Electronic Cigarette Dependence: User and Device Characteristic Predictors

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Electronic Cigarette Dependence: User and Device Characteristic Predictors

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Thesis submitted to the Eberly College of Arts and Sciences at West Virginia University in partial fulfillment of the requirements for the degree of Master of Science in Psychology

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Understanding the dependence potential of electronic cigarettes (ECIGs) is critical to informing prevention and regulatory efforts. Extant work on ECIG dependence is limited, in part due to the vast number of products that differ on their ability to deliver nicotine. Further, existing research is based largely on former/current cigarette smokers, and thus confounds dependence on nicotine via ECIGs versus cigarettes. This study evaluated ECIG device/liquid characteristics and use behaviors as predictors of ECIG dependence in a sample of experienced ECIG users who never smoked cigarettes. Participants completed an online survey that assessed ECIG device/liquid features, use behavior, and ECIG dependence. Additionally, participants uploaded a picture of their personal ECIG product, which was compared to their survey responses for accuracy. Accounting for demographic variables, longer durations of ECIG use and a greater number of use days/week were associated with higher dependence scores. Notably, few ECIG characteristics or device types predicted dependence level after accounting for demographics and use behavior. Comparisons between participants’ self-reports and pictures revealed that agreement was excellent for features of refillable and disposable, good for adjustable power, fair for nicotine formulation, and moderate for device type. Results demonstrate that ECIG device/liquid features are not salient predictors of dependence in never-smoking ECIG users. Future research should include a larger and more diverse sample. Additionally, future work may benefit from a more precise measure of nicotine delivery, as well as verification of ECIG characteristics by requiring participants to provide a picture of their product.
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INTRODUCTION

Tobacco use in the United States (U.S.) is an ongoing public health issue that has been exacerbated by the rise in popularity of electronic cigarettes (ECIGs). An estimated 8.1 million (3.2%) U.S. adults used ECIGs in 2018. They are currently the third most popular tobacco product, following combustible cigarettes (13.7%) and cigars (3.9%; Creamer et al., 2019). Whereas cigarette use has dropped to the lowest recorded prevalence rate (Wang, 2018), ECIG use has increased. From 2017-2018, ECIG use increased by 46.2% in adults aged 18-24 (Dai & Leventhal, 2019). An even more dramatic increase was observed among youth, with prevalence rates rising from 11.7% to 20.8% among high school students – an increase of 77.8% (Gentzke et al., 2019). As ECIG use becomes more prevalent, the need for regulation of such products increases. In 2009, the U.S. Food and Drug Administration (FDA) was granted regulatory control of cigarettes, smokeless tobacco, and roll-your-own tobacco under the Family Smoking Prevention and Tobacco Control Act (Tobacco Control Act; FDA, 2020). An extension of this act, the “Deeming Rule,” gave the FDA authorization to declare regulatory control over emerging tobacco products. Consequently, in 2016, the FDA extended their regulatory authority to include cigars, hookah, pipe tobacco, and ECIGs. Since then, the FDA has introduced several ECIG-specific regulations including banning the sale of ECIGs to minors and requiring nicotine warning statements on ECIG products (FDA, 2020). More recently, the FDA prohibited the sale of cartridge-based liquids in flavors other than tobacco and menthol. Other regulations for ECIG products have been slower to unfold. For example, under the Tobacco Control Act, all tobacco products on the market as of August 8, 2016, must be reviewed and approved by the FDA to gain market approval. The deadline for ECIG manufacturers to submit premarket applications for
review was September 9, 2020. The FDA received applications for 6.5 million tobacco products from more than 500 companies, and has denied marketing approval for 55,000 flavored ECIG products from 3 companies to date (FDA, 2021b).

**Electronic Cigarettes**

ECIGs are electronic nicotine delivery systems intended to provide users with nicotine through the inhalation of an aerosol. Although ECIGs differ on some design characteristics (e.g., appearance, size), they share common features of a battery, a heating element, a vaporization chamber, a storage component for liquid, and the liquid solution (Bhatnagar et al., 2014; Breland et al., 2017; Williams & Talbot, 2019). The liquid solution typically contains propylene glycol, vegetable glycerin, nicotine, and flavorings (Breland et al., 2017). The battery, which is activated through the manual press of a button or inhalation through the mouthpiece, powers the heating element causing the liquid contained in the ECIG to aerosolize. The user is then delivered nicotine upon inhalation of the aerosol.

ECIGs have evolved considerably since they were first patented in 2003 (Breland et al., 2017). First-generation devices, or “cig-alikes,” are similar in size and appearance to combustible cigarettes. They feature low-voltage batteries and prefilled liquid storage components, otherwise known as cartomizers. Some of these models are disposable and are intended to be discarded after use. In contrast, second-generation devices, or “clearomizers,” feature a transparent liquid reservoir or tank that can be refilled with liquid as needed. These devices are often pen shaped and bear little resemblance to cigarettes. Third-generation ECIGs, or “mods,” allow the user to modify certain device features relative to previous generation devices. Specifically, users can adjust the voltage/wattage, and resistance of the device to affect nicotine delivery, as well as refill their tanks with liquid as desired (Williams & Talbot, 2019).
With both second- and third-generation devices that are refillable, users have more control over the ratio of the liquid constituents and nicotine concentration. The next type of ECIG to emerge was the pod-style device. These fourth-generation devices, which use prefilled pods of liquid, were quick to become the most commonly used ECIG among adolescents and young adults starting around 2017 (King et al., 2018; McKelvey et al., 2018). They are known for their concealable nature (Spindle & Eissenberg, 2018) and their high nicotine concentration relative to other brands (Eissenberg et al., 2018; Talih et al., 2019; Zhu et al., 2014). Most recently, disposable ECIGs that resemble pod-based devices entered the market. These modern disposable devices are cheaper than non-disposable ECIGs and come in a variety of flavors (Leventhal et al., 2021). Like pod-based devices, modern disposable ECIGs are concealable and contain high concentrations of nicotine (Leventhal et al., 2021; Williams, 2020). Pictures of these various ECIG device types and individual features can be found elsewhere (Truth Initiative, 2021; Williams & Talbot, 2019; Williams, 2020).

**ECIG Dependence**

Nearly all of the ECIGs sold in the U.S. contain nicotine (Romberg et al., 2019), an addictive substance. Nicotine dependence is recognized as a medical condition by the World Health Organization (2018) and the American Psychiatric Association (APA; 2013). It is defined by Falcone et al. (2016; p. 122) as:

a chronic, relapsing disorder characterized by a compulsive urge to take the drug that persists in the face of negative social consequences, loss of control over drug intake, and emergence of a withdrawal syndrome consisting of negative physical and affective symptoms in the absence of the drug.
The most common way to assess nicotine dependence is via surveys that consider multiple symptoms of dependence such as withdrawal, use despite harm, tolerance, and craving. Such work has demonstrated that ECIGs are dependence producing, but may be less so than cigarettes (Browne & Todd, 2018; Etter & Eissenberg, 2015; González Roz et al., 2017; Liu et al., 2017; Morean, Krishnan-Sarin, & O’Malley, 2018; Rass et al., 2015). In one study (Liu et al., 2017), features of dependence were compared between exclusive ECIG users and cigarette smokers using the national-level Population Assessment of Tobacco and Health (PATH) survey. Relative to cigarette smokers, exclusive ECIG users were less likely to self-report addiction, to have strong cravings for their product, to feel like they really needed to use their product, and to find it difficult to keep from using their product (Liu et al., 2017). Despite this, the exclusive ECIG users did show characteristics of dependence, with over three quarters self-reporting addiction. In other work, Etter and Eissenberg (2015) administered dependence questionnaires to daily ECIG users, nicotine gum users, and cigarette smokers. Results indicated that ECIG users were less dependent on their product than cigarette smokers, and equally or less dependent than users of nicotine gum.

