Second-hand Effects of Electronic Cigarette Use

A Signature Honors Project on Electronic Cigarettes

By: Ronald (Trey) Mooring III and Sarah E. Fresquez

Faculty Mentor: Dr. Sinan Sousan

Abstract

Introduction: Electronic cigarette (ECIG) use is increasing in popularity among youth and puts both users and bystanders at risk of inhaling harmful substances. Two experiments were conducted to examine ECIG emissions, one being in the laboratory and the other in a field setting.

Methods: The laboratory experiment analyzed differences in emissions from the popular ECIG JUUL using a variety of puffing procedures. The selected puffing procedures were designed to simulate real-world use in which a JUUL user removes and reinserts the disposable pod between puffs. The field experiment consisted of participants vaping in their vehicles for 30-minute sessions. This provided discrete and real-time measurements of Particulate Matter (PM) mass concentrations for a passenger's secondhand exposure to the driver's ECIG use.

Results: Results of the laboratory experiment demonstrated how removing and reinserting the JUUL pod increases $PMM_{2.5}$ emissions. Mean real-time PM2.5 mass concentration was 65.06 $\mu g/m^3$ for experiment 1, 375.50 $\mu g/m^3$ for experiment 2, 501.94 $\mu g/m^3$ for experiment 3, and 834.69 $\mu g/m^3$ for experiment 4. Results of the field experiment demonstrated that across 41 sessions, the average $PM_{2.5}$ mass concentration was 214 $\mu g/m^{3,}$ and the average PM_1 mass concentration was 187.3 $\mu g/m^3$. The average $PM_{2.5}$ mass concentration is 45 times higher than the average of the 7 control experiments.

Discussion: The laboratory experiment emphasizes the major impact puffing protocols have on JUUL emissions. In every experiment, $PM_{2.5}$ emissions increased after the JUUL pod was inserted into the device. As a result, ECIG emissions should be evaluated using puffing protocols that take these real-world behaviors into account. Furthermore, the field experiment

demonstrates how engaging in ECIG use in vehicles exposes passengers to increased levels of PM_1 and $PM_{2.5}$ concentrations. This ultimately puts passengers at significant health risk.

Introduction

In 2018, electronic cigarette (ECIG) use among youths was declared an epidemic (EPA 2018). This advisory was declared to address the growing health problem we face as a nation. However, immediate action is needed because of the possible health effects that ECIG use has on the body. ECIG use is currently on the rise and since 2014, ECIGs have been widely used (T. W. Wang et al. 2020). This is concerning due to the lack of available knowledge surrounding the long-term effects of ECIG use.

According to the CDC, ECIG use exposes users to potentially harmful substances such as nicotine, cancer-causing chemicals, heavy metals, volatile organic compounds, and ultrafine particles (CDC 2021). These substances pose a risk to users because they are inhaled into the body. What is not absorbed into the user's body can then be exhaled and negatively affect the individuals located around them (bystanders). The categories of the negative health effects included systemic effects, nicotine poisoning, and mechanical injury, with the body systems most affected being the respiratory, gastrointestinal, cardiovascular, neurological, and immune (Hua and Talbot 2016). If users are exposed to such health risks, it can only be assumed that those bystanders inhaling secondhand aerosol also face similar health risks.

While most studies that revolve around ECIGs focus on the effects of firsthand exposure, there is another type of exposure that is often left. This is in reference to secondhand exposure. Secondhand exposure refers to a nonuser's exposure when an active ECIG user is near the vicinity. ECIG aerosol exhaled by an ECIG user still contains many harmful substances, such as nicotine, ultrafine particles, and cancer-causing agents (T. Wang et al. 2017). This puts a nonuser at risk of inhaling these substances, especially in confined spaces like passenger vehicles where the aerosols have limited dispersion. As a result, aerosol concentrations are higher in enclosed spaces than in an outdoor setting (Kulmala, Asmi, and Pirjola 1999).

These harmful substances are contained within the aerosol that the ECIG generates and the user inhales. Particulate Matter (PM) is defined as solid and liquid particles suspended in the air or a gas (Hinds 1999). Particle size is of great interest and indicates particle deposition in the lungs. Particles 1.0 µm (PM_1) and smaller and 2.5 µm ($PM_{2.5}$) and smaller are of interest due to their health effects. Prolonged exposure to $PM_{2.5}$ has been linked to cardiovascular disease and asthma (Kloog et al. 2013). Additionally, exposure to PM_1 poses significant health risk because their small size allows them to travel further through a person's respiratory tract and even translocate into the bloodstream (Zwozdziak et al. 2016).

ECIGs are electronic devices that produce an aerosol using an atomizer by heating a liquid. The aerosol is then inhaled and exhaled by the user to deposit the desired chemicals in the body. ECIG fluids were found to produce propylene glycol, glycerol, nicotine, and carbonyl aerosol (Geiss et al. 2015). While there are many different ECIG devices, the main components they share include a battery, a heating element (atomizer), and a liquid reservoir. ECIGs are often separated into three distinct types. These types include tanks and mods, rechargeable ECIGs, and disposable ECIGs (Health 2021). ECIGs that can be considered tanks and mods are often called box mods, while ECIGs that can be considered rechargeable are often called pod mods. Box mod ECIGs are a specific type of ECIG that are often characterized by their larger size, larger battery, and more customization for temperature and wattage control. Pod mod ECIGs operate by heating a replaceable or refillable liquid pod containing nicotine, flavorings, and other chemicals to produce an inhalable aerosol. Lastly, a disposable ECIG has a limited amount of liquid that cannot be replaced or refilled. The device is to be disposed of after the liquid is depleted.

For the 2021-2022 academic year, two experiments were performed. The first was conducted in a laboratory setting, and the second was conducted in field settings with participants in their vehicles. The laboratory experiment was performed to analyze the particulate matter concentrations from the popular ECIG JUUL and how their emissions are impacted by laboratory puffing procedures. Cigarette emissions are examined in laboratory settings using standardized puffing protocols; however, real-world human cigarette puffing behaviors do not necessarily reflect those of the controlled laboratory standards. Therefore, if cigarette emissions differ between the laboratory setting and real-world applications, then it is likely that ECIGs will follow suit. This is especially likely because ECIG-specific puffing protocols have not been established, meaning that studies conducted are based on protocols developed for standard cigarettes.

The JUUL device was chosen for this experiment because it has a chip designed to deliver a specific wattage once a pod has been attached to the battery. This wattage is designed to decrease steadily over time and directly correlates with the amount of nicotine that a "puff" from the device delivers (Smets et al. 2019). This means that users are expected to experience a decreasing nicotine concentration over time. To overcome this decrease in nicotine, research and internet forums describe how ECIG users are vaping by removing and reinserting the pod before taking each puff. This resets the chip designed to reduce the wattage, and the user experiences higher concentrations of nicotine and other chemicals with each puff. This laboratory experiment served to measure the particulate matter generated from a JUUL device using four different puffing procedures to better simulate real-world ECIG use and demonstrate their effects on ECIG emissions.

The objective of the second experiment, or the field experiment, was to quantify the secondhand exposure from ECIGs in passenger vehicles. This was accomplished using a combination of discrete and real-time measurements to determine the mass concentration of $PM_{2.5}$ and PM_1. Gravimetric analysis uses filters to quantify the exposure and perform discrete measurements. This method relies on a pump-based collection of airborne particles with a pre-weighed filter. This filter is then post-weighed and the collected particulate matter is determined by the subsequent mass difference (O'Connor et al. 2014). On the other hand, optical monitors capture real-time measurements based on sensing particle mass or inertia.

The field study was completed in vehicles with multiple aerosol collection devices set to analyze the air surrounding the relative breathing zone of a person sitting in the vehicle's passenger seat. This was done while a participant vaped off and on in the driver's seat for 30 minutes. The objective of the study was to quantify the secondhand exposure from ECIGs in passenger vehicles. The study was completed in vehicles with multiple aerosol collection devices set to analyze the air surrounding the relative breathing zone of a person sitting in the vehicle's passenger seat.

Methods

Laboratory Experiment

One component of the research conducted with ECIGs involved analyzing their exposure in a laboratory-controlled setting. This experiment quantified the $PM_{2.5}$ mass concentrations from the ECIG JUUL to determine how these emissions are impacted by laboratory puffing procedures. These experiments were performed to better capture behaviors that people engage in while using a JUUL that is not reflected in the current laboratory puffing procedures. The behavior analyzed in this experiment was the action of removing and reinserting the JUUL pod before taking a puff.

Real-time and Discrete Monitors

Real-time particulate matter mass concentrations generated from the JUUL device were measured using the pDR-1500 monitor (pDR 1500, Thermo Scientific, Franklin, MA, USA). The cut point of this device was set to 2.5 μm for each experiment using a cyclone, meaning that the device collected $PM_{2.5}$ mass concentration. Before the experiments, the pDR-1500 was calibrated to a flow rate of 1.52 L/min and zero-calibrated using particle-free air.

