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Short communication

# Assessing electronic cigarette effects and regulatory impact: Challenges with user self-reported device power

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ABSTRACT

*Background:* Electronic cigarettes (ECIGs) aerosolize liquids for user inhalation that usually contain nicotine. ECIG nicotine emission is determined, in part, by user behavior, liquid nicotine concentration, and electrical power. Whether users are able to report accurately nicotine concentration and device electrical power has not been evaluated. This study's purpose was to examine if ECIG users could provide data relevant to understanding ECIG nicotine emission, particularly liquid nicotine concentration (mg/ml) as well as battery voltage (V) and heater resistance (ohms, Ω) – needed to calculate power (watts, W).

*Methods:* Adult ECIG users (N = 165) were recruited from Los Angeles, CA for research studies examining the effects of ECIG use. We asked all participants who visited the laboratory to report liquid nicotine concentration, V, and Ω.

*Results:* Liquid nicotine concentration was reported by 89.7% (mean = 9.5 mg/ml, SD = 7.3), and responses were consistent with the distribution of liquids available in commonly marketed products. The majority could not report voltage (51.5%) or resistance (63.6%). Of the 40 participants (24.8%) who reported voltage and resistance, there was a substantial power range (2.2–32,670 W) the upper limit of which exceeds that of the highest ECIG reported by any user to our knowledge (i.e., 2512 W). If 2512 W is taken as the upper limit, only 30 (18.2%) reported valid results (mean 237.3 W, SD = 370.6; range = 2.2–1705.3 W).

*Conclusions:* Laboratory, survey, and other researchers interested in understanding ECIG effects to inform users and policymakers may need to use methods other than user self-report to obtain information regarding device power.

## 1. Introduction

Electronic cigarettes (ECIGs) use an electrically-powered heating element to aerosolize for user inhalation a liquid that usually contains nicotine (Breland et al., 2017). ECIG nicotine emission is determined in large part by three factors: (1) the device's electrical power output (measured in watts or W); (2) liquid nicotine concentration; and (3) user behavior (i.e., puff number and duration; Talih et al., 2015). Early ECIG models delivered little nicotine to users (e.g., Vansickel et al., 2010; Bullen et al., 2010), possibly as a result of low electrical power (i.e., less than 10 W). However, when low-power devices (e.g., 7.3 W) are paired with high nicotine concentration liquid (e.g., 36 mg/ml nicotine), they can meet or exceed the nicotine delivery profile of a combustible tobacco cigarette (Ramôa et al., 2016). Recent ECIG models with higher voltage (V) batteries, lower resistance (Ω) heating elements, and more sophisticated electronics enable their power output to exceed 150 W (e.g., Wagener et al., 2016), allowing low nicotine concentration liquids to deliver nicotine effectively to users. In fact, 10 puffs from high power ECIGs (mean = 70 W) filled with 4 mg/ml nicotine liquid (on average) can match the nicotine delivery of a tobacco cigarette (Wagener et al., 2016).

While Wagener et al. (2016) report devices powered as high as 162.4 W, there may be an upper limit to device power. An informal internet search on youtube.com of high power ECIG devices (using the search terms "high watt," "high power," "vaping," and "ecigs") revealed few mass-marketed ECIGs operating above 500 W, and the highest customized device that we could find for which operating characteristics were clearly identified involved a 14.7 V battery and a 0.086 Ω heating element (although these device characteristics could not be verified; $V^2/\Omega$ = 2512 W; https://www.youtube.com/watch?

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v=6NKmBRIudQc). In a video depicting use of this device, the user described the experience: "As you can see, stupid and pointless." and "…the limit of what a human can vape…". The user's description of the device indicates that devices with wattages at this level produce aversive sensory effects and are unlikely to be used by many ECIG users; therefore, 2512 W may be the upper limit to device power.

Variations in ECIG device power have implications for ECIG users and policymakers. With regard to users, higher power devices may increase abuse liability and nicotine dependence as higher power devices produce more nicotine-containing aerosol for inhalation (e.g., Sleiman et al., 2016; Talih et al., 2017) and may also increase adverse health effects as the aerosol produced by these higher power devices also can be more toxicant-laden than low power devices (Gillman et al., 2016; El-Hellani et al., 2016). With regard to policymakers, the availability of higher power devices limits the impact of regulations regarding nicotine liquid concentration. For example, the European Union's (EU's) Tobacco Products Directive 2014/40/EU limits ECIG liquids to no more than 20 mg/ml nicotine to allow "for a delivery of nicotine that is comparable to the permitted dose of nicotine derived from a standard cigarette…" (European Parliament and the Council, 2014). This intended effect will not be met when a 70 W device paired with only 4 mg/ml liquid can mimic a cigarette's nicotine delivery profile (Wagener et al., 2016). Hence, regulating ECIG nicotine emissions requires accurate data on both power and liquid nicotine concentration.