Of the available survey-based studies, only two have suggested that ECIG users are more dependent on their product than cigarette smokers (Jankowski et al., 2019; Johnson et al., 2018). Johnson et al. (2018) found that dependence scores were significantly higher for their sample of ECIG users than previously recorded scores for samples of cigarette users using the same questionnaire. Notable, however, is that the participants of this study were attendees of an ECIG convention, and thus unlikely to best represent the general population of ECIG users. In another study, Jankowski et al. (2019) compared dependence scores of exclusive ECIG users, dual users of ECIGs and cigarettes, and exclusive cigarette users. Dependence scores among exclusive
ECIG users were significantly higher than those for exclusive cigarette smokers. In addition, dual users reported higher levels of dependence for ECIGs than for cigarettes. Importantly, in both of the aforementioned studies, the majority of exclusive ECIG users had a history of cigarette use.

According to Fagerström and Eissenberg (2012), nicotine dependence should be assessed in a product-specific manner. While all tobacco products deliver nicotine, they do not all do so via the same method of administration. Products that deliver higher nicotine concentrations and/or with rapid speed (e.g., cigarettes) are thought to be more dependence producing than products that deliver lower nicotine concentrations and/or with slower speed (e.g., smokeless tobacco, nicotine gum; Carter et al., 2009). While both ECIGs and cigarettes deliver nicotine via inhalation, a relatively rapid method of nicotine administration, ECIG design features are less standardized than those for cigarettes (Shihadeh & Eissenberg, 2015). Moreover, ECIGs typically contain only a few ingredients in the liquid, whereas cigarettes contain around 600 ingredients (American Lung Association, 2020; CDC, 2021). Many of those cigarette ingredients were added with the goal of improving delivery of nicotine to the user (Rabinoff et al., 2007). Therefore, it is not surprising that some ECIGs deliver very little nicotine (Farsalinos et al., 2014; Hajek et al., 2015; Maloney et al., 2020) and others deliver nicotine at doses similar to or exceeding that of cigarettes (Hiler et al., 2017; Ramôa et al., 2016; Wagener et al., 2017).

Also relevant is that because not all tobacco products deliver nicotine in the same vehicle, they do not necessarily share sensory and/or behavioral features. Smokeless tobacco (SLT), for example, which is consumed orally, provides the user with a much different taste, smell, and behavioral experience than products that are inhaled (e.g., ECIGs, cigarettes, hookah; Fagerström & Eissenberg, 2012). Even tobacco products with a similar method of administration differ on
some facets of sensory experience. Though both cigarettes and ECIGs provide the user with the sight of exhaled smoke/vapor and the feeling of that smoke/vapor hitting the throat, the products differ on taste, smell, and the look and feel of the product in the hand. Cigarettes and ECIGs also involve different behaviors. For instance, use of a single cigarette typically requires 8-15 puffs and takes about five mins, while use of an ECIG is more sporadic (i.e., ECIG users may take only a few puffs, but do so numerous times/day; Shihadeh & Eissenberg, 2015). In addition, although the hand-to-mouth action is similar for both products, ECIGs may be held differently than cigarettes and may require the press of a button for activation. Indeed, ECIGs are more similar to cigarettes than many other tobacco products, but still differ from cigarettes in many ways. For this reason, it is important to assess dependence on ECIGs specifically by considering their unique characteristics. Those characteristics may be specific to the device being used, as well as to the user.

**Device and Liquid Characteristics**

ECIGs vary widely in their ability to deliver nicotine to the user (Eissenberg, 2010; Farsalinos et al., 2014; Hajek et al., 2015; Hiler et al., 2017; Ramôa et al., 2016; Wagener et al., 2017), in part because of the many different product characteristics that can be modified (Shihadeh & Eissenberg, 2015). Few existing studies have examined the effect of these features on ECIG dependence level (Do et al., 2022), and only one study has examined these effects in ECIG users who have never smoked cigarettes (Douglas et al., 2022). Research on this population is important, as it overcomes the potential confound of dependence from cigarettes. Findings from such studies can help inform regulatory efforts aimed at tobacco-related harm prevention and reduction. The below sections detail these different ECIG characteristics, and demonstrate how modifications to each may influence nicotine yield (the amount of nicotine
emitted from the mouth end of the ECIG in the aerosol/vapor) and/or delivery (the amount of nicotine delivered to the user as measured via biological fluids; Blank et al., 2019).

**Device Power**

One device characteristic that influences nicotine yield and/or delivery is device power (measured in Watts), which is determined by voltage (measured in Volts) and resistance (measured in Ohms, Ω). Specifically, the voltage can be increased and/or the resistance can be decreased to increase power output. Higher-powered devices increase the temperature at which the heating element (e.g., metallic coils) aerosolizes the liquid, and thus more vapor is produced. When puff topography, nicotine concentration, and other device characteristics are held constant, higher-powered devices produce a greater nicotine yield and delivery than lower-powered devices (DeVito & Krishnan-Sarin, 2018; Kosmider et al., 2018; Talih et al., 2015; Wagener et al., 2017). For instance, when using machine-generated puffs, Kosmider et al. (2018) found that the mean nicotine yield increased from 39.3 μg/puff to 80.8 μg/puff as wattage increased from 3.3 W to 9.6 W. In a human laboratory study, Hiler et al. (2020) compared the nicotine delivery profile of a 40.5 W, 0.5 Ω device and a 13.5 W, 1.5 Ω device, controlling for nicotine concentration (3 or 8 mg/mL), flavor, voltage, and device type. Nicotine delivery was greater among participants using the higher-powered device regardless of nicotine concentration (Hiler et al., 2020).

**Liquid Characteristics**

In addition to device power, the characteristics of the liquid may also influence nicotine yield and delivery. The concentration of the nicotine in the liquid is one of the most salient determinants of nicotine delivery for most ECIG products. Available nicotine concentrations commonly range from 0-36 mg/mL for freebase solutions, but have been documented as high as
87.2 mg/mL (Breland et al., 2017; National Academies of Sciences, Engineering, and Medicine, 2018). In a study examining nicotine delivery, Hiler et al. (2017) assigned participants to one of three conditions varying on nicotine concentration (8, 18, or 36 mg/mL) and measured their nicotine plasma level after a bout of puffing. Controlling for device type, solvent ratio, and puff number, ECIG-experienced users in the 36 mg/mL group had the highest nicotine plasma level ($M = 17.9$ ng/mL, $SD = 17.2$), followed by users in the 18 mg/mL group ($M = 13.0$ ng/mL, $SD = 6.2$), and users in the 8 mg/mL group ($M = 8.2$ ng/mL, $SD = 7.8$). Similar results were observed by Talih et al. (2015) using machine-based puffing; nicotine yield was higher for liquid with a higher nicotine concentration (18 vs. 36 mg/mL).

Liquids may not only contain nicotine, but that nicotine may be in unprotonated (freebase) or protonated (nicotine salt) form. Freebase nicotine is nicotine in its purest form. It has a higher pH than nicotine salt and is more volatile and easily absorbed when all other variables (e.g., device power, nicotine concentration) are held constant (El-Hellani et al., 2015). Nicotine salts, on the other hand, are derived from loose-leaf tobacco. Salt solutions are used in newer, pod-style devices (e.g., JUUL) and modern disposables (e.g., Puff Bar) and may provide users with a more pleasant experience due to their lower pH level (Talih et al., 2019). Still, nicotine salt solutions contain up to 10 times more nicotine than freebase solutions (Barrington-Trimis & Leventhal, 2018), though work examining the nicotine delivery profile of such products is limited. In a sample of ECIG-naïve cigarette smokers, Maloney et al. (2020) found that JUUL delivered significantly less nicotine to the blood than cigarettes after 90 mins of ad libitum puffing ($M = 11.5$ ng/mL, $SD = 9.3$ vs. $M = 21.0$ ng/mL, $SD = 10.2$, respectively). In contrast, in a sample of ECIG-experienced users, JUUL delivered a similar amount of nicotine to the blood as cigarettes ($M = 20.4$ ng/mL, $SD = 15.0$ vs. $M = 19.2$ ng/mL, $SD = 17.6$, respectively).
and significantly more nicotine to the blood than refillable and cig-alike ECIG styles (Hajek et al., 2020).