Equipment Set Up

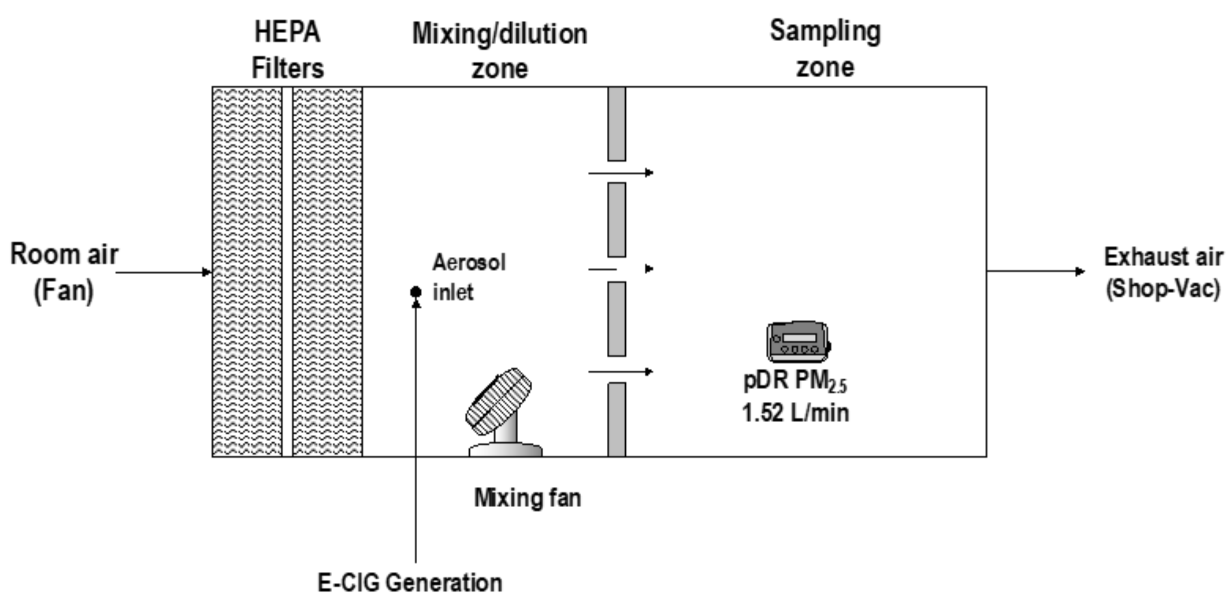

Figure 1 Experimental chamber used to measure ECIG exposure

The experimental setup of the 0.5 m^3 exposure chamber is shown in figure 1. The exposure chamber had two sections, the Mixing/dilution zone and the Sampling zone, which were divided by a honeycomb air straightening center. This separation ensured a homogenous mixture between when the aerosol generation occurred and when it reached the monitoring instruments. Each experiment was performed with particle-free air in the exposure chamber, no airflow, and operating mixing fans. Before each experiment, room air was pumped into the chamber with a flowrate of 1.00 m^3 /min and passed through two 99.99% HEPA filters to ensure that the chamber only consisted of particle-free air. The clean air then reached the mixing/dilution zone where the aerosol inlet was located. During the experiment and the aerosol generation, no airflow was to enter or exit the exposure chamber. The mixing fan distributed the aerosol through the chamber.

Aerosol Generation

For this experiment, aerosol was generated into a controlled exposure chamber from a JUUL using four different puffing procedures. These puffing procedures differed in the number of times the pod was removed and reinserted into the device. The aerosol from these four experiments was generated using a diaphragm pump (Thomas 1420-0504, Gardner Denver, Davidson, NC) and a clock generator (TFIS 12-240VUC 1CO CG, Weidmüller Interface GmbH & Co. K.G., Detmold, Germany) to emulate human puffing behavior. The diaphragm vacuum pump delivered aerosol from the ECIG device to the chamber in increments of time as the clock generator allows.

For each experiment, ten puffs were generated from a fully charged JUUL with a new JUUL pod. The diaphragm pump was calibrated to operate at 1.5 L/min flow rate. A 3 second puff ON protocol with a 27 second OFF interval was used. This totals 5 minutes of aerosol generation for each experiment and a total of four experimental puffing protocols. For Experiment 1, the pod was inserted into the device only before the first puff and all ten puffs were then generated. For Experiment 2, the pod was removed and reinserted between puffs five and six. For Experiment 3, the pod was removed and reinserted after puffs two, four, six, and eight. For Experiment 4, the pod was removed and reinserted after every puff.

Data Analysis

The data analysis for this experiment was calculated as the mean and median $PM_{2.5}$ mass concentrations. These values were calculated from the time that the first puff was generated until 60 seconds after the last puff was generated.

Field Experiment

Various aerosol collection devices were used to quantify the mass concentration of $PM_{2.5}$ and PM_1. These devices include the AirChek Touch Sample Pump, Mini-WRAS, pDR-1500, and the SidePak AM520. The devices sampled the air in the relative breathing zone of a person in the front passenger seat of a vehicle. This collection occurred while a participant vaped ON and OFF for 30 minutes.

Device Name	Cost ($)	Size range	Flowrate	Concentration Range (µg/m^3)	Number Concentration
AirChek Touch Sample Pump	5,000		1-5 L/min		
Mini-WRAS	30,000	10 nm-35 µm	1.21 L/min	0-100,000	Yes
pDR-1500	7,000	1.0-10 µm	1.0-3.5 L/min	0-400,000	No
SidePak AM520	5,000	0.1-10 µm	0-1.8 L/min	0-100,000)	No

Table 1: Aerosol measurement instruments specifications used in the current work

Real-time and Discrete Monitors

pDR-1500

The personal DataRAM Aerosol Monitor 1500 (pDR-1500) is a photometer created by Thermo Fisher Scientific Inc. (Franklin, MA, USA). This device provided real-time sampling for both $PM_{2.5}$ and PM_1 every second. Additionally, the device has integrated filter sampling that was used for gravimetric filter analysis. For each 30-minute session, a pDR-1500 was used and calibrated to measure PM2.5 concentrations (1.52 L/min). For some sessions, a second pDR-1500 was used to measure real-time PM1 concentrations (3.46 L/min). The devices were calibrated before each session using a zero filter, and a new pre-weighed 37-nm quartz filter (Binder-Free Quartz Depth Filters, SKC, 225-1827, USA) was used to capture the aerosol for gravimetric analysis. The filter type was quartz because the lack of carbon allows for post chemical analysis. Both devices were set to record at 1-second intervals.

SidePak AM520

The TSI SidePak AM520 (SN 5202114002, Shoreview, MN, USA) is a photometer that was selected because of its popularity among ECIG studies (Sousan et al. 2022). For this experiment, the device was set to monitor $PM_{2.5}$ mass concentration using an impactor. Before each session, the device was calibrated using a zero filter.

Mini-WRAS

The Mini-WRAS (Mini-WRAS1.371, GRIMM, Germany) is a portable wide-range aerosol spectrometer that provides real-time monitoring of micro-sized and nano particles. The device works by combining both optical and electrical detection methods. Particles 250 nm and less in diameter are analyzed using a Faraday cup electrometer. For particles greater than 250 nm in diameter, optical detection is used by measuring the scattered light intensity of the particle. The device was operated with a laptop and through the included Mini-WRAS_V10-0 software.

AirChek TOUCH Pump

The SKC AirChek TOUCH Pump (220-50000TC, Serial Number 23150, USA) was used to provide filter measurements of PM_1 for each session. The device works by pulling the air to be sampled through a filter cassette so that any present mass lands on the filter and can be measured through gravimetric analysis. Before each session, the device was calibrated to the correct flow rate using the SKC Chek-mate flow calibrator. The device flowrate was set at 1.81 L/min to measure PM_1.

37-nm quartz filters

Three 37-nm quartz filters were used for each session. One of the filters was used for PM_1, one for $PM_{2.5}$, and one was used as a blank. The "blank" filter was used to determine the relative effects of humidity for each session. Each filter was weighed three times before use under proper humidity conditions of 30% to 50% (Strand, Stolzenberg, and Andren 1978). The filters were weighed using the METTLER TOLEDO XPR26 DeltaRange© microbalance (Columbus, Ohio USA), and neutralized using an electrostatic electrode (11140161, METTLER TOLEDO, EN-C, Canada). The average of the three values was used, and the standard deviation was kept under 0.010. Quartz filters were selected because they contain no carbon. This is crucial so that the filters can be chemically analyzed. One downside of using quartz filters over other filters is that they are more susceptible to variations in water contents (Widziewicz-Rzońca and Tytła 2020). After each session, the filters were placed into a desiccator for 48 hours to remove water content from the filters. After the 48-hour window, the filters were post weighed three times. The average of these values was used, and the standard deviation was kept under 0.010. To help ensure proper weighing technique 10 mg and 100 mg standards were weighed along with the filters each weighing session.

