibration and traveled to and from the event location. Based on this exercise, an average 0.09 μg formaldehyde/sample (~2-times the typical background mass on formaldehyde field blanks used in this study) was added. This is within the acceptable background concentrations for DNPH sorbent tubes (< 0.15 μg). Acetaldehyde was not detected. Control and event results for formaldehyde in Table 2 have been blank corrected based on this exercise. This error resulted in only minor adjustments to the reported concentrations.

[b] Formaldehyde concentration of 11 μg/m^3 and acetaldehyde concentration of 29 μg/m^3 collected on pump with 5.46% pre/post calibration agreement.

[c] Formaldehyde concentration of 12 μg/m^3 and acetaldehyde concentration of 5.6 μg/m^3 collected on pump with 5.3% pre/post calibration agreement.

[d] Two formaldehyde and acetaldehyde tubes were not labeled & were matched volume sample:concentration by researchers.

[e] Formaldehyde concentration of 29 μg/m^3 and acetaldehyde concentration of 15 μg/m^3 collected on pump with 14.99% pre/post calibration agreement; formaldehyde concentration of 56 μg/m^3 and acetaldehyde concentration of 17 μg/m^3 collected on pump with 13.67% pre/post calibration.

[f] Event 1 TWAs used for these calculations.

(three e-cigarette conventions, one e-cigarette fundraiser concert) were studied in three Southeastern States in the United State from April 2016 to March 2017. Event attendance varied from approximately 150–1500 attendees (including vendors). We observed that most attendees and vendors used an e-cigarette during events.

Venues for Events 1 & 3 were modern buildings with high ceilings typical of a large convention center (~30–45 feet) and a noticeable air draft that indicated a highly functioning heating, ventilation, and air conditioning (HVAC) system. The Event 4 venue was a tradeshow with lower ceilings (~13 feet). The Event 2 venue was a small concert hall with 2 levels of balconies and a high ceiling (~35 feet). All venues had doors open during the events. Information about the event venues is provided in Table 1.

3.2. Air sampling

In total, samples collected included 19 for nicotine, 13 for formaldehyde, 13 for acetaldehyde, 6 for acrolein, and 13 for propylene glycol. Acrolein was not detected on any control or event sampling sorbent tube and this chemical is excluded from the analysis. Samples were excluded due to random pump failure, > 5% pre/post pumps calibration agreement (unless otherwise noted), and tubing malfunctions inside the backpack (n = 32). Results (geometric mean, median, range, and sample size) by chemical across sampling days, events, and overall are provided in Table 2.

3.2.1. Formaldehyde

Overall, formaldehyde concentrations at e-cigarette events were low and comparable to background concentrations. The median (25th, 75th, range) concentration of formaldehyde across all venues was 12.0 (10.0, 29.0, 6.5-59) μg/m^3 during e-cigarette events and 12.5 (11.0, 16.5, 9.9-20) μg/m^3 during empty control sampling, and 10.5 (9.6, 17.0, 9.0-45) μg/m^3 during crowded control sampling.

Formaldehyde concentrations in Event 1 measured during both control sampling days were higher than those measured at the e-cigarette event. Formaldehyde e-cigarette concentrations in Event 2 were similar to control concentrations. Event 3 formaldehyde concentrations were highest during empty control sampling, though the lower end of the range of control concentrations did include concentrations measured at the e-cigarette event. Event 4 formaldehyde concentrations measured during the e-cigarette event were higher than those measured during control sampling, though event concentrations did overlap with crowded control concentrations.

3.2.2. Acetaldehyde

Acetaldehyde concentrations tended to be higher during crowded control sampling than during empty control sampling or e-cigarette events. The median (25th, 75th, range) concentration was 9.7 (7.0, 14.0, 5.3–18) μg/m^3 during e-cigarette events, 15.5 (8.0, 24.0, 4.3–29) μg/m^3 during crowded control sampling, and 3.5 (2.1, 4.2, < 2.7–4.2) μg/m^3 during sampling when the venue was empty.

Acetaldehyde concentrations were higher during crowded control sampling than concentrations measured at e-cigarette events for Event 1 and 2. Only during Event 3 were acetaldehyde concentrations higher during the e-cigarette event than during crowded control sampling. Event 4 acetaldehyde concentrations measured during the crowded control sampling day were slightly higher than those collected at the e-cigarette event, though concentrations overlapped.

Empty control sampling concentrations are only available for two events. Event 1 and Event 3 empty control concentrations are both lower than the crowded control and e-cigarette event concentrations for these venues.