While device power is clearly important to understanding ECIG effects, many studies of ECIG users have not reported data regarding the power of the devices that those ECIG users use regularly (e.g., Vansickel and Eissenberg, 2013; Spindle et al., 2017a,b; Christensen et al., 2014; Brown et al., 2014; Hitchman et al., 2015; Sutfin et al., 2015). Of those that did, sample size was small (e.g., Wagener et al., 2017; N = 20) or more than 50% of respondents did not know the power (wattage) of their device (Harvanko et al., 2017). We are unaware of any published study examining the proportion of users who can report product parameters that are critical to understanding nicotine emissions (i.e., nicotine concentration, voltage, and resistance).

The purpose of this study was to examine the extent to which experienced ECIG users could provide data relevant to understanding ECIG nicotine delivery, particularly liquid nicotine concentration (mg/ml) as well as battery voltage and heater resistance. Based on previous reports and the internet search referred to above, we expected liquid nicotine concentration to range from 0 to 36 mg/ml (higher concentrations are available, but generally are diluted before use; Breland et al., 2017) and power to range from 7 to 2512 W (this upper limit likely is extreme, but has been documented).

## 2. Methods

### 2.1. Participants

Adult ECIG users (N = 165) were recruited from the Los Angeles, CA metropolitan area via online and physical advertisements announcing the opportunity to participate in research studies examining the effects of ECIG use. Eligibility criteria were: (1) current ECIG use (i.e., ≥1 day/week for ≥1 month); (2) no recent use of smoking cessation medication; (3) no plan to cut down or quit ECIGs in the near future; (4) not pregnant or breastfeeding; and (5) aged ≥18 years old. All participants provided written informed consent, and the USC IRB approved study protocols.

### 2.2. Procedures

In two of the studies, 121 young adult ECIG users (Study 1 n = 101, Study 2 n = 20; 57.5% current smokers) attended a single laboratory visit in which they self-administered experimenter-provided ECIGs (for details on the paradigm see Goldenson et al., 2016). In the other study, adult concurrent combustible cigarette and ECIG users (N = 44) attended five visits in which they smoked their own preferred-brand cigarettes and used their own ECIGs. In all studies, the measures included in the current report were collected at the first laboratory visit.

### 2.3. Measures

All participants completed self-report questionnaires assessing e-cigarette nicotine concentration ("What nicotine concentration do you usually use in your e-cigarette?"), device voltage ("What voltage do you prefer?"; the use of the word "prefer" was chosen to account for variable voltage devices that allow the user to control this variable using circuitry internal to the device) and atomizer resistance ("What is the resistance of your atomizer?"). Response options for each question were open-ended. Participants also completed measures assessing demographics, ECIG use characteristics (i.e., puffs per day) and smoking characteristics (i.e., past 30-day smoking, cigarettes smoked per day).

### 2.4. Data analysis

Device wattage was calculated using $W = V^2/\Omega$.

## 3. Results

### 3.1. Participant characteristics

Of the 165 participants in the pooled sample, the mean age was 27.7 years (*SD* = 7.69); 65.5% were men; the ethnic distribution was 43.0% White non-Hispanic, 32.7% Black non-Hispanic, 8.5% Hispanic, 12.1% Asian, and 3.7% Other Race; 68.5% were past 30-day combustible cigarette smokers in addition to being ECIG users. Of the 161 participants who reported daily ECIG puff number, the mean was 81.1 (*SD* = 131.9) ECIG puffs/day. Of the 113 participants who reported being past 30-day cigarette smokers, 95 reported that their mean daily cigarette consumption was 10.5 cigarettes/day (*SD* = 7.2).

### 3.2. Liquid nicotine concentration, battery voltage, heating element resistance, and power

Table 1 provides descriptive statistics for reported liquid nicotine concentration, battery voltage and heater resistance as well as wattage as calculated based on available data. Nearly all of the participants (89.7%) reported liquid nicotine concentration, and all their responses were consistent with values available in most marketed products (Breland et al., 2017), but the majority did not report device voltage (51.5%) or resistance (63.6%) by leaving the answer option blank, and some values were nonsensical (e.g., two reported 0 V and one reported 0 Ω). Of the participants (24.8%) who reported both voltage and resistance, calculated wattage revealed a substantial range (2.2–32,670 W), the upper limit of which exceeds that of the highest custom-made ECIG we could identify (i.e., 2512 W, see Introduction).

**Table 1**
Self-reported liquid nicotine concentration, battery voltage, heater resistance (N = 165), and calculated wattage.

| | Reported Nicotine Concentration (mg/mL; *n* = 148) | Reported Voltage (V; *n* = 80) | Reported Resistance (Ω; *n* = 60) | Calculated Wattage ($W = V^2/\Omega$; *n* = 40)[a] |
|---|---|---|---|---|
| Mean | 9.5 | 24.5 | 1.5 | 3926.5 |
| SD | 7.3 | 28.3 | 1.8 | 8343.5 |
| Median | 6.0 | 8.2 | 0.5 | 204.9 |
| Range | 0.0–30.0 | 0.0–110.0 | 0.0–7.0 | 2.2–32670.0 |

[a] One participant reported 3.7 V and 0.0 Ω; these data were not included in calculated wattage.