Participant Information

For each session, information was taken from the participant. The participant's car type, ECIG type, and the number of ECIG puffs were recorded. Participants were required to be 18 years of age or older. They were required to use their personal vehicle and bring their own ECIGs. Participants were required to keep their vehicle doors and windows closed. The participants had the choice to keep the vehicle ON or OFF and whether they wanted to have the A/C or heat ON or OFF. For each session, a specific puffing protocol was used. The total time for vaping was 30 minutes for all sessions. For the first minute of the session, the participants were told not to vape. Then for the next five minutes, the participants were told to vape once every 30 seconds. There were no vaping restrictions for the remainder of the session, and the participants could choose to vape as much or as little as they wanted or stop vaping. The IRB approval for the vehicle study can be found in Apendix A.

Equipment Set Up

The experimental set up inside the vehicle is shown in Figure 2. The equipment for each session was set up similarly for each session. A PVC ladder was placed onto the front passenger seat of the participant's vehicle. The top rung of the lab had 5 tubes attached to it for the Mini-WRAS, pDRs, and the SidePak. These tubes ran from the top rung positioned in the relative breathing zone to the inlet port on each device. The Mini-WRAS and its accompanied laptop were set up in the back seat along with the pDRs. The SidePak and the AirChek pump (when used) were kept in the front seat. The blank filter was placed on the dashboard of the vehicle. Photos of the front and back seats of the participant's vehicle during a session are shown in Figure 2(b) and 2(c), respectively.

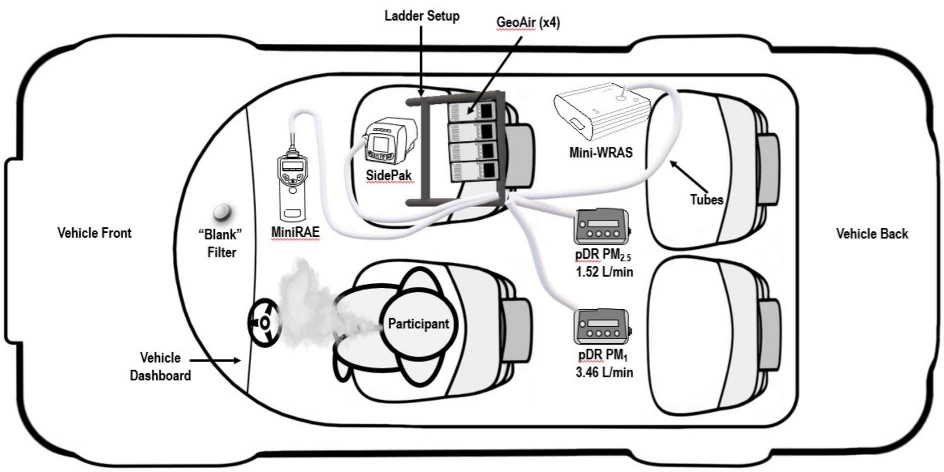

Figure 2(a) Vehicle Schematic displaying the aerosol monitoring equipment set-up

Figure 3(b) Front seat of the vehicle displaying the aerosol monitoring equipment set-up

Figure 2(c) Back seat of the vehicle displaying the aerosol monitoring equipment set-up

Data Analysis

After each session, the data was downloaded and tabulated accordingly. Using MATLAB_R2021b (version 9.11.0.1769968), the data was time-paired and tabulated to PM_1, and $PM_{2.5}$ files. The Mass concentration of PM_1 and $PM_{2.5}$ were determined from the filters by dividing the net mass gained by the flow rate of the device and the 30-minute run time. Using the time-paired files, mass concentration time series figures were constructed for $PM_{2.5}$ and PM_1. The data was then average for each monitoring instrument and organized by ECIG device type. These types are Box Mod (BM), Pod Mod (PD), and Disposable (DP).

Results and Discussion

Laboratory Experiment

The time series plots of the PM2.5 mass concentration for the four experiments are shown in Figure 3. For experiment 1, the mean real-time $PM_{2.5}$ mass concentration was 65.06 µg/m^3 (SD=99.53, Median=16.01 µg/m^3, Range=0-1222.00 µg/m^3). For experiment 2, the mean real-time PM2.5 mass concentration was 375.50 µg/m^3 (SD=346.45, Median=265.47 µg/m^3, Range=0-1478.20 µg/m^3). For experiment 3, the mean real-time $PM_{2.5}$ mass was concentration was 501.94 µg/m^3 (SD=450.00, Median=374.71 µg/m^3, Range=0-1780.00 µg/m^3). Lastly, for experiment 4, the mean real-time PM2.5 mass concentration was 834.69 µg/m^3 (SD=578.34, Median=725.34 µg/m^3, Range=0-2643.00 µg/m^3.

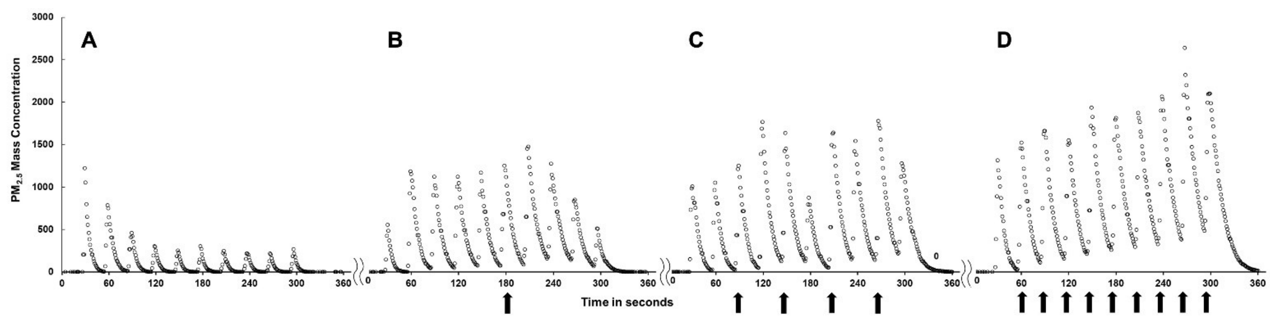

Figure 4 JUUL Device real-time $PM_{2.5}$ Mass Concentrations generated inside of a 0.5 m^3 exposure chamber for all four experiments

The average concentration in Figure 3 demonstrates that $PM_{2.5}$ concentration increased with each experiment. These results indicate that the mass concentration also increased with the number of times the pod was removed and reinserted. In addition, the data indicate that the concentration varied greatly, despite the consistent 10 puffs generated for each experiment. In all of the experiments, $PM_{2.5}$ concentrations increased after a JUUL pod was inserted into the device. Ten puffs from a JUUL in which the pod was removed and reinserted after each puff resulted in mean $PM_{2.5}$ concentrations that were 13 times higher than when ten puffs were generated without removing the pod. While not every JUUL user engages in the act of removing and reinserting their pod to purposely increase the wattage. It is clear that there are some users who do engage in this puffing behavior, and it needs to be accounted for when examining emissions. This experiment demonstrates how some JUUL users are engaging in behaviors that increase both their and bystanders' exposures to nicotine and other harmful toxicants.

This study represents the major impact puffing protocols have on emission results. Another study conducted by Son et al, also evaluated the emission impacts of human use patterns, device settings, and flavorings. This study differs in the fact that they focused specifically on carbonyl emissions under real-world vaping conditions. Results indicated how ECIGs carbonyl emissions were highest under higher power outputs, certain liquid flavorings, and puff volume. With this, it was concluded that public health administrations need to "consider the vaping conditions which generated higher carbonyls, such as higher power output with PG e-liquid, when developing ECIG product standards" (Son et al. 2020). This demonstrates another example as to how real-world vaping conditions differ from laboratory control standards.

<u>Field Experiment</u>

Throughout two semesters, a total of 41 experimental and 7 control sessions were conducted. For each session, PM_1 and $PM_{2.5}$ real-time data were collected and shown below for the Mini-WRAS, pDR, and SidePak. The names of the various ECIGs used and the number of sessions are shown in Table 2.