ECIG liquid also often contains two major solvents, propylene glycol (PG) and vegetable glycerin (VG), that may affect nicotine yield and delivery. The ratio of PG to VG can range anywhere from 100% PG (0% VG) to 100% VG (0% PG), and evidence suggests that higher levels of PG result in increased nicotine delivery and “throat hit” (i.e., user ratings of vapor hitting the back of the throat). For example, machine-based puffing reveals increased nicotine yield as the ratio of PG to VG increases (Kosmider et al., 2018). Similarly, in experienced ECIG users, higher plasma nicotine levels are observed for higher levels of PG than VG in the liquid (Spindle et al., 2018). Conversely, liquids with a higher level of VG than PG are reported to produce a larger, thicker cloud of exhaled vapor (Baassiri et al., 2017; Harvanko et al., 2019) and these clouds may nonetheless provide an important visual cue for users. Moreover, some users, known colloquially as “cloud chasers,” use liquids with higher levels of VG to perform “tricks” with the exhaled vapor (Measham et al., 2016). Thus, users choose a PG/VG ratio based on personal preference, making trade-offs between the higher nicotine delivery provided by PG and the larger vapor cloud (i.e., visual cue) provided by VG.

Finally, the way in which the liquid is administered may influence nicotine delivery. While most users pour their liquid into a tank that saturates a wick system (Yingst, Foulds, et al., 2019), others drip their liquid directly onto the heating coil. This method, referred to as “direct dripping,” is reported by users to increase control over throat hit, flavor, and the amount of vapor expelled from the device (Talih et al., 2016). The association between direct dripping and nicotine yield has not been directly studied; however, Talih and colleagues (2016) found that nicotine yield was positively associated with the frequency of dripping. For instance, two puffs
between dripping resulted in a nicotine yield of 1.03 mg, while four puffs between dripping resulted in a nicotine yield of 0.07 mg.

**User Characteristics**

In addition to modifications to device/liquid characteristics, it is necessary to consider user experience and behavior when evaluating nicotine yield and delivery. Individuals vary in their ability to extract nicotine from ECIGs, largely due to their ECIG and tobacco use history, and the characteristics of their puffing behavior (Blank et al., 2019; Farsalinos et al., 2015; Hajek et al., 2015; Hiler et al., 2017; Lee et al., 2015). The following sections describe each and delineate their relation to nicotine yield and delivery.

**ECIG Experience**

Experienced ECIG users are shown to be more efficient at obtaining nicotine from ECIGs, relative to naïve users (Farsalinos et al., 2015; Hiler et al., 2017). For instance, ECIG-experienced users achieve significantly higher plasma nicotine levels than ECIG-naïve smokers after taking 10 standardized puffs, as well as after 60 minutes of ad libitum use, when the device and liquid characteristics are held constant (Farsalinos et al., 2015). Similarly, Hiler et al. (2017) observed significantly higher plasma nicotine levels in ECIG-experienced users relative to ECIG-naïve users after a single 10-puff bout when the same device and liquid were used. These differences in users’ ability to obtain nicotine from ECIGs are likely the result of practice. In a sample of ECIG-naïve cigarette smokers, for example, total nicotine intake increased by 79% from baseline over four weeks of ECIG use (Hajek et al., 2015). While not assessed in this study, other work suggests that ECIG-naïve users may learn to adjust their puffing behavior in as little as one week of practice (Lee et al., 2015).
ECIG Puff Topography

Changes in puff topography (e.g., puff number, duration, volume, flow, interpuff interval) reliably lead to changes in nicotine delivery for several tobacco products. Cigarette smokers, for example, alter their puff volume and duration to obtain desired levels of nicotine from cigarettes that have a lower nicotine yield than their usual brand (Herning et al., 1981; Russell et al., 1975). A similar behavior may occur among cigarette smokers when they switch to ECIGs. In one study, smokers who were most successful in completely switching to an ECIG were those who increased their puff durations and total inhalation time per day (Guerrero-Cignarella et al., 2018). Also, ECIG users have shown to take more puffs and longer puffs when they use a liquid with a low, vs. a high, nicotine concentration (Dawkins et al., 2016). Such changes in puff topography may explain the differences in nicotine intake between ECIG-naïve and ECIG-experienced individuals. Experienced ECIG users tend to take longer and/or larger puffs than their ECIG-naïve counterparts (Farsalinos et al., 2015; Hiler et al., 2017), and longer puffs have been shown to result in increased nicotine delivery when device type, power level, puff number, and interpuff interval are held constant (Blank et al., 2019).

Predictors of ECIG Dependence

As demonstrated, ECIGs vary widely in terms of their device and liquid characteristics, and thus wide variation in user behavior and in nicotine delivery is observed. Consequently, it may be difficult to identify reliable predictors of ECIG dependence. Thus far, extant work has shown that higher dependence scores are associated with only a few device/liquid characteristics among ECIG users who are current or former cigarette smokers: the presence of nicotine (vs. no nicotine; Morean, Krishnan-Sarin, & O’Malley, 2018; Morean, Krishnan-Sarin, Sussman, et al., 2018), higher liquid nicotine concentrations (Foulds et al., 2015; Harvanko et al., 2018; Martinez
et al., 2019), and devices that are larger than a cigarette or have a button that is used to activate the device (e.g., tank-style devices; Foulds et al., 2015). Work from our own laboratory reveals a similar pattern among never-smoking ECIG users, with only devices that contain nicotine (vs. devices that do not contain nicotine) predicting higher ECIG dependence scores (Douglas et al., 2022). In contrast, when individual device features are combined to create categories of device types, significantly higher dependence scores are observed for users of devices with non-refillable cartridges (e.g., fourth-generation devices) and refillable tanks (e.g., second-generation devices) relative to earlier disposable ECIGs (often first-generation devices; Douglas et al., 2022). The fact that device and liquid characteristics may be better predictors of dependence when considered in terms of device type rather than individually is not surprising. ECIG users of devices with relatively higher wattages (i.e., increased power) also report use of liquid with relatively lower nicotine concentrations (Smets et al., 2019; Wagener et al., 2017). Indeed, the amount of nicotine yielded by a high voltage/low nicotine concentration combination (e.g., third- and fourth-generation devices) can be comparable to that for a low voltage/high nicotine concentration combination (e.g., first and second-generation devices) when all other parameters are held constant (Talih et al., 2015).

Still, there exist hundreds of different combinations of available device and liquid characteristics: device voltage (e.g., up to 5.2 V), electrical resistance, liquid storage unit (e.g., refillable and non-refillable cartridges, tanks, and pods), liquid nicotine concentration (e.g., 0 to > 75 mg/mL), liquid solvent ratio (e.g., 100% PG to 100% VG), and liquid flavorings. Thus, more work is needed to examine these features alone and in various combinations to determine which are the most reliable predictors of ECIG dependence. This work can help inform regulatory efforts aimed at tobacco-related harm prevention and reduction.
As for user behavior, higher dependence scores have been associated with a longer history of ECIG use, a heavier pattern of ECIG use (e.g., more use days/month, more puffs per vaping episode), and a shorter latency to vape after awakening among former or current cigarette smokers (Do et al., 2022; Foulds et al., 2015; Leventhal et al., 2021; Martínez et al., 2019; Morean, Krishnan-Sarin, & O’Malley, 2018; Piper et al., 2019). In our study using ECIG users who have never smoked cigarettes, more ECIG-use days in the past 30 predicted higher dependence scores (Douglas et al., 2022). While the aforementioned studies provide valuable insight into the variables that may predict ECIG dependence, limitations exist in regard to the measures used and/or users’ knowledge of their device.

