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Increased JUUL emissions from initial puffs after removing and reinserting pod

Eric K. Soule[1,2,*], **Sinan Sousan**[3,4], **Dillon Streuber**[1], **Sarah Fresquez**[1], **Ronald Mooring**[6], **Rola Salman**[2,5], **Soha Talih**[2,5], **Jack Pender**[6]

[1.]Department of Health Education and Promotion, College of Health and Human Performance, East Carolina University, Greenville, NC, 27858, USA

[2.]Center for the Study of Tobacco Products, Virginia Commonwealth University, Richmond, VA, 27858, USA

[3.]Department of Public Health, Brody School of Medicine, East Carolina University, Greenville, NC, 27858, USA

[4.]North Carolina Agromedicine Institute, Greenville, NC, 27858, USA

[5.]Mechanical Engineering Department, Maroun Semaan Faculty of Engineering and Architecture, American University of Beirut, Beirut, 1107 2020, Lebanon

[6.]Department of Chemistry, Thomas Harriot College of Arts & Sciences, East Carolina University, Greenville, NC, 27858, USA

Abstract

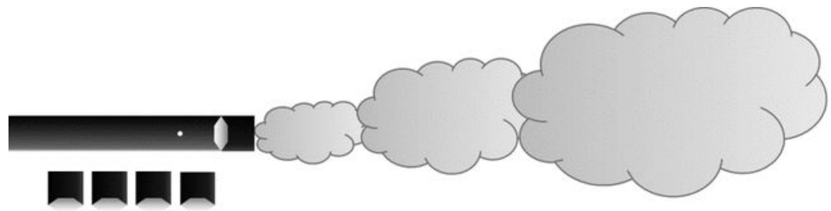
Standard laboratory electronic cigarette (ECIG) puffing protocols that do not consider user behaviors, such as removing and resinserting a pod, may underestimate emissions. This study compared JUUL emissions from four 10-puff bout procedures. We generated ECIG aerosol in a chamber using a JUUL device and measured concentrations of particulate matter ≤2.5 μm in diameter ($PM_{2.5}$). The JUUL pod was removed and reinserted 0 times, 2 times, 4 times, and 9 times in Experiments 1–4 respectively. Mean real-time $PM_{2.5}$ concentration was 65.06 μg/m^3 (SD=99.53) for Experiment 1, 375.50 μg/m^3 (SD=346.45,) for Experiment 2, 501.94 μg/m^3 (SD=450.00) for Experiment 3, and 834.69 μg/m^3 (SD=578.34) for Experiment 4. In this study, removing and reinserting a JUUL pod resulted in greater $PM_{2.5}$ concentrations compared to puffing protocols in which the JUUL pod was not removed and reinserted. ECIGs should be examined and evaluated based on ECIG users' real-world behaviors.

Graphical Abstract

*Corresponding Author: Dr. Eric K. Soule, Department of Health Education and Promotion, Mail Stop 529, East Carolina University, 1000 East 1st Street, Greenville, NC 27858 USA.

Conflict of Interest

Eric Soule is named on a patent for a smartphone app that determines electronic cigarette device and liquid characteristics.



Cigarette emissions are often examined by utilizing a “standard” puffing protocol in laboratory settings, such as the International Standardization Organization (ISO) regimen[1], in which cigarettes are machine “smoked” with a controlled number of puffs, puff volume, and puff duration. However, “real-world” human cigarette puffing behaviors may generate more than double the toxicant emissions compared to cigarette emissions generated from ISO protocols[2]. Additionally, research has documented the tobacco industry’s attempts to undermine standard puffing protocols through product designs, such as cigarette filter ventilation[3], that cause standard puffing protocols to underestimate cigarette emissions.

While standard puffing protocols have not been established for electronic cigarettes (ECIGs), many laboratory studies use consistent puffing protocols that are similar to standard cigarette puffing protocols to examine ECIG use[4,5]. However, little is known about whether these puffing protocols affect ECIG emissions. ECIGs use an electric heater to aerosolize a liquid for user inhalation[6]. There are some reports of ECIG users engaging in behaviors to produce a better “hit,” including removing and resinserting an ECIG pod (i.e., cartridge that contains ECIG liquid) between puffs[7]. Research has not examined how emissions are affected when standard puffing protocols simulate the user behavior of removing and reinserting an ECIG pod. Thus, because laboratory research examining ECIG toxicant emissions using standard puffing regimens that do not consider some common user behaviors may underestimate toxicant emissions, there is a need to examine ECIG emissions using puffing protocols that account for different user behaviors. The purpose of this study was to measure aerosol generated from a popular ECIG device (JUUL) using four different procedures.