ECIG Name	Number of Sessions
Control	7
Hyde Edge	11
Kang Onee Stick (KOS)	10
Vuse Alto	6
Esco Bar	3
Geek Vape	2
JUUL	2
Novo 3	2
Box Air Bar	1
Elf Bar	1
Frozen Monster Bar (FMB)	1
Nord X	1
Novo 2	1

Table 2 Name of ECIG used and how many sessions it was used for

PM_1 Mass Concentration

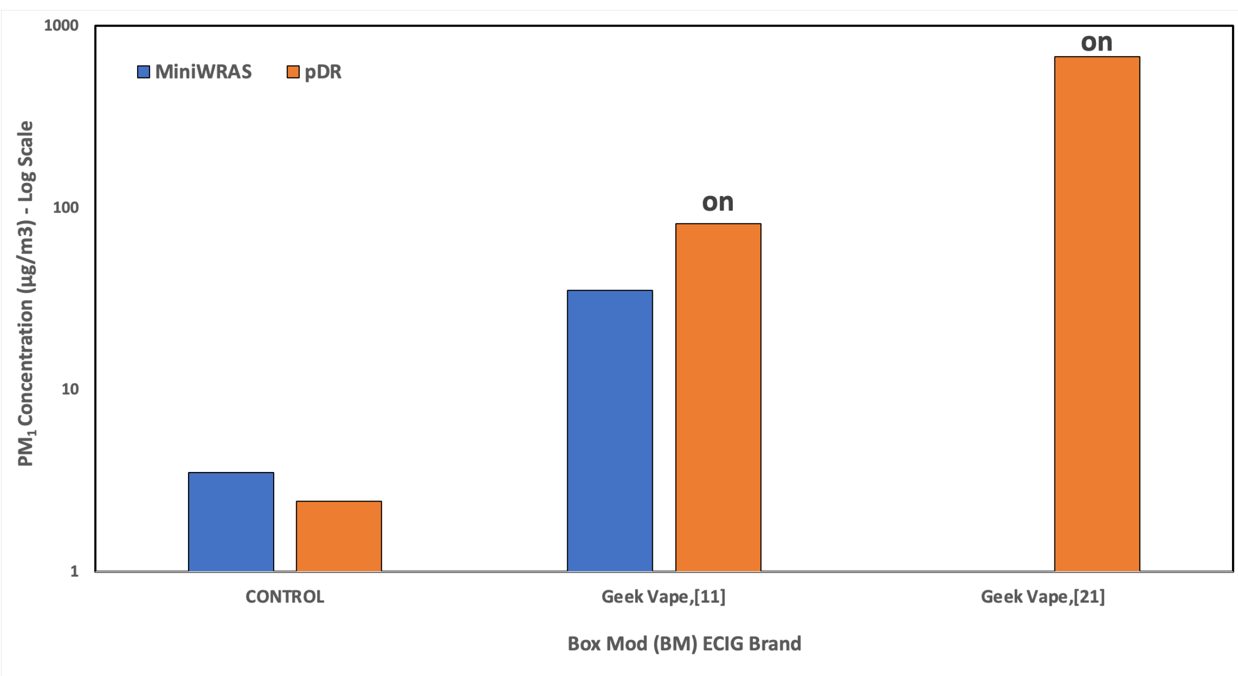

Figure 5(a)

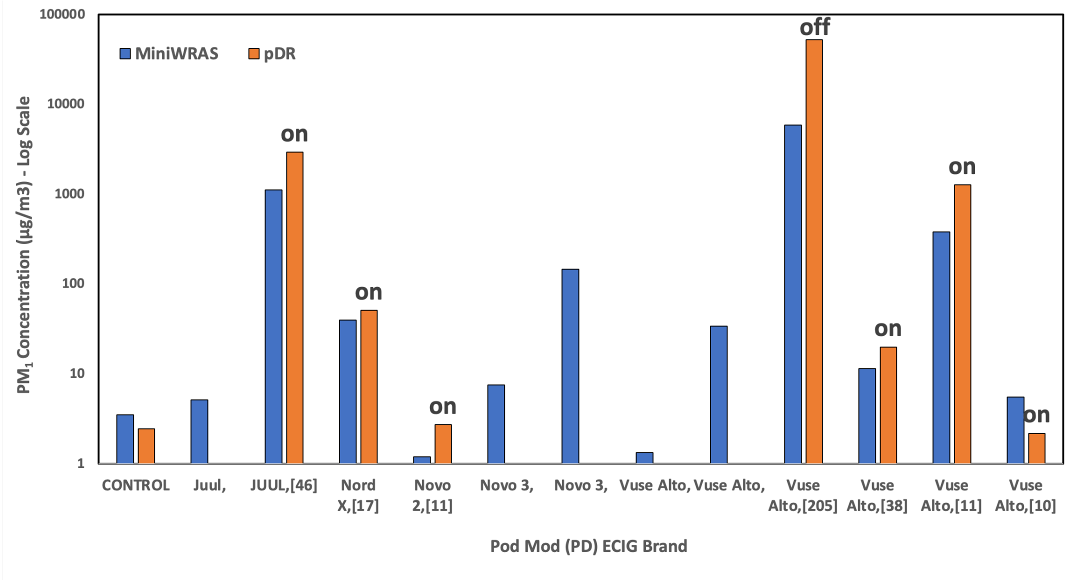

Figure 5(b)

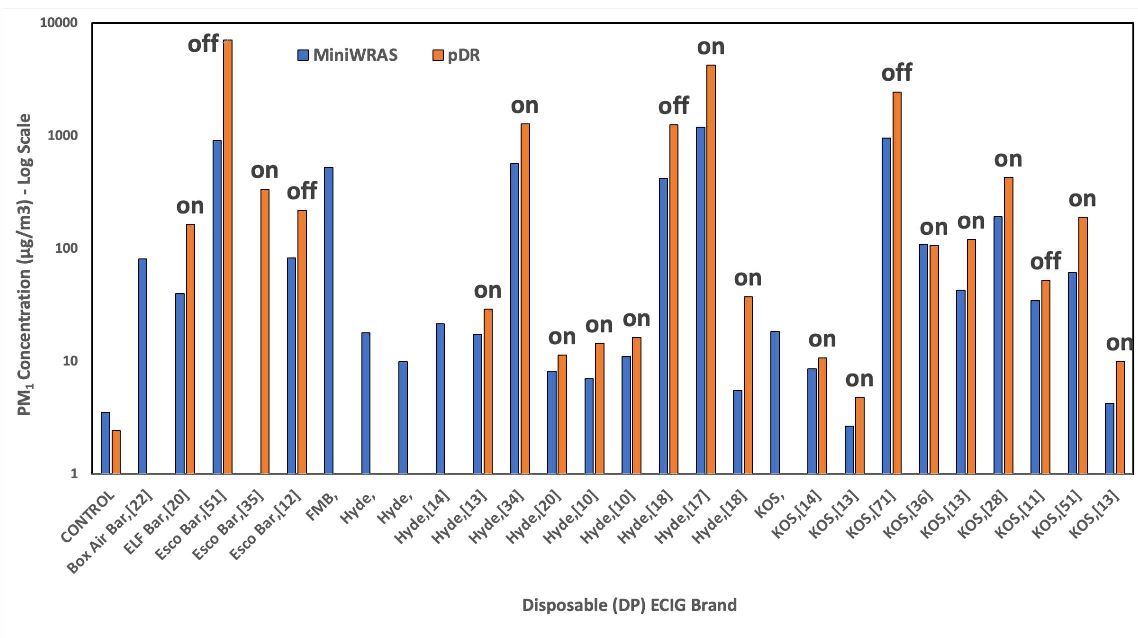

Figure 5(c)

Figure 5: The average PM_1 mass concentration for a) Box Mod, b) Pod Mod, and c) disposable for different ECIG devices. The x-axis represents each individual session and displays the ECIG used and the number of puffs, if available, in brackets. Above each session, if available, lies the on/off status of the vehicle. The y-axis represents a log scale due to the high variance in concentration.

Box Mod (BM)

Based on all the scheduled sessions, only two participants used BM devices. The PM_1 average mass concentrations from these sessions are displayed in Figure 5(a). Both devices were Geek Vapes, where one participant vaped 11 puffs and the other 21 puffs. The session with 21 puffs only recorded mass concentrations with the pDR, which gave a PM_1 mass concentration value higher than the session with 11 puffs. Both sessions were operated with the vehicle turned on, so the devices were used in similar conditions and produced expected results of increasing mass concentrations in response to an increase in puffs. The average of the pDR data from the BM sessions was 155 times higher than that of the controls. Compared to the control session average, the BM session's Mini-WRAS produced results that were 10 times higher.

Pod Mod (PD)

Out of the scheduled participant sessions, twelve participants used PD devices. The PM_1 mass concentrations from these sessions are displayed in Figure 5(b). The PD device reporting the highest PM_1 mass concentration was the Vuse Alto session, with 205 puffs. The device reporting the second highest PM_1 mass concentration was the JUUL, in which the user took 46 puffs. The minimum reported PM_1 mass concentration value was from the Novo 2 device with 11 puffs. In every session where the pDR-1500 was used, the concentration reported was higher than the Mini-WRAS. The average of the PD sessions produced a pDR average of 409 and a Mini-WRAS average of 8 times as high as the controls.

The Vuse Alto mass concentrations have a high variance between the different numbers of puffs. This variance in results is likely due to differences in the participant's air conditioning.

With different air circulation, it is possible the measuring devices were limited in what aerosol generation was captured.