**ECIG Measurement Limitations**

Current survey measures for assessing ECIG use are limited in several ways. First, the majority of existing surveys have not been validated for ECIG use. Most are those originally designed for cigarette smoking that have been adapted for ECIGs (e.g., terms like “cigarette” and “smoking” are merely replaced with “ECIG” and “vaping”), though some initial validation testing has been conducted on a few measures: the E-cigarette Dependence scale (EDS; Morean, Krishnan-Sarin, Sussman, et al., 2018), the Penn State Electronic Cigarette Dependence Index (PSECDI; Foulds et al., 2015), and the e-cigarette Fagerström Test of Cigarette Dependence (e-FTCD; Piper et al., 2019). Still, questions included in such measures may not apply to ECIG use. One such question is “Do you find it difficult to refrain from vaping in places where it is forbidden?” ECIG use is permitted in many locations where cigarettes are not, and is often used even in places where it is prohibited due to its discreet nature relative to cigarette smoking. Indeed, many users report that they can “stealth” vape, or use their ECIG such that it does not create vapor clouds that are noticeable by others (Keamy-Minor et al., 2019; McKelvey &
Halpern-Felsher, 2020). Notably, other measures of tobacco dependence have yet to undergo validation testing for ECIGs, including the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM-V) of the APA (2013). Second, the individual questions used to assess device/liquid characteristics or behaviors may lack detail. As an example, questions may probe whether the respondent uses a device that allows the voltage to be adjusted (e.g., “Does your e-cig have a button or control on it that allows you to control or vary the device voltage?”), but not the specific voltage level used by the respondent (e.g., 3.3 V vs. 5.2 V). Similarly, characteristics are sometimes evaluated via forced-choice options that automatically categorize responses (e.g., “0-3,” “4-6,” “7-9,” or “> 9” mg/mL nicotine), thus excluding important details. A possible reason for the exclusion of more detailed questions involves users’ poor knowledge regarding the characteristics of their device/liquid and/or differences in the nomenclature used between user and research groups (Alexander et al., 2016; Coleman et al., 2018; Ozga et al., 2021; Pearson et al., 2020). Furthermore, ECIG users may vary on how they prefer to quantify their ECIG use (Cassidy et al., 2017).

**ECIG Knowledge Limitations**

ECIG products have been available in the U.S. for over a decade, but researchers are only now beginning to reveal the extent to which users are uninformed about ECIG products. In a sample of young adults who had ever heard of pod-style ECIGs, the largest proportion “did not know” the nicotine concentration of any of the devices assessed (e.g., JUUL, Suorin Drop, Myblu; McKelvey & Halpern-Felsher, 2020). In fact, only 7% of those who had heard of JUUL devices were able to accurately report the nicotine content (59 mg/mL; McKelvey & Halpern-Felsher, 2020). Moreover, ECIG users may not have a clear understanding of what nicotine concentration means based on common labeling conventions (Morean et al., 2021). After
adolescents were informed that JUUL contains “5% nicotine” (a high strength), the majority incorrectly stated that JUUL had a “low” or “medium” nicotine strength (Morean et al., 2019). Many ECIG users are also unable to report the specific voltage or resistance of their device, or report values that are implausible (Rudy et al., 2017). Prior work suggests that even exclusive ECIG users are confused over the differences between some ECIG products (Alexander et al., 2016). For instance, few members of a focus group could describe the differences between vape pens, electronic nicotine delivery devices, e-hookahs, and e-pens, although most were familiar with the terms (Alexander et al., 2016).

On the other hand, some confusion may simply be due to differences in the terms being used between users and the research community (Alexander et al., 2016; Pearson et al., 2020). In a sample of smokers posting about ECIGs on the internet, 92% used the term “e-cig” but none used “electronic nicotine delivery system,” which is common in the scientific literature (Pearson et al., 2017). The term “e-cigarette” has been associated more frequently with first-generation devices, while “vapes” has been associated more frequently with second- and third-generation devices (Pearson et al., 2020). It is not surprising, therefore, that 39% of adolescents respond “no” or “I don’t know” to the question, “Do you consider a JUUL to be a type of e-cigarette?” (Morean et al., 2019). Interestingly, a similar phenomenon has been described previously for cigar products. As many as three quarters of adolescent cigar users have reported using brand-specific “Black & Milds,” but not “cigars” despite the fact that “Black & Milds” are a type of cigar (Nasim et al., 2011; Yerger et al., 2001). Limitations in ECIG users’ knowledge of their device, as well as discrepancies in the terms being used between ECIG users and researchers, may lead to inaccurate interpretations of study findings. Thus, more research is needed to identify areas of disconnect, which may in turn lead to more accurate study measures.
Statement of the Problem

After years of effort by those in the research and public health communities, rates of combustible cigarette use are now the lowest in recorded history: a 67% reduction since 1965 (Wang, 2018). In contrast, rates of ECIG use are on the rise, including among groups with little history of other tobacco product use (Creamer et al., 2019). While the majority of adult ECIG users have some history of cigarette smoking (CDC, 2016), ECIG use among never smokers is becoming more popular (Dai & Leventhal, 2019). From 2014 to 2018, the prevalence of ECIG use among young adult never smokers increased from 1.5% to 4.6% (Dai & Leventhal, 2019). There are concerns that ECIG use promotes dependence, particularly among these generally tobacco-naïve groups. Our understanding of ECIG dependence is limited, however, by the vast number of available products that differ in terms of their device/liquid features and thus their ability to deliver nicotine. Further complicating this issue is that users may have a limited understanding the products that they use, making it difficult for researchers to accurately measure product features and use behaviors. The primary purpose of this study is to evaluate ECIG use behaviors and device/liquid characteristics as predictors of dependence. A secondary purpose is to evaluate users’ understanding of their products by comparing their survey responses to pictures of their device/liquid that they provide.

Implications

Evaluating predictors of ECIG dependence and user knowledge has several public policy regulation implications. Currently, the FDA has regulatory authority over the manufacturing, marketing, and distribution of tobacco products, including ECIGs (FDA, 2020). The FDA defines “tobacco product” as "any product made or derived from tobacco that is intended for human consumption, including any component, part, or accessory of a tobacco product” (FDA,
Although accessories (e.g., screwdrivers, lanyards) of newly deemed ECIG products were excluded from FDA control, product components and parts (e.g., batteries, liquid) were included under the Deeming Rule (FDA, 2019). Consequently, the FDA has authority to limit or remove ECIGs with certain device characteristics in the interest of public health. Therefore, research is needed to inform policy by evaluating the degree to which the use of certain ECIG characteristics predict dependence. Policy implications also exist in regard to user knowledge. Currently, the FDA has the ability to regulate ECIG product packaging. For instance, nicotine warning statements (“WARNING: This product contains nicotine. Nicotine is an addictive chemical.”) must comprise at least 30% of the portion of the package that is most likely to be presented to the consumer (FDA, 2018b). Further, the FDA prohibits the use of certain terms (‘light,’ ‘low,’ and ‘mild’) on tobacco product packaging as they may mislead consumers (FDA, 2018a). Research elucidating ECIG users’ knowledge of their devices can help regulatory agencies make more informed decisions about product packaging and the dissemination of ECIG information.