3.2.3. Propylene glycol

The median (25th, 75th, range) propylene glycol concentration across all e-cigarette events was 305.5 (230.0, 410.0, < LOD-490) μg/m^3. Propylene glycol was not detected during control sampling at any venue.

There was a large variation in the Event 1 propylene glycol concentrations [individual samples ≤ LOD–440 μg/m^3]. Weighted averages were calculated for the length of time air sampling was conducted on the pump (Time-Weighted Average ["TWA"]) were ≤LOD-366.5 μg/m^3. Five samples that comprised one TWA were below the limit of detection. The volunteer wearing the backpack containing the pump for these 5 samples was exposed to e-cigarette aerosol for the entire event.

3.2.4. Nicotine

The median (25th, 75th, range) nicotine concentration across all e-cigarette events was 1.1 (< 0.37, 1.8, < 0.36–2.2) μg/m^3. Nicotine was not detected during control sampling at any venue. Nicotine concentrations were below the limit of detection for all Event 3 samples (n = 5). Event 3 had the smallest crowd and the least amount of visible e-cigarette aerosol.

4. Discussion

A recent review concluded that secondhand e-cigarette aerosol may contain chemicals at concentrations that could impact the health of those exposed (Hess et al., 2016). Our study characterized secondhand e-cigarette exposures to formaldehyde, acetaldehyde, nicotine, acrolein, and propylene glycol using active air sampling methods in a natural e-cigarette environment with high levels of e-cigarette aerosol. Results in our study indicate formaldehyde and acetaldehyde concentrations during e-cigarette events are comparable to concentrations present when the venue is empty and during non-e-cigarette events in the venue. Low concentrations of nicotine and high concentrations of propylene glycol were present only during the e-cigarette events.

Acrolein was not detected during any control or event sampling period. This could be because the method was a low-flow method that allowed for only ~36 L of air to be sampled during the events. Other studies used additional methods in chamber environments and were also unable to detect acrolein in e-cigarette aerosol (Geiss et al., 2015; Kosmider et al., 2014; Schober et al., 2014).

It is proposed that e-cigarette devices oxidize propylene glycol and glycerol to produce formaldehyde, acetaldehyde, acrolein, glyoxal and methylgloxal during use (Ohta et al., 2011). Results of this study do not provide convincing evidence that secondhand e-cigarette aerosol produced by human subjects in a natural environment contains elevated levels of formaldehyde or acetaldehyde.

This study shows that acetaldehyde concentrations were generally the highest during crowded control sampling days. Crowded control sampling events typically had attendance similar to, if not larger than, the e-cigarette events. Humans reportedly exhale concentrations of acetaldehyde even higher than concentrations measured in this study (Turner et al., 2006), which could explain the observation.

This study was designed, in part, to characterize occupational exposures. Formaldehyde concentrations detected in this study were well below the United States Occupational Safety and Health Administration's (OSHA) regulatory occupational Permissible Exposure Limit (PEL) 8-h TWA of 0.75 ppm (0.92 mg/m^3) (OSHA, 1993). However, samples collected during both control sampling (Event 3 & 4) and an e-cigarette event (Event 4) were above the NIOSH Recommended Exposure Limit (REL) 8-h TWA of 0.016 ppm (19.65 μg/m^3) (NIOSH, 1988). The United States Environmental Protection Agency (USEPA) has not established a Reference Concentration (RfC) for formaldehyde (EPA, 1989). Reference Concentrations are estimates of the concentrations of chemicals to which members of the general population can be exposed continuously over a lifetime via inhalation without the exposures resulting in adverse health effects (EPA, 2002).

Acetaldehyde concentrations collected during both control sampling days and e-cigarette events are below the OSHA 8-h TWA PEL

(200 ppm, 360 mg/m^3) (OSHA, 1993). NIOSH has not established a REL for acetaldehyde. The US EPA established an RfC of 9.0 μg/m^3 for acetaldehyde (EPA, 1991a). This RfC was exceeded during both e-cigarette events and crowded control events.

Nicotine concentrations in e-cigarette aerosol reported in the literature are obtained using various study design parameters (i.e. different volumes of the sampling room or chamber, different voltages of e-cigarettes, different ventilation parameters, different quantity of e-cigarette users, etc.), but the reported nicotine concentrations tend to be similar to those reported here (range = < 0.01-7.00 μg/m^3) (Ballbe et al., 2014; Czogala et al., 2014; Geiss et al., 2015; Melstrom et al., 2017; Schober et al., 2014; Schripp et al., 2013).