Disposable (DP)

Out of the scheduled participant sessions, twenty-seven used DP devices. The PM_1 mass concentrations from these sessions are displayed in Figure 5(c). The DP device reporting the highest PM_1 mass concentration was the Esco Bar session with 51 puffs. The lowest average was the first KOS session with 13 puffs. In every session, the pDR-1500 recorded a higher concentration than the Mini-WRAS. Similar to the PM sessions, in every session where the pDR-1500 was used, the reported concertation was higher than the Mini-WRAS. The average pDR session produced results 286 times higher than the control session average. The Mini-WRAS resulted in a vehicle session average 58 times higher than the control.

The Esco Bar device sessions showed PM_1 mass concentrations that generally increased with the number of puffs produced, likely because the vehicles were turned off. The Hyde and KOS sessions showed great variance between the number of puffs and the resulting PM_1 mass concentration. The differences may be attributed to the vehicle air conditioning or the puffing behaviors of the participants.

Between the device types, the BM produced PM_1 mass concentrations that were not significantly different than the results of PD and DP devices. A study conducted by Sousan et al. (2022) examined PM_1 mass concentrations in a chamber setting with 30-minute sessions and no airflow. In this study, the BM device VooPoo Drag 2 produced higher mass concentrations than the JUUL and Hyde devices studied. While the VooPoo Drag 2 was not used in the field study, the findings that BM devices produced the highest average mass concentrations were expected but not reflected by field study results. This may be attributed to the fact in both BM sessions, the participant's vehicle was on. With the vehicle engine on, air could have been recirculating throughout the vehicle. This is unlike the chamber experiments where no air was circulating. In the Sousan et al. study, the JUUL device produced the lowest mass concentrations for all PM sizes while the Hyde varied. The field study's Hyde devices produced concentrations that nearly matched the JUUL 46-puff session, but in fewer puff counts. In both studies, the BM devices with higher wattages produced higher mass concentrations than their lower wattage counterparts.

$PM_{2.5}$ Mass Concentration

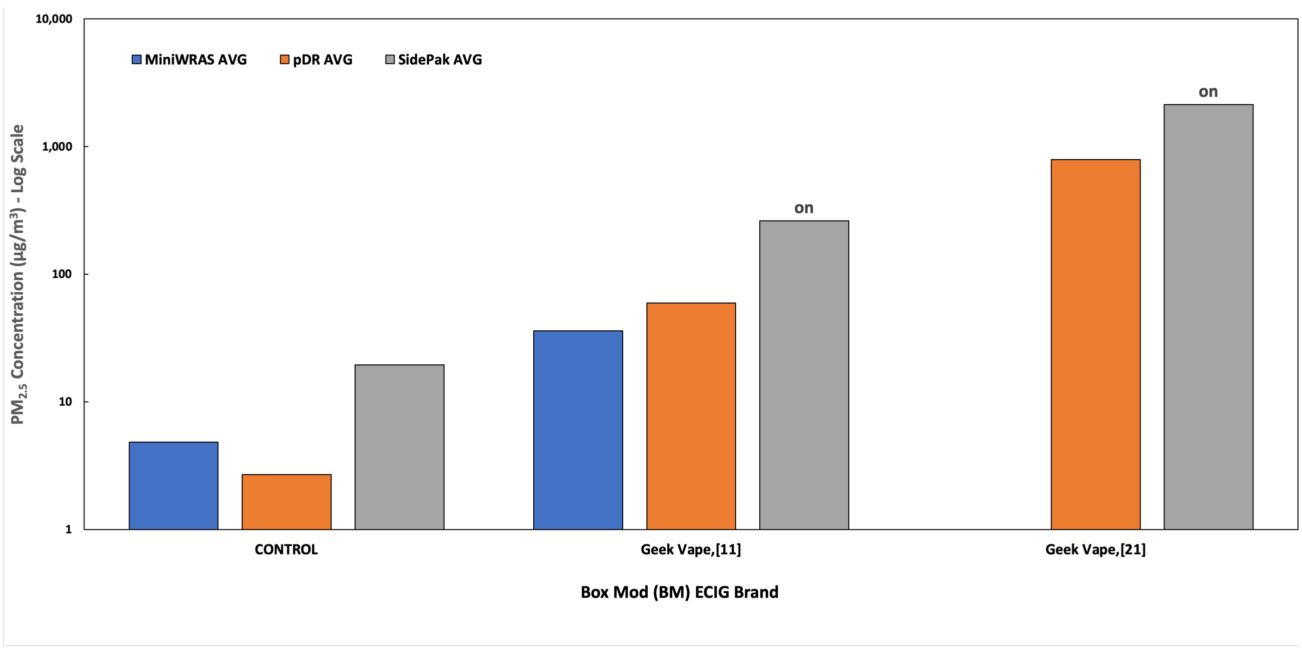

Figure 6(a)

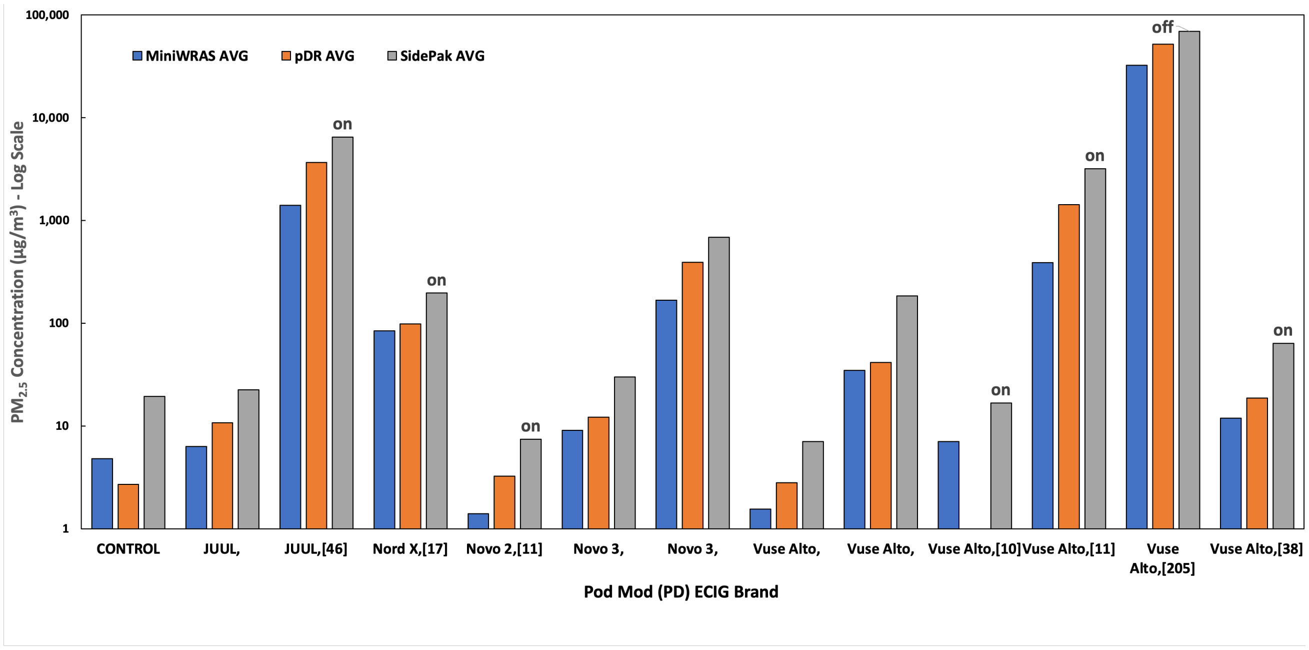

Figure 6(b)

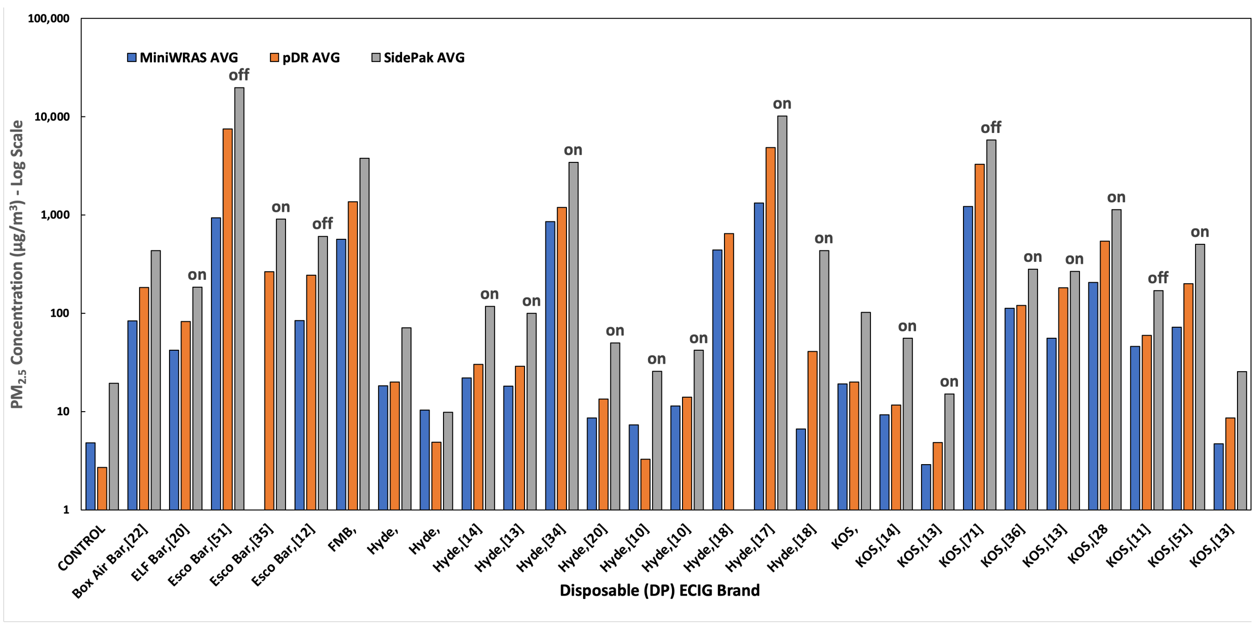

Figure 6(c)