**METHOD**

**Participants**

A purposive sample of experienced ECIG users were recruited through Amazon Mechanical Turk (MTurk; https://www.mturk.com/), internet forum websites such as Reddit (https://www.reddit.com/), and West Virginia University (WVU) survey listservs. Participants were required to be English speakers, ≥ 18 years of age, self-report current use of a nicotine containing ECIG on an average of ≥ 4 days per week for at least ≥ 3 months, and currently reside in the United States. Individuals were excluded if they reported lifetime use of > 100 cigarettes.
Procedures

A survey was advertised on MTurk, online forums, and listservs with the title *Survey on Electronic Cigarette Use/Vaping*. Interested individuals were provided a link to the survey, which was hosted on Qualtrics (https://www.qualtrics.com/). Those who clicked on the link first completed a set of screening questions that were used to determine eligibility (Appendix A). Individuals were considered ineligible if they chose not to answer any of these questions or if they did not meet the inclusion/exclusion criteria discussed above. Participants recruited through MTurk were compensated $0.05 for completing the screening questionnaire, regardless of whether they were eligible. Participants recruited via other avenues (e.g., online forums, WVU listservs) that were deemed ineligible were not compensated for completing the screening questions. All eligible participants who provided informed consent continued to the subsequent sections of the survey, which took approximately 30 minutes to complete. Survey questions assessed participants’ ECIG and other tobacco use patterns, device and liquid characteristics, and level of dependence. Participants were asked to answer all questionnaire items; however, they were permitted to skip questions at their discretion. After answering all the survey questions, participants were required to upload a picture of their most frequently used ECIG device/liquid. Upon verification of study completion by research staff, participants recruited via MTurk were paid a bonus of $3.95 ($4.00 total) and participants recruited via online forums and WVU listservs were emailed a $4.00 Amazon.com Gift Card.

Multiple techniques were employed to improve the quality of the data collected. First, participants were required to pass a test known as the Completely Automated Public Turing test to tell Computers and Humans Apart (CAPTCHA). As an example, the participant might be shown a picture that is broken up into sections, and asked to click on the specific sections that
contain all or parts of an object (e.g., a traffic sign, a bridge). Second, to detect possible robots, participants were required to answer correctly a question that was included in the form of a picture (“Dog is to puppy as cat is to…”). Third, the survey contained two questions designed to check participants’ attention (“Please select ‘yes’ for this question.”). Forth, participants were required to upload a picture of their personal ECIG device and liquid (for details, see ECIG Device Characteristics and Use History below). This served as an additional validation measure. Participants who did not pass these validation checks were excluded from the full sample. Finally, to improve the quality of survey responses, response requirements were used on Qualtrics. For example, if the question required a numerical response, participants could not enter a letter into the response box.

Measures

Demographic and Drug Use Characteristics

Participants were asked to provide basic demographic information including their age, gender, sexual identity, race, ethnicity, income, and level of education (Appendix B). Additional questions assessed participants’ lifetime and past 30-day use of tobacco products, including cigarettes, cigars (e.g., large, small, cigarillo), smokeless tobacco (e.g., dip, snus, chew), hookah/waterpipe, and nicotine replacement therapy (e.g., gum, patch, lozenge, inhaler). Lifetime and past 30-day use of alcohol and other substances (e.g., benzodiazepines, cannabinoids, stimulants, opiates) was also assessed (Appendix C).

ECIG Device Characteristics and Use History

Participants were asked to provide a thorough description of their ECIG use history (Appendix D) and the characteristics of the ECIG device/liquid that they use most often (as in Yingst et al., 2019; Appendix E). Specifically, participants reported on the average number of
days per month over the past 3 months that they used an ECIG, as well as their duration of ECIG use in units of months or years. Participants were also asked about the individual features of their most-used ECIG (e.g., nicotine concentration, adjustable power), as well as the device type (e.g., mod, pod).

Importantly, research shows that some users may have a limited understanding of the features of the products that they use (Morean et al., 2021; Rudy et al., 2017). To confirm that participants reported their device characteristics accurately, they were asked to upload pictures of their most frequently used ECIG device and liquid (Appendix F). To maintain confidentiality, they were instructed to make sure nothing identifiable was present in the photo. They also were instructed to include a unique code in their photo to ensure that they did not upload pictures found on the internet or elsewhere. Participants who did not upload a clear picture with the requested information were not compensated and were excluded from the final sample.

**PSECDI**

The Penn State Electronic Cigarette Dependence Index (PSECDI) was the primary measure used to assess ECIG dependence (Foulds et al., 2015; Appendix G). The PSECDI consists of 10 items modified from the Penn State Cigarette Dependence Index, with language changed from “cigarette” to “e-cigarette.” The measure has been shown to predict ECIG dependence in a sample of ex-cigarette smokers (Foulds et al., 2015). Scores on the PSECDI range from 0-20 with higher scores indicating increased dependence.

**EDS**

The four-item E-Cigarette Dependence Scale (EDS) was also used to assess ECIG dependence (Morean, Krishnan-Sarin, Sussman, et al., 2018; Appendix H). The EDS was adapted from the Patient-Reported Outcomes Measurement Information System (PROMIS) Item
The four-item EDS consists of questions on a 5-point scale ranging from 0 (*never*) to 4 (*almost always*). Higher mean scores indicate higher levels of dependence.

**DSM-V Tobacco Use Disorder**

Another measure that was used to assess ECIG dependence was adapted from the DSM-V diagnostic criteria for tobacco use disorder (APA, 2013). This general measure of nicotine dependence was included in this study so that comparisons with the other, ECIG-specific, measures could be made. All language was changed from “tobacco” to “e-cig/vape.” Scores on this measure range from 0-12 and indicate no dependence (0-1), or mild (2-3), moderate (4-5), or severe (> 6) dependence. Due to low cell sizes, scores indicating no dependence or mild dependence were combined for analyses. This no/mild dependence category served as the dependent-variable reference group in the multinominal logistic regression models.

**Participant Safety and Rights**

This study was exempt from IRB approval; however, participants’ safety and rights were assured through an IRB-acknowledged protocol. Participants were made aware of the WVU Office of Research Integrity and Compliance, and their right to contact this office with any questions about their role as participants. De-identified data were stored on password-protected computers.

**Data Preparation and Analysis**

**Data Preparation**

Prior to conducting the statistical analyses, the survey data were cleaned and appropriately prepared. The following variables were used in the regression analyses based on self-reports. Values for participants who reported their ECIG use duration in months were
converted to years. For device type, participants were asked, “Which of the following best describes the style of your e-cig/vape?” Response options included a) cig-alike, b) vape pen, c) mod, and d) pod. This variable was dummy coded with “pods” as the referent group. For individual ECIG characteristics, participants reported on whether their device a) is refillable (vs. not refillable), b) is disposable (vs. not disposable), and c) has adjustable power capabilities (vs. does not have adjustable power capabilities). These variables were all coded 0 = no, 1 = yes. Respondents also reported on d) their most frequently used nicotine formulation (0 = freebase, 1 = salt), as well as e) flavor, and f) nicotine concentration. Survey response options for flavor were tobacco, mint/menthol, fruit, sweet/candy, alcoholic drink, clove/spice, and chocolate. Due to low cell sizes for other flavors, this variable was dichotomized into 0 = non-mint/menthol, 1= mint/menthol for analyses. For nicotine concentration, participants had the option to report in units of mg/mL or a percentage. Nicotine concentrations reported as a percentage were converted to mg/mL by multiplying the value by 10 (see Morean et al., 2021). Values for participants who reported both a 5% nicotine concentration and use of a JUUL- or NJOY- brand device were corrected to reflect their known nicotine concentrations of 59 mg/mL and 58 mg/mL, respectively (JUUL Labs, 2021; NJOY, 2021). Nicotine concentrations > 100 mg/mL were removed from analyses, as such values exceed those of any known product on the market at the time of data collection. Indeed, for reported concentrations that exceeded this cutoff, research staff searched online retail websites to confirm that no such concentrations were available for those specified styles/brands.