All nicotine concentrations reported in this study are below the occupational OSHA PEL and NIOSH REL (0.5 mg/m^3, 8-h TWA) (NIOSH, 2016; OSHA, 1993). For comparison, Ballbe et al. (2014) reported airborne nicotine inside the homes of e-cigarette users was (GM ± Geometric standard deviation [GSD]) 0.13 ± 2.4 μg/m^3 (Ballbe et al., 2014). In the same study, airborne nicotine inside the homes of tobacco smokers was reportedly (GM ± GSD) 0.74 ± 4.05 μg/m^3.

Propylene glycol concentrations found in this study are similar to the results of studies that used human subject e-cigarette users. For example, propylene glycol concentrations reportedly ranged from 110.0–395.0 μg/m^3 in a chamber study using human subject users (Schober et al., 2014). Propylene glycol was not detected on five sorbent tubes during Event 1 of this study. It could be that the tubes were exchanged before an acceptable mass could accumulate (every 60 min). This is likely, given aerosol was visibly present the entire event. Schripp et al. (2013) also observed visible aerosol in the chamber study but was unable to detect propylene glycol after a short sampling period.

Occupational exposure guidelines are not available for propylene glycol. The Agency for Toxic Substances and Disease Registry (ATSDR) established a propylene glycol Minimal Risk Level (MRL), which is a level at which continuous exposure is not likely to cause harm (ATSDR, 1997). Most concentrations measured at e-cigarette events were above ATSDR intermediate MRL (established for > 14–364 days of exposure) for inhalation exposure of 9.0 ppb (28.01 μg/m^3). Though secondhand exposures to e-cigarette aerosol do not likely last 24-h for this period of time, the MRL does provide a number for comparison. The U.S. EPA has not established a RfC for propylene glycol (EPA, 1991b). Given that e-cigarettes are emerging and that exposures measured in this study are much higher than the intermediate MRL, further research is needed to determine if a new health guidance value is warranted.

Five chemicals were sampled and measured in this study, though other chemicals (i.e. metals and additional VOCs) have been detected in e-cigarette aerosol (Czogala et al., 2014; Geiss et al., 2015; Goniewicz et al., 2014; Kosmider et al., 2014; McAuley et al., 2012; Saffari et al., 2014; Schripp et al., 2013). Particulate matter in the form of supersaturated propylene glycol has also been reported to be elevated in e-cigarette environments (Schripp et al., 2013). A recent study at a small e-cigarette convention reports particulate matter concentrations were elevated and ranged from 31.68-818.88 μg/m^3 (Soule et al., 2017). Future studies in this environment should sample for a wider range of chemicals to more comprehensively characterize secondhand e-cigarette exposures.

This study used standard sampling methods that are most appropriate for the chemicals of concern. However, as Kosmider et al. (2014) highlighted, sorbent tubes are designed to capture chemicals only in the gas phase. The authors stated that chemicals present in the particle phase might not be fully captured by sorbent tubes. If so, this study may have underestimated the concentrations of chemicals present in e-cigarette environments.

Limitations of this study included a small sample size at four Southeastern e-cigarette events. Control concentrations were not collected on the day of the event. One must assume background concentrations were the same on both control and event days. Mixing of indoor and outdoor air likely occurred because all venues had doors open to outside. Outdoor air monitoring was not conducted and the contribution of contaminants from outdoor air is not characterized in this study. Ventilation flow rates were not accounted for in this study. Variations in ventilation flow rates across sample days and events could influence the concentrations of contaminants present in the venues.

5. Conclusion

This study is the first to sample for formaldehyde, acetaldehyde, nicotine, acrolein and propylene glycol in a public e-cigarette environment. The e-cigarette environment chosen likely had the highest concentration of e-cigarette secondhand aerosol present in a public venue. A strength of this study design is that it allowed us to sample secondhand e-cigarette aerosols produced by a variety of users and e-cigarette devices under real-use conditions. Formaldehyde and acetaldehyde concentrations during e-cigarette events were comparable with control concentrations for each venue. Results showed low levels of nicotine present. Propylene glycol concentrations were elevated. More research is needed to determine possible adverse health effects of the concentrations of propylene glycol found here. The results reported here are only for passive e-cigarette exposures. Research has demonstrated systematic retention of some e-cigarette aerosol chemicals (i.e nicotine, propylene glycol, and vegetable glycerin) in the body of the user (St Helen et al., 2016). E-cigarette users receive primary exposures to chemicals that are retained in the body and may not be detected in the exhaled aerosol.

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Conflict of interest

None.

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