Figure 6: The average $PM_{2.5}$ mass concentration for a) Box Mod, b) Pod Mod, and c) disposable for different ECIG devices. The x-axis represents each individual session and displays the ECIG used and the number of puffs, if available, in brackets. Above each session, if available, lies the on/off status of the vehicle. The y-axis represents a log scale due to the high variance in concentration.

Box Mod (BM)

The average $PM_{2.5}$ mass concentrations from the Mini-WRAS, pDR, and SidePak during the two sessions where a BM device was used are shown in Figure 6(a). Both sessions were conducted using the ECIG device “Geek Vape”. While this is a small sample size, the results demonstrate that $PM_{2.5}$ concentration increased with puff number. The SidePak resulted in the highest mass concentration for all monitors in both sessions. While the Mini-WRAS data was unable to be collected from the second session, results from the first session demonstrate that the Mini-WRAS and pDR have a closer average mass concentration. The control session represents the average concentration of the 7 conducted control sessions. In comparison between the control session and the 2 BM sessions the pDR-1500 concentration was 157 times higher, and the SidePak concentration was 63 times higher.

Pod Mod (PD)

The average $PM_{2.5}$ mass concentrations from the Mini-WRAS, pDR, and SidePak during the 12 sessions where a PD device was used are shown in Figure 6(b). Throughout the study, 4 different PD devices were used. The results were interesting for the Vuse Alto brand because the session with 38 puffs had a significantly lower average mass concentration compared to the 11-puff session. This could be due to numerous factors, including car type and whether the participants had their air conditioning/heat ON or OFF, which was not recorded. Like the BM, the SidePak had the highest PM2.5 mean concentrations for each session. In comparison between the control session average and the PD sessions, the Mini-WRAS reported concentrations were 40 times higher, the pDR-1500 concentrations were 190 times higher, and the SidePak concentrations were 52 times higher.

Disposables (DP)

The average $PM_{2.5}$ mass concentrations from the Mini-WRAS, pDR, and SidePak during the 27 sessions where a DP device was used are shown in Figure 6(c). Similar to the PM_1 results, the ECIG device with the highest mass concentration was the Esco Bar with 51-puffs. This was true even with one session for the KOS brand having more puffs at 71. Observing the other two Esco Bar sessions, the results demonstrate remarkably similar mass concentrations. Despite the varying puff counts of 35-puffs for one session and 12-puffs for the other session. The 12-puff Esco Bar session was conducted with the car off. Therefore, the absence of AC/heat circulating throughout the car could have been attributed to similar concentrations despite the varying puff count. Examining the 11 Hyde sessions conducted, the highest puff counted resulted in only the second highest mass concentrations. The 18-puff Hyde session also demonstrates that having the car off and without any air circulation is likely to result in higher $PM_{2.5}$ concentrations. There were also 10 sessions conducted using a Kang Onee Stick (KOS). The KOS session with 71-puffs resulted in a lower concentration than the 51-puff Esco bar session. In every session, the Mini-WRAS reported the lowest mass concentration. The Novo 2 and Vuse Alto also had sessions with the lowest average $PM_{2.5}$ mass concentrations. While the Mini-WRAS resulted in the lowest mass concentrations, there were two sessions where pDR had the lowest concentration. Both sessions were conducted using the Hyde. In terms of the ECIG with the lowest concentration, some of the Hyde sessions had the lowest mass concentrations. In comparison between the control session average and the DP sessions, the Mini-WRAS reported concentrations 50 times higher, the pDR-1500 reported concentrations that were 286 times higher, and the SidePak reported concentrations that were 98 times higher.

Across all the $PM_{2.5}$ results, the SidePak monitor recorded the highest concentrations. This was unsurprising as other ECIG studies that have used the SidePak monitor reported that it results in the highest concentrations, relative to other aerosol monitors. This was recently reported in (Sousan et al. 2022), where the SidePak measured concentrations that were 31 and 4 times higher than what the Mini-WRAS and the pDR values, respectively.

In 2019, Schober et al. conducted a similar study. This study examined $PM_{2.5}$ concentrations in 7 passenger vehicles while tobacco products and new electronic smoking products were used. There are a few major differences between the methodology of the two studies. The Schober study measured emissions from the back seat of each vehicle in the breathing zone of a child, the participants were driving the vehicle, and the windows were kept open either 2 or 5 cm. Emissions were collected using the Grimm 1.107 OPC and a Grimm NanoCheck 1.320. This device is made by the same company that makes the Mini-WRAS. The Mini-WRAS combines the optical particle counter of the Grimm 1.107 with electrical particle counting to measure smaller particle sizes. Results of Schober's study demonstrated that when an ECIG was used, 5 of the 7 cars reported an increase in $PM_{2.5}$ concentrations ranging from 75-490 $\mu g/m^3$.(Schober et al. 2019). This is comparable to the calculated 214 $\mu g/m^3$ average of the vehicle field study. This is the average of the 40 experimental sessions, excluding the 205-puff outlier. Even with the differences between the two studies, both results demonstrate that ECIGs use in vehicles exposes passengers to increased levels of particulate matter emissions.

Time Series Comparison

While these results outline the average particulate matter concentration across all the sessions, the monitoring instruments allow for an examination of the real-time concentrations during the entire 30-minute session span. During one of the sessions, the participant took 205 puffs. This was significant because the average number of puffs between all the sessions was 29 puffs. Therefore, we compared particulate matter concentrations of $PM_{2.5}$ from the 205-puff session with a session of a more average number of puffs (38) in Figure 7. Both participants used the same type of device, the Vuse Alto. These sessions differ in the number of puffs and whether the participant's vehicle was ON or OFF.

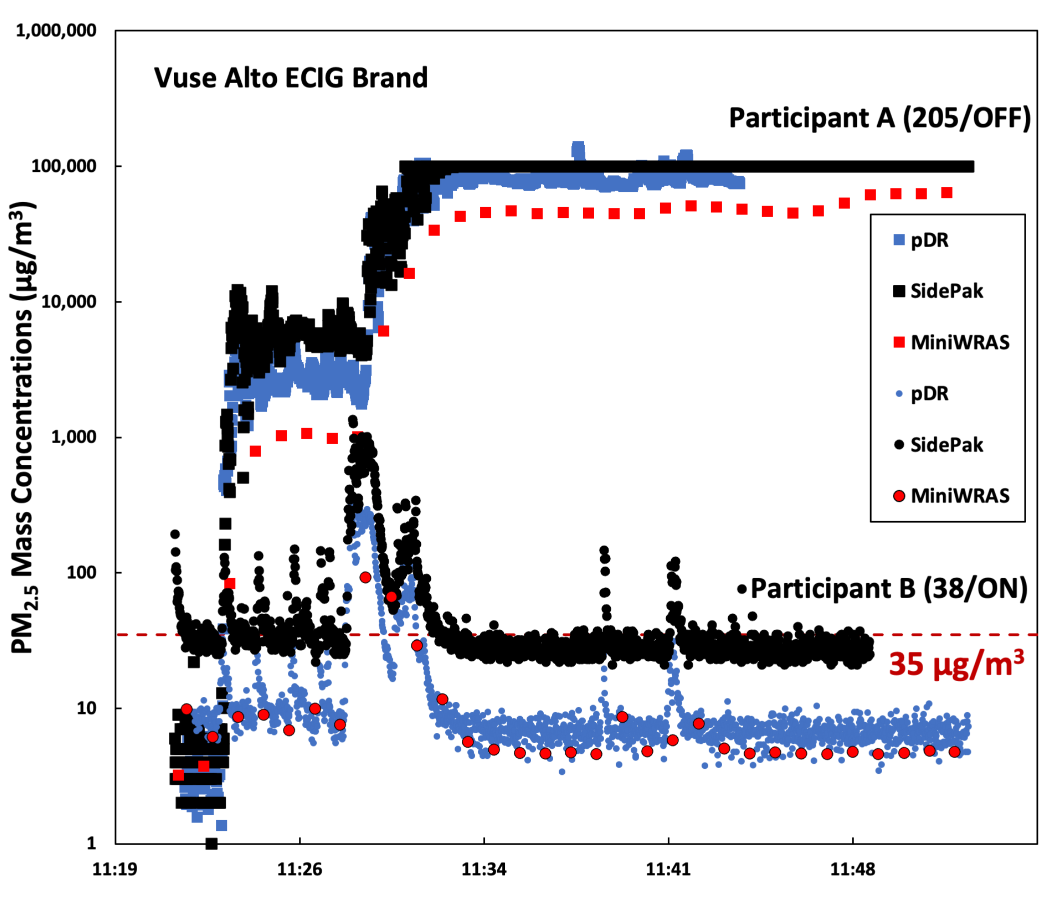

Figure 7(a) $PM_{2.5}$ mass concentration ($\mu g/m^3$), log scale vs time in seconds