The pictures provided by participants were coded by two independent raters according to individual device characteristics and device type. These variables were used in the picture-based regression analyses. In addition, they were compared to participants’ self-reports as a secondary
study outcome. Raters coded devices into one of five categories: a) cig-alike, b) vape pen, c) mod, d) pod-style, e) modern disposable. These device types were dummy coded for regression analyses with pods as the reference category. Raters coded individual device characteristics according to a) whether the device was refillable (0 = no, 1 = yes), b) whether it had adjustable power capabilities (0 = no, 1 = yes), c) flavor (0 = non-mint/menthol, 1 = mint/menthol), d) liquid nicotine concentration (continuous), and e) nicotine formulation (0 = freebase, 1 = salt). Characteristics that were not directly identifiable in the photos were searched for on Google and/or device manufacturers’ websites. Nicotine formulation is typically only reported on websites if the solution is a salt, and freebase solutions contain notably less nicotine than salt-based solutions. Thus, liquids for which there was no mention of nicotine formulation on the internet that had low nicotine concentrations (i.e., < 20 mg/mL) were coded as freebase solutions. Liquid flavor was initially coded as the exact flavor specified on the container (e.g., blood orange mango, classic tobacco). These flavors were then categorized based on groupings from the PATH study: tobacco, mint/menthol, fruit, sweet/candy, alcoholic drink, nonalcoholic drink, clove/spice, chocolate, and other. Notably, the cell sizes for flavors other than mint/menthol were too small to treat separately. Characteristics for which the independent raters did not agree were assessed by a third rater. Device and liquid characteristics that could not be determined via visual inspection of pictures or an internet search were considered missing.

Next, data were examined to determine the level and pattern of missingness. Little’s MCAR test determined that the data were missing completely at random (all p’s > .05). Variables were then examined to ensure that they met the assumptions of regression models. The distribution of the variables was assessed through skew and kurtosis values, as well as visual inspection of a histogram. The continuous dependent variables were determined to be normally
distributed. Residuals were plotted against predicted values to determine whether the data met the assumption of homoscedasticity. Normal P-P plots were examined to determine whether the residuals were normally distributed. In addition, multivariate outliers were investigated in terms of leverage, discrepancy, and influence. Finally, the variables were assessed for multicollinearity using a Variance Inflation Factor (VIF) standard of > 4.0. Picture-based nicotine formulation (77.9% salt, 22.1% freebase) was excluded from subsequent analyses due to multicollinearity with nicotine concentration (VIF > 4.0, \( r_{pb} = .91, p < .001 \)).

**Data Analysis**

Regression analyses were conducted using *Mplus* version 8.6. Full information maximum likelihood (FIML) was used to estimate missing values. First, Pearson correlations examined bivariate associations among variables of interest. Next, mean differences in dependence scores were assessed as a function of individual (e.g., refillable; rechargeable) and combined (i.e., device type) ECIG characteristics. These differences were assessed using independent-samples t-tests and one-way analyses of variance (ANOVA) for PSECDI and EDS measures, and using chi-square tests of independence for the DSM-V measure. Tukey’s Honestly Significant Difference post-hoc tests were used to follow-up on significant ANOVA results where appropriate. Next, separate multivariable linear (PSECDI, EDS) and multinominal logistic (DSM-V) regressions were used to determine whether ECIG device/liquid features and user behavior could be used to predict dependence scores after controlling for participant age, gender, and race.

PSECDI score was the outcome variable for models 1-5. Model 1 included demographic variables, ECIG use duration in years, and ECIG use days/week as predictors. Models 2-5 included the same predictors as model 1, with the addition of ECIG characteristic predictors:
self-reported individual characteristics (model 2), self-reported device type and nicotine concentration (model 3), picture-based individual device characteristics (model 4), and picture-based device type and nicotine concentration (model 5). Models 6-15 followed the same pattern, but with EDS score (models 6-10) and DSM-V dependence level (models 11-15) as outcome variables. $R^2$ is reported to explain the amount of variance in ECIG dependence score that is accounted for by the linear regression models. Findings were considered statistically significant at $p < 0.05$.

Cohen’s kappa ($\kappa$) determined the level of agreement between raters for device type, as well as agreement between participants’ self-reported device characteristics and ECIG picture characteristics, using SPSS version 27. Self-reported “don’t know” responses to questions (e.g., nicotine formulation, adjustable power, disposable) were coded as missing.

**Study Hypotheses**

Based on previous research, variables that were expected to significantly predict dependence were duration of ECIG use (as in Foulds et al., 2015; Johnson et al., 2018) and daily (vs. nondaily) ECIG use (as in Morean, Krishnan-Sarin, Sussman, et al., 2018). Among liquid characteristics, higher nicotine concentrations were expected to predict ECIG dependence (as in Foulds et al., 2015), as higher nicotine concentrations have been shown to increase nicotine delivery (Hiler et al., 2017; Ramôa et al., 2016). Furthermore, when ECIGs were considered in terms of device types, dependence scores were expected to be higher for users of device types with better nicotine delivery capabilities (e.g., use of tank-style ECIGs vs. cig-alike devices; as in Douglas et al., 2022).
RESULTS

Participant Demographics

A total of 4449 individuals completed the screening questionnaire; 81.3% were from MTurk and 18.7% were from WVU listservs or Reddit. Individuals were excluded for no ECIG use in the past 30 days (n = 936), smoking > 100 cigarettes in their lifetime (n = 856), using an ECIG on an average of < 4 days per week (n = 401), not using an ECIG with nicotine (n = 133), using an ECIG for < 3 months (n = 36), living outside of the U.S. (n = 2), and being < 18 years old (n = 2). Further, n = 1205 were excluded > 1 reason. Of those who met the eligibility criteria, n = 512 provided informed consent and continued to the study survey, where n = 282 uploaded a picture. Of these participants, only n = 141 uploaded an acceptable picture (i.e., with survey code, not a stock photo). Finally, n = 134 uploaded an acceptable picture and completed the survey. These participants were included in the final sample.

Of the N = 134 participants included in the final sample, 56.0% were recruited via WVU listservs or Reddit and 44.0% were recruited via MTurk. Demographic characteristics for this final sample are shown in Table 1. Participants had a mean age of 23.37 (SD = 5.63) years. The majority identified as female (59.8%) and white race (82.3%). Of the 17.7% who did not identify as white race, races reported included 6.9% Multiracial, 5.4% Asian, 4.6% Black, and 0.8% Puerto Rican. Participants reported using ECIGs for an average of 6.51 (SD = 0.90) days per week for 2.50 (SD =1.43) years. The mean ECIG liquid nicotine concentration across all devices was 35.87 (SD = 22.83) mg/mL based on self-report, and 41.93 (SD = 20.81) mg/mL based on ECIG pictures (not shown in table). When device types were considered separately, the self-reported mean nicotine concentration was 9.05 (SD = 11.82, range = 3.00-50.00) mg/mL for mods and 42.10 (SD = 20.06, range = 0.05-60.00) mg/mL for non-mods. Based on pictures, the
mean nicotine concentration was 5.00 (SD = 3.87, range = 3.00-18.00) mg/mL for mods and 48.00 (SD = 15.52, range = 3.00-60.00) mg/mL for non-mods. All participants reported smoking ≤ 100 cigarettes in their lifetime (M = 20.36, SD = 27.38).