JUUL device puffing protocol

We conducted four experiments in which we generated aerosol into a 0.5 m^3 exposure chamber using a diaphragm pump (Thomas 1420–0504, Gardner Denver, Davidson, NC) to puff JUUL devices purchased in the United States (Tobacco flavor, 5% nicotine concentration label). The JUUL device was chosen as it is one of the most popular ECIG devices, particularly among youth[8–10]. For each experiment, we generated 10 puffs (as in[4,5]) from a single fully-charged JUUL and a new JUUL pod using a 1.5 L/min flow rate with 3 second puffs (as in[11]) and a 30s inter-puff interval. For Experiment 1, the JUUL pod was inserted into the device and all 10 puffs were generated according to the above described puffing protocol. Experiments 2–4 were the same as Experiment 1, however, for Experiment 2 after five puffs the device was disconnected from the pod for 15 seconds and then reinserted before the next puff occurred and the final five puffs were generated (See Figure 1).

For Experiment 3, the JUUL device was disconnected from the pod and reinserted after every two puffs. For Experiment 4, the JUUL device was disconnected from the pod and reinserted after each puff (Figure 1). Before each experiment, five puffs were generated from each pod to ensure that the pod was functioning properly with a rest time of 10 minutes from after these initial puffs before beginning each experiment. The different procedures were used to generate puffing bouts that differ in number as reported by JUUL users, with many users reporting intermittent use and taking less than four puffs per bout or some taking 5–10 puffs per bout[12]. The puffing procedures also replicate a behavior reported on internet forums in which JUUL users describe removing and reinserting JUUL pods in order to get the device to "hit properly"[13].

Real-time particulate matter concentration measurement

Real-time particulate matter mass concentrations of particles 2.5 μm in diameter and smaller ($PM_{2.5}$) were measured using the pDR-1500 monitor (pDR 1500, Thermo Scientific, Franklin, MA, USA). The monitor is a medium-cost photometer that was operated with a cyclone at 1.52 L/min to measure $PM_{2.5}$ and includes a built-in 37 mm filter holder that can be used to perform gravimetric analysis. Mean and median $PM_{2.5}$ values were calculated by analyzing $PM_{2.5}$ concentration measurements from the time that the first puff was generated until 60 seconds after the last puff was generated. The pDR-1500 was zero-calibrated with filtered air prior to measurements. A correction factor was developed that is unique to JUUL-generatedaerosol by collecting real-time and discrete filter measurements using the pDR-1500 in the same experimental setup described above for a runtime of 60 minutes to exceed the limit of detection of the filter. The correction factor was then calculated by dividing the filter concentration by the average real-time concentration measured[14]. This correction factor (0.59) was applied to all $PM_{2.5}$ concentration measurements.

During Experiment 1, the mean real-time $PM_{2.5}$ concentration was 65.06 μg/m^3 (SD=99.53, Median=16.01 μg/m^3, Range=0–1222.00 μg/m^3). As displayed in Figure 1, $PM_{2.5}$ concentrations were highest after the first puff was generated. $PM_{2.5}$ then decreased steadily until leveling out after the initial five puffs. Experiment 2 mean real-time $PM_{2.5}$ concentration (Mean= 375.50 μg/m^3, SD=346.45, Median=265.47 μg/m^3, Range=0–1478.20 μg/m^3) was higher than Experiment 1, but followed a similar pattern of having peak $PM_{2.5}$ values in the puffs after the device was powered on and then decreased. The first peak $PM_{2.5}$ concentration occurred after the second puff was generated and then decreased in the following puffs. After the pod was disconnected and reinserted following puff number five, $PM_{2.5}$ concentrations increased to another peak after puff seven, and then decreased for the last three puffs.

For Experiment 3, the mean $PM_{2.5}$ concentration of 501.94 μg/m^3 (SD=450.00, Median=374.71 μg/m^3, Range=0–1780.00 μg/m^3) was greater than Experiments 1 and 2. Experiment 3, in which the pod was removed and reinserted after every other puff (i.e., after puff two, four, six, and eight), the peak $PM_{2.5}$ concentration occurred after puff nine. Mean $PM_{2.5}$ concentration for Experiment 4, in which the pod was removed and reinserted after each puff, was the highest of all the experiments (Mean= 834.69 μg/m^3, SD=578.34, Median=725.34 μg/m^3, Range=0–2643.00 μg/m^3). Peak $PM_{2.5}$ concentrations occurred after puff nine.

Using identical puffing procedures that only differed by the number of times a JUUL pod was removed and reinserted, aerosol generated from 10 puffs from a JUUL device in four experiments generated $PM_{2.5}$ concentrations that differed greatly. Compared to when the JUUL pod was inserted and 10 puffs were generated without removing the pod, 10 puffs from a JUUL in which the pod was removed and reinserted after each puff resulted in mean $PM_{2.5}$ concentrations inside of the exposure chamber that were 12.8 times higher. In all of the experiments in the current study, $PM_{2.5}$ concentrations increased after a JUUL pod was inserted into the device. This is consistent with recent findings that JUUL devices yield more nicotine during initial puffs after being powered on and decrease until steadying at the fifth puff[15].