The 205-puff session resulted in increased particulate matter concentrations of both PM_1 and $PM_{2.5}$ compared to the 38-puff session. Two different concentration patterns can be seen based on the initial 5 minutes of timed puffing for both sessions. With the 205-puff session, the concentration stays consistent during those 5 minutes. This contrasts with the 38-puff session, where the concentration had multiple distinct peaks indicating when the puffs were taken. With the 38-puff session, the participant had their vehicle on while the participant with the 205-puffs session did not. The peaks can most likely be attributed to the participant having some type of air circulation during their session that helped decrease the concentration of $PM_{2.5}$ between puffs.

Another way to analyze the results of this vehicle study is to compare the particulate matter concentrations to EPA standards. These standards are put in place as guidelines to protect people regarding respiratory health. The latest EPA guidelines have the outdoor environmental $PM_{2.5}$ 24-hour standard at 35 $\mu g/m^3$ ("EPA (AQI)" n.d.). This means that a person should not be exposed to anything of a higher concentration in a 24-hour period. World Health Organization (WHO) guidelines stipulate that $PM_{2.5}$ should not exceed 5 $\mu g/m^3$ annual mean, or 15 $\mu g/m^3$ 24-hour mean ("WHO (AQG)" 2006). A comparison of this standard to the average concentration across the vehicle sessions will yield insight into the levels of exposure people experience in a vehicle, while the driver engages in ECIG use. Omitting the 205-puff session outlier from the average results in a $PM_{2.5}$ average concentration of 214 $\mu g/m^3$. Not only is this almost 6 times higher than the EPA standard and 14 times higher than WHO 24-hour mean, but this exposure is also only during a 30-minute period. Passengers in a vehicle with someone who is using an ECIG are exposing themselves to $PM_{2.5}$ concentrations that have been deemed to be significantly unsafe by the EPA and WHO. The study worked to expose how toxic it is to use ECIGs in small, enclosed spaces, like passenger vehicles.

The results from the vehicle study demonstrate the risk that passengers face in vehicles where someone is currently vaping. Results indicate that this risk, while always present, varies depending on many factors. These factors include device type, puff number, vehicle status, and air circulation status. A vehicle passenger is at risk of various PM_1 and $PM_{2.5}$ concentrations while someone engages in ECIG use.

Conclusion

ECIG use has rapidly become popular, especially among youths. Its popularity stems, in part, because it is seen as a safer alternative to traditional cigarettes. This presents a major problem because it indicates that people ignore the detrimental short-term health effects that result from ECIG use. Users are also ignoring the unknown long-term health effects of ECIG use. This lack of awareness and belief that ECIG use is safe has resulted in the widespread practice of ECIG use in indoor settings. This is unlike traditional cigarettes, where it has become commonplace to be banned in public indoor settings. One of these common enclosed places where ECIG use is common is in passenger vehicles. ECIG use in such enclosed spaces creates the risk of secondhand exposure. This exposure puts those not engaging in ECIG use at similar health risks to the person actively puffing.

In a laboratory setting, cigarettes are analyzed using laboratory puffing procedures. These standards have never been created specifically for ECIGs. Additionally, human puffing behaviors are not always the same as these laboratory-controlled standards. The laboratory component of this investigation analyzed the $PM_{2.5}$ mass concentrations from the popular ECIG JUUL to determine how these emissions are impacted by laboratory-controlled standards. This was done using four different 10-bout puffing procedures that differed in the number of times the JUUL pod was removed and reinserted into the device. The behavior of removing and reinserting the pod before successive puffs has been found to be popular from survey and internet forum research. The results provided a clear demonstration of the impact laboratory puffing procedures have on ECIG emissions. In every experiment $PM_{2.5}$ mass concentrations increased after the pod was removed and reinserted into the device. The study demonstrated how real-world use can result in $PM_{2.5}$ mass concentrations that are 13 times higher than what current laboratory standards would report. As a result, bystanders are unknowingly being exposed to increased particulate matter concentrations.

The field component of this study involved quantifying the secondhand PM_1 and $PM_{2.5}$ concentrations inside a vehicle while the driver engages in ECIG use. Results indicate that particulate matter mass concentrations heavily varied from session to session. This difference can be attributed to different devices being used, different device types being used, and the number of puffs that each participant took during their session. While the level of exposure varied, all sessions demonstrated increased PM_1 and $PM_{2.5}$ mass concentrations resulting from the participants' ECIG use. This presents a significant health risk for passengers in vehicles where someone is engaging in ECIG use.

References

CDC. 2021. "About ECIGs (ECIGs)." https://www.cdc.gov/tobacco/basic_information/ECIGs/about-ECIGs.html.

EPA. 2018. *Public Health Consequences of ECIGs*. Edited by Kathleen Stratton, Leslie Y. Kwan, and David L. Eaton. Washington, D.C.: National Academies Press. https://doi.org/10.17226/24952.

Geiss, Otmar, Ivana Bianchi, Francisco Barahona, and Josefa Barrero-Moreno. 2015. "Characterisation of Mainstream and Passive Vapours Emitted by Selected ECIGs." *International Journal of Hygiene and Environmental Health* 218 (1): 169–80. https://doi.org/10.1016/J.IJHEH.2014.10.001.

Health, CDC's Office on Smoking and. 2021. "Smoking and Tobacco Use; ECIGs." *MMWR. Morbidity and Mortality Weekly Report* 65 (42): 1177. https://doi.org/10.15585/MMWR.MM6542A7.

Hinds, William. 1999. *Aerosol Technology: Properties, BeAerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, 2nd Editionhavior, and Measurement of Airborne Particles, 2nd Edition*. 2nd ed.

Hua, My, and Prue Talbot. 2016. "Potential Health Effects of ECIGs: A Systematic Review of Case Reports." *Preventive Medicine Reports* 4 (December): 169–78. https://doi.org/10.1016/J.PMEDR.2016.06.002.

Kloog, Itai, Bill Ridgway, Petros Koutrakis, Brent A. Coull, and Joel D. Schwartz. 2013. "Long- and Short-Term Exposure to PM2.5 and Mortality: Using Novel Exposure Models." *Epidemiology (Cambridge, Mass.)* 24 (4): 555. https://doi.org/10.1097/EDE.0B013E318294BEAA.

Kulmala, Markku, Ari Asmi, and Liisa Pirjola. 1999. "Indoor Air Aerosol Model: The Effect of Outdoor Air, Filtration and Ventilation on Indoor Concentrations." *Atmospheric Environment* 33 (14): 2133–44. https://doi.org/10.1016/S1352-2310(99)00070-9.

Schober, Wolfgang, Ludwig Fembacher, Adela Frenzen, and Hermann Fromme. 2019. "Passive Exposure to Pollutants from Conventional Cigarettes and New Electronic Smoking Devices (IQOS, ECIG) in Passenger Cars." *International Journal of Hygiene and Environmental Health* 222 (3): 486–93. https://doi.org/10.1016/J.IJHEH.2019.01.003.

Smets, Jorien, Frank Baeyens, Martin Chaumont, Karolien Adriaens, and Dinska van Gucht. 2019. "When Less Is More: Vaping Low-Nicotine vs. High-Nicotine E-Liquid Is Compensated by Increased Wattage and Higher Liquid Consumption." *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 723* 16 (5): 723. https://doi.org/10.3390/IJERPH16050723.

Son, Yeongkwon, Clifford Weisel, Olivia Wackowski, Stephan Schwander, Cristine Delnevo, and Qingyu Meng. 2020. "The Impact of Device Settings, Use Patterns, and Flavorings on Carbonyl Emissions from ECIGs." *International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 5650* 17 (16): 5650. https://doi.org/10.3390/IJERPH17165650.