**Cohen’s kappa Results**

Agreement between independent raters for picture-based ECIG device type was excellent (κ = .95). Agreement between participants’ self-reports and pictures was excellent for individual features of refillable (κ = .92) and disposable (κ = .89), good for adjustable power (κ = .70), and fair for nicotine formulation (κ = .38, all p’s < .001). Incorrect responses were provided by 3.7% of participants for refillable, 3.9% for disposable, 12.5% for adjustable power, and 28.2% for nicotine formulation. Agreement for device type was moderate (κ = .53, p < .001), with 26.1% disagreement between self-reports and pictures. Based on the pictures, raters classified participants’ devices as vape pens (6.3%), mods (18.9%), and pods/disposables (74.8%). For participants who chose the term “pen” (26.1%) to describe their device, raters classified 65.5% of their devices as a “pod/disposable” using the same terms. For participants who chose the term “mod” (20.7%) to describe their device, raters classified 21.7% of their devices as “pod/disposable.” Also notable is that nearly 15% of participants said that none of the pictures resembled their device; raters classified these devices as pens (5.2%), box mods (15.8%), and USB-shaped pods (74.7%). “Don’t know” responses, which were coded as missing for analyses, were provided by 1.5% of participants for adjustable power, 3.0% for disposable, and 31.3% for nicotine formulation.

**Bivariate Results**

Tables 2 and 3 display bivariate Pearson correlations for key study variables based on self-reports and pictures, respectively.
**Self-Report Measures**

Table 4 shows descriptive statistics and univariate comparisons for PSECDI and EDS scores as a function of device characteristics for both self-reports and pictures. As shown in this table, no significant differences in PSECDI scores were observed for any individual characteristic (|t|s| < 1.41, ps > .05). In contrast, mean PSECDI scores differed significantly as a function of device type, $F(2, 110) = 3.88, p = .024$. Scores were higher for users of pod-style devices relative to cig-alikes/pens (Tukey’s HSD; $p = .025$). The only individual characteristic that was associated with EDS score was menthol flavoring: EDS scores were significantly higher for users who reported menthol/mint flavored liquid relative to other flavors ($p = .038$). EDS scores did not differ by device type, $F(2, 110) = 1.23, p = .298$. For the DSM-V, the distribution of dependence levels differed by devices that have adjustable power [$\chi^2 (2) = 6.65, p = .036$] and those that are refillable [$\chi^2 (2) = 8.14, p = .017$]. However, no significant differences in DSM-V levels were observed for device type [$\chi^2 (4) = 7.21, p = .125$].

**ECIG Pictures**

Mean scores for the PSECDI did not differ as a function of individual characteristics (|$t$’s| < 1.04, ps > .05) or device type [$F(3, 128) = 2.50, p = .063$]. For the EDS, the pattern of results was comparable to that based on self-reports. Scores differed by flavor, $t(102) = -2.20, p = .03$, with higher scores observed for menthol/mint flavored liquid relative to other flavors. EDS scores did not differ by device type, $F(3, 128) = 1.97, p = 123$. Finally, the distribution of DSM-V dependence levels was not influenced by any individual characteristic ($\chi^2$’s < 4.85, ps > .05), but did differ by device type, $\chi^2(6) = 14.17, p = .028$.

**Regression Results**

**Self-Report Measures**
The results of the multivariable linear regressions predicting PSECDI score from self-reported ECIG characteristics are shown in Table 5. For model 1, longer durations of ECIG use and more ECIG use days/week were associated with higher dependence scores, controlling for age, gender, and race. These ECIG use behaviors significantly predicted PSECDI score in all subsequent models. Model 2 contained the same predictors as model 1, with the addition of individual ECIG characteristics. Notably, no self-reported individual ECIG characteristics significantly predicted PSECDI score. Model 3 consisted of the same predictors as model 1, as well as ECIG device type and nicotine concentration. Relative to using pod-style ECIGs, using cig-alike/vape pens and mods was associated with lower dependence scores. Findings for the EDS are presented in Table 6, and demonstrate that the pattern did not differ from that observed for the PSECDI. For the DSM-V, multinomial logistic regression models are shown in Table 9. Older age was associated with decreased odds of having severe dependence relative to no/mild dependence. Additionally, a higher number of ECIG use days/week was associated with greater odds of having severe dependence compared to no/mild dependence across all models. In model 12, which examined self-reported individual ECIG characteristics, using a device designed to be refilled with liquid was associated with decreased odds of having severe relative to no/mild dependence. In the same model, using nicotine salt ECIG liquid (vs. freebase nicotine ECIG liquid) was associated with increased odds of having severe dependence.

**ECIG Pictures**

Table 7 presents the results of the multiple linear regressions predicting PSECDI score from ECIG characteristics based on pictures. With regard to individual ECIG characteristics, higher nicotine concentrations were associated with higher dependence scores (model 4). In model 5, no ECIG device types were significantly associated with PSECDI score over and above
the influence of demographics and ECIG use behaviors. Findings were similar for the EDS measure, with results presented in Table 8; no individual ECIG characteristics (model 9) or device types (model 10) predicted EDS score, over and above demographics and ECIG use behaviors. Finally, Table 9 shows multinominal logistic regression models predicting DSM-V dependence level from picture-based ECIG characteristics. In model 14, older age was associated with decreased odds of having both moderate and severe dependence relative to no/mild dependence. Additionally, reporting more ECIG use days/week was associated with greater odds of having severe dependence in models 14 and 15.

**DISCUSSION**

The primary purpose of this study was to evaluate ECIG use behaviors and device/liquid characteristics as predictors of dependence in a sample of never-smoking ECIG users. Given that no gold-standard measure of ECIG dependence currently exists, three different measures were included: the PSECDI, EDS, and DSM-V. Also, device characteristics were assessed via two different measurement methods, that of self-reports and that of device pictures. The effects of individual ECIG characteristics (e.g., nicotine concentration, adjustable power, refillable), as well as device type (e.g., pen, mod, pod) were analyzed. A secondary purpose of this study was to compare ECIG users’ self-reports of their device/liquid characteristics to the pictures that they provided.

**Comparison of Participants’ Self-Reports and Pictures**

Agreement between participants’ self-reports and device pictures was good or excellent for individual features of refillable, disposable, and adjustable power. This finding is not surprising, as these features are those users must interact with regularly (e.g., regularly refilling...
the liquid, replacing the entire device after use, adjusting power to desired level). Indeed, previous research shows that ECIG users are less likely to report “don’t know” for basic product features such as refillable and disposable (Felicione et al., 2021). In comparison, agreement for nicotine formulation (salt vs. freebase) was only fair. Users of ECIGs that are prefilled with liquid may be unaware of their nicotine content, perhaps because they are less interested in individualizing their liquid features. That is, the sample of ECIG users included here may be choosing devices based on their brand popularity and/or flavor options, without particular concern for liquid features. In fact, these users may not even be aware that liquid nicotine exists in different forms. This is concerning, as using a high-concentration nicotine salt solution in a high-powered device would result in extreme levels of nicotine delivered to the user.

For device type, agreement between self-reports and pictures was moderate, with nearly 30% of participants’ responses not matching that of research staff. As an example, a large portion of devices designated as “pods” by raters were described as “pens” by users. Similarly, many users reported that none of the pictures resembled these rater-designated “pod” devices. These findings may be explained by discrepancies in the terminology used by ECIG users and researchers. There also exist products that do not fall neatly into one category of device type (Ozga et al., 2021). Some pod-style ECIGs, for example, are also modifiable. Users of these modifiable, pod-style ECIGs may have selected “mod” instead of “pod” for their device type. These findings highlight the potential limitations of research that relies on user-reported device and liquid characteristics.