The observed variation in emissions across conditions may be related to the periodic build up of gas bubbles around the JUUL heating coil during puffing, preventing intimate contact between the coil and the liquid and causing aerosol output to drop. Users on social media report this phenomenon and advise flicking, removing and reinstalling, or squeezing the pod to remove the bubbles and thereby restore the “hit” of the JUUL[16]. Importantly, while increased nicotine emissions in the first puffs may increase the potential for JUUL to produce dependence, increased $PM_{2.5}$ in the first puffs also likely increases user and bystander exposure to toxicants and the risk of negative health effects. While it is unclear whether the increased nicotine and $PM_{2.5}$ in the first puffs from JUUL devices are the result of an intentional design characteristic, JUUL users and bystanders are likely exposed to greater amounts of toxicants than laboratory studies may predict if they assume emissions from all puffs generated from a JUUL are the same.

There are several implications of greater toxicant emissions in the first puffs of JUUL devices. Greater nicotine emissions in the first puffs may allow users to get higher doses of nicotine in a shorter period of time relatively easily, potentially making JUUL devices appealing for “stealth vaping”[17] in locations where ECIG use is not permitted. These behaviors have been reported by ECIG users who report being addicted to ECIG use[18]. Importantly, while this device characteristic may result in greater nicotine exposures to users, clinical laboratory studies in which 10–15 puffs are taken in close succession may not reveal this if all puffs are assumed equal. That is, while laboratory studies may suggest that 15 puffs from a JUUL deliver cigarette-like doses of nicotine[19], 10 real-world puffs from a JUUL device may deliver more nicotine and toxicants to users. Indeed, while some JUUL users may take 10 sequential puffs without removing and reinserting pods, survey research suggesting some users engage in shorter bouts[11] and posts on internet forums that describe removing and reinserting pods to get “better throat hit”[7] suggest that some JUUL users are likely engaging in behaviors that are increasing their and bystanders’ exposures to nicotine and other toxicants.

This study had several limitations. We used four protocols in laboratory settings. While these protocols were informed from standard puffing protocols used in clinical laboratory settings and puffing behaviors reported in the scientific literature, emissions generated from actual user puffing behaviors in real-world settings may differ. There may also be other factors that influence protocols that are likely common in real world settings such as using a device with a different battery charge level (e.g., low battery or fully charged) allowing a device to sit for a longer period between puffs. Future research should examine the impact of these and other user reported behaviors on ECIG emissions. We report $PM_{2.5}$ concentrations, however, the current study does not describe the specific chemicals present in the generated aerosol. This study also examined ECIG aerosol captured in an exposure chamber, which may not be representative of primary exposures among users. Future studies are needed, including those capturing all primary ECIG emissions, to determine the chemical content of ECIG emissions which are needed to inform on the potential toxicity of different puffing behaviors. Finally, we only tested one type of ECIG device. Future studies are needed to see if other devices have similar differences in emissions depending on how they are used.

These data have significant impacts for regulatory policy. As regulators, such as the U.S. Food and Drug Administration, evaluate the potential risks and benefits of ECIGs, they will need to utilize puffing protocols that represent the multitude of ways in which ECIGs are used in real-world settings. That is, because ECIG devices are used differently than other tobacco products, ECIGs should be examined and evaluated based on ECIG users' real-world behaviors.

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Data Availability Statement

Data are available upon reasonable request.

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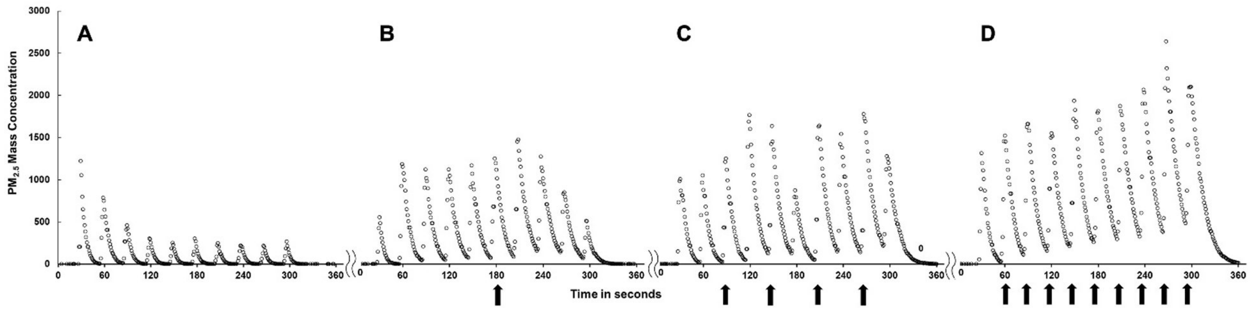

Figure 1.

Real-time concentrations of particulate matter 2.5 μm in diameter or smaller ($PM_{2.5}$) inside of a 0.5 m^3 chamber generated from Experiment 1 (A), Experiment 2 (B), Experiment 3 (C), and Experiment 4 (D). Arrows indicate the times when the JUUL pod was removed and reinserted during each 10-puff bout. For Experiment 1, the pod was inserted into the JUUL device before the first puff and all 10 puffs were generated from the device. For Experiment 2, the pod was also 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.