Sousan, Sinan, Jack Pender, Dillon Streuber, Meaghan Haley, Will Shingleton, and Eric Soule. 2022. "Laboratory Determination of Gravimetric Correction Factors for Real-Time Area Measurements of ECIG Aerosols." https://doi.org/10.1080/02786826.2022.2047152.

Strand, John, Thomas Stolzenberg, and Anders W. Andren. 1978. "A Constant Relative Humidity-Temperature Chamber for the Accurate Weight Determination of Air Particulate Matter Collected on Filters." *Atmospheric Environment (1967)* 12 (10): 2027–28. https://doi.org/10.1016/0004-6981(78)90141-5.

"The National Ambient Air Quality Standards for Particle Pollution REVISED AIR QUALITY STANDARDS FOR PARTICLE POLLUTION AND UPDATES TO THE AIR QUALITY INDEX (AQI)." n.d. Accessed April 16, 2022.

Wang, Teresa, Kristy Marynak, Isreal Agaku, and Brian King. 2017. "Secondhand Exposure to ECIG Aerosol Among US Youths." *American Medical Association* 171 (5): 490–92.

Wang, Teresa W., Linda J. Neff, Eunice Park-Lee, Chunfeng Ren, Karen A. Cullen, and Brian A. King. 2020. "ECIG Use Among Middle and High School Students — United States, 2020." *MMWR. Morbidity and Mortality Weekly Report* 69 (37): 1310–12. https://doi.org/10.15585/mmwr.mm6937e1.

"What Are Volatile Organic Compounds (VOCs)? | US EPA." n.d. Accessed December 5, 2021. https://www.epa.gov/indoor-air-quality-iaq/what-are-volatile-organic-compounds-vocs.

"WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide." 2006.

Widziewicz-Rzońca, Kamila, and Malwina Tytła. 2020. "Water Sorption by Different Types of Filter Media Used for Particulate Matter Collection under Varying Temperature and Humidity Conditions." *International Journal of Environmental Research and Public Health* 17 (14): 1–15. https://doi.org/10.3390/ijerph17145180.

Zwozdziak, A., I. Sówka, E. Willak-Janc, J. Zwozdziak, K. Kwiecińska, and W. Balińska-Miśkiewicz. 2016. "Influence of PM1 and PM2.5 on Lung Function Parameters in Healthy Schoolchildren—a Panel Study." *Environmental Science and Pollution Research International* 23 (23): 23892. https://doi.org/10.1007/S11356-016-7605-1.

Apendix A

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
4N-64 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** ·
rede.ecu.edu/umcirb/

Notification of Initial Approval (Committee)

From: Biomedical IRB
To: Eric Soule
CC:
Date: 5/12/2021
Re: UMCIRB 21-000546
Vaping inside of vehicles field study

I am pleased to inform you that at the convened meeting on 5/12/2021 at 12:15 PM of the Biomedical IRB, the committee voted to approve the above study. Approval of the study and the consent form(s) is for the period of 5/12/2021 to 5/11/2022.

The Biomedical IRB deemed this study Minimal Risk.

As the Principal Investigator you are explicitly responsible for the conduct of all aspects of this study and must adhere to all reporting requirements for the study. Your responsibilities include but are not limited to:

1. Ensuring changes to the approved research (including the UMCIRB approved consent document) are only initiated with UMCIRB review and approval except when necessary to eliminate an apparent immediate hazard to the participant. All changes (e.g. a change in procedure, number of participants, personnel, study locations, new recruitment materials, study instruments, etc.) must be prospectively reviewed and approved by the UMCIRB before they are implemented;

2. Ensuring that only valid versions of the UMCIRB approved, date-stamped informed consent document(s) are used for obtaining informed consent (consent documents with the IRB approval date stamp are found under the Documents tab in the ePIRATE study workspace);

3. Promptly reporting to the UMCIRB all unanticipated problems involving risks to participants and others;

4. Applying for continuing review and receive approval of continuation of the study prior to the study's current expiration date. Application for continuing review should be submitted no less than 30 days prior to the expiration date. Lapses in approval (i.e. study expiration) should be avoided to protect the safety and welfare of enrolled participants and liability to the University; and

5. Submission of a final report when the study meets the UMCIRB criteria for closure. Study approval should not be allowed to expire simply because the study is completed, rather the UMCIRB should be formally notified of study completion via the final report process.

The approval includes the following items:

Document	Description
Brief Description for HBTRL Website(0.02)	Recruitment Documents/Scripts
Consent Form(0.02)	Consent Forms
Flyer(0.01)	Recruitment Documents/Scripts
Screener consent information sheet(0.01)	Consent Forms
Screening survey(0.01)	Data Collection Sheet
Screening Survey(0.01)	Surveys and Questionnaires
Scripts for recruitment and scheduling(0.01)	Recruitment Documents/Scripts
Study Protocol(0.01)	Study Protocol or Grant Application
Survey(0.01)	Data Collection Sheet
Survey(0.01)	Surveys and Questionnaires

For research studies where a waiver or alteration of HIPAA Authorization has been approved, the IRB states that each of the waiver criteria in 45 CFR 164.512(i)(1)(i)(A) and (2)(i) through (v) have been met. Additionally, the elements of PHI to be collected as described in items 1 and 2 of the Application for Waiver of Authorization have been determined to be the minimal necessary for the specified research.

The following UMCIRB members were recused for reasons of potential for Conflict of Interest on this research study:

None

The following UMCIRB members with a potential Conflict of Interest did not attend this IRB meeting: None

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

Trey Mooring Personal Reflection

Introduction

Towards the end of the summer before my junior year I was beginning to think about what I wanted to for my signature honors project. At this point, it looked like we would be able to be back on campus and have in-person classes. I knew that given the opportunity I wanted to do something that involved hands-on research in a lab. As a result, I sent in an application to join a research project involving electronic cigarette use in vehicles. This immediately interested me because I have seen first-hand just how many people, especially youths, who are engaging in heavy electronic cigarette use. This project seemed like a perfect opportunity learn about something that I didn't have a lot of prior knowledge in but sparked my curiosity.

My Roles and Contributions

With this project, I worked as a pair with fellow honors student Sarah Fresquez. We worked as a part of a larger team that was a joint effect between us in Dr. Sousan's lab and other students in Dr. Soule's lab. For the vehicle study, my role consisted of filter pre and post weighs, equipment calibration, setting up the equipment in the participants vehicles, downloading the data, and analyzing the data. For any laboratory studies that were conducted, my role involved setting up and conducting the chamber experiments. Sarah and I worked as a team to share these responsibilities.

Personal growth

Throughout these two semesters I feel as if I have grown as a person. This project required a contracted 12 hours of laboratory work a week. This was the first time that I have had an actual job before. This project also required me to work as a team. To do this I applied what I head learned in honors 2000/3000. This was helpful because in my future professional life working as a team is something that will be required of me. This experience has helped to give me a greater sense of personal responsibility.

Growth as an Honors Student

Throughout these past two semesters I feel as if I have grown as a student. This project has required a lot of time and effort that I would have otherwise put into my other classes. This meant that I had to adapt to this new schedule in order to keep up with everything I needed to do. At first, finding 12 hours a week in my schedule seemed like a daunting task. This was immediately remedied by the fact that I thoroughly enjoyed the work that I was doing with this project. Having less time in my week required me to be more productive with my time and procrastinate less. Even though I had less time I found myself getting my assignments done days in advance. Learning how to manage such a full schedule will help me later in life and in graduate school.

Personal Barriers

One personal barrier that I faced while working on this project has to do with conversation with friends. My roommate someone who uses electronic cigarettes. Before this project, I didn’t have any problems with him vaping in places like my room or my vehicle. This was because, like most people, I didn't really understand the risk that I was exposing myself to being in the presence of someone who is engaging in electronic cigarette use. After working on this project for some I asked him not to vape around me. While he was immediately willing to stop, it was hard to bring up the conversation.

Lessons for future honors students

One lesson that I have for any future honors students is to really take the time to enjoy your experience in all your honors classes. This is especially true in honors 2000 and 3000. While it may not feel like it at times, these classes are very important. They provide you with a one-of-a-kind experience that will be useful in both your personal and academic lives. Learning to work as a group is a key takeaway from the experience of these classes. This lesson has been something that I have brought with me to all my other classes at ECU, especially this honors project.

Another lesson that I have for any future honors students is to really make the most of your signature honors project. Find something that you really find interesting so that you will take something of value away from the experience. Everything that I have learned from this experience will be useful to be later in life.

Conclusion

All in all, I am thankful to be a part of the honors college because it has pushed me to do things that I don't know if I would have done otherwise. My experience working on this project for these past two semesters has led me to both personal and academic growth. Electronic cigarette research was something that I never thought I would be getting into, but I am glad I did. With project I have been a part of an amazing team and met some great people.