User Behavior Predicting Dependence

Accounting for demographic characteristics, longer durations of ECIG use and a greater number of ECIG use days/week were associated with higher PSECDI and EDS scores. For the
DSM-V measure (APA 2013), a greater number of ECIG use days/week – but not duration of use – was associated with severe dependence relative to no/mild dependence. These results are largely consistent with studies based on current or former smokers suggesting that a lengthier history and/or a heavier pattern of ECIG use are associated with higher levels of dependence (Do et al., 2022; Foulds et al., 2015; Leventhal et al., 2021; Martínez et al., 2019; Morean, Krishnan-Sarin, & O’Malley, 2018; Piper et al., 2019; Yingst et al., 2021). They also are consistent with our own recently published work showing that, among never-smoking ECIG users, more frequent past 30-day use significantly predicts ECIG dependence (Douglas et al., 2022). Notably, the ECIG dependence items included in that work were largely different from those used herein because the data derived from a national-level survey administered between 2016-2018 (Hyland et al., 2017).

**ECIG Characteristics Predicting Dependence**

*Individual ECIG Characteristics*

After accounting for ECIG use behaviors and demographics, very few individual ECIG characteristics were associated significantly with dependence regardless of the measure used. One such characteristic was nicotine concentration, which predicted dependence level only via the PSECDI and only based on picture-based characteristics. Nicotine concentration is positively associated with nicotine yield and delivery (Hiler et al., 2017; Ramôa et al., 2016; Talih et al., 2015); however, prior work evaluating nicotine concentration as a predictor of ECIG dependence shows mixed findings. Some studies based on samples of current or former ECIG users demonstrate a positive association between nicotine concentration and ECIG dependence (Foulds et al., 2015; Harvanko et al., 2018; Martínez et al., 2019), while others show no such effect (Do et al., 2022; Piper et al., 2019). These inconsistent findings may be explained in part by the types
of devices used by participants in the study samples. Indeed, nicotine concentration can interact with device power to determine the amount of nicotine delivered to the user (Wagener et al. 2017). Consequently, both low and high liquid nicotine concentrations could result in comparable nicotine delivery assuming they are used with higher versus lower powered devices, respectively.

The only other individual ECIG characteristic that was associated with dependence in the current study was self-reported use of salt-based nicotine (vs. freebase). Users of salt-based nicotine formulations were more likely to have severe dependence relative to no/mild dependence on the DSM-V. Because nicotine salt solutions contain significantly more nicotine than freebase solutions (Barrington-Trimis & Leventhal, 2018), it is expected that salt-based formulations would lead to greater nicotine absorption and thus greater dependence. Still, research on this phenomenon is currently limited (Gholap et al., 2020). It also is unknown whether nicotine formulation, like nicotine concentration, interacts with other device features such as power to influence nicotine delivery to the user. If these individual characteristics do interact with device features, then they are unlikely to be reliable predictors of dependence unless considered within the same device type and brand (i.e., when all other individual characteristics are held constant).

**Device Type**

After controlling for demographics, use behavior, and nicotine concentration, device type predicted ECIG dependence only for the PSECSI based on self-reports. Specifically, self-reported use of a cig-alike/pen-style ECIG or mod was associated with a lower PSECDI score relative to use of pod-based devices. This finding is supported by extant work showing that cig-alikes and mods deliver less nicotine than pod-based ECIGs (Yingst, Hrabovsky, et al., 2019),
and may be consistent with our own previous work. Specifically, in our secondary analysis of national-level data from 2016-2018, lower dependence levels were observed for ECIG users of devices that were disposable relative to those that used non-refillable cartridges (Douglas et al., 2022). Based on the brand information provided by participants in this dataset, as well as the period of data collection, disposable devices appeared to be mostly ‘first generation’ cig-aliases while non-refillable cartridges appeared to include the newer pod-style devices such as JUUL. Still, more work is needed to confirm these findings.

Strengths

The current study has several strengths. First, the use of participant-provided pictures to verify ECIG device/liquid characteristics is novel and increases the validity of study findings. Discrepancies in the terminology used between ECIG users and the research community may lead to an inaccurate interpretation of study results (Ozga et al., 2021). As an example, adolescents are more likely to endorse ECIG use if survey items specify a device type (e.g., JUUL, Vuse) rather than referring to “e-cigarettes” more broadly (Morean, Camenga, Bold, et al., 2018). Similar findings have been reported for surveys that assess use of certain types of cigars (Nasim et al., 2011). Thus, asking participants to provide a picture of their own device and liquid may circumvent some of these challenges regarding terminology (Nian et al., 2021). Further, the use of participant-provided pictures helps to verify that real ECIG users completed the survey, as opposed to bots or professional survey takers (Hardesty et al., 2021). Although some bots and professional survey takers are able to upload photos, such photos are unlikely to be unique (e.g., not found through a quick internet search) and/or to include the required validation code. Second, the current study employed the use of three measures of ECIG dependence that together capture multiple symptoms of nicotine/tobacco dependence (e.g.,
withdrawal, craving, use despite harm, tolerance, and interruption of daily activities). While the PSECDI and EDS are specifically designed to assess ECIG dependence, the DSM-V is a more general measure of nicotine dependence that is likely to be used in a clinical setting. Also, none of these measures are currently considered a gold-standard for assessing ECIG dependence. Thus, the inclusion of multiple measures improves the validity of our findings and makes cross-measure comparisons possible. Finally, the current study is strengthened by the inclusion of experienced ECIG users who are never-smokers. Much of the existing literature is based on samples of current or former cigarette smokers (Do et al., 2022; Foulds et al., 2015; Morean, Krishnan-Sarin, Sussman, et al., 2018; Piper et al., 2019; Yingst et al., 2021); therefore, our sample of never-smokers reduces the potential confound of nicotine dependence from cigarettes.

**Limitations**

Despite these strengths, the results of the current study should be considered in light of several limitations. First, self-reports may have been influenced by social-desirability bias, leading to under- or over-reporting symptoms of dependence and/or ECIG consumption. Still, the dependence levels observed herein were higher than those reported in prior studies (Du et al., 2019; Foulds et al., 2015; Morean, Krishnan-Sarin, Sussman, et al., 2018; Yingst et al., 2021; Yingst, Foulds, et al., 2019). Indeed, the never-smoking ECIG users included here had an average score of 10.0 on the PSECDI and 2.2 on the EDS. In contrast, other work shows average scores of 6.6 to 8.6 on the PSECDI (Buu et al., 2021; Du et al., 2019; Foulds et al., 2015; Piper et al., 2019; Yingst et al., 2021; Yingst, Foulds, et al., 2019), and of 1.4 on the EDS (Morean, Krishnan-Sarin, Sussman, et al., 2018), including among some samples of ECIG users who also smoked cigarettes. No known studies have used the DSM-V diagnostic criteria as a measure of ECIG dependence. Another potential limitation is the cross-sectional nature of the study, making
causal and temporal inferences impossible. Future work should consider using a longitudinal design to determine the causal effect of using specific ECIG device/liquid characteristics on dependence.

Additionally, study findings may have been influenced by inconsistencies in the terminology used between ECIG users and researchers (Alexander et al., 2016; Ozga et al., 2021; Pearson et al., 2020). Participants may have been unfamiliar with the response options used to describe their device type (e.g., cig-alike, pen, pod, mod) or other ECIG features (e.g., atomizer, cartomizer). The term “vape” was used alongside “e-cig” in the study survey; however, items did not account for slang or alternative names for most ECIG characteristics. Moreover, previous research has found that ECIG users may have difficulty understanding or are unaware of certain features of their device (McKelvey & Halpern-Felsher, 2020; Morean et al., 2021; Rudy et al., 2017). To circumvent some of these challenges, definitions were provided for some ECIG device/liquid features (e.g., “Liquids are often described as containing a percentage of vegetable glycerin (VG) and/or propylene glycol (PG). For instance, liquids might be 0% VG and 100% PG, or 30% VG and 70% PG.”). Still, participants may have guessed on items for which they were confused, or skipped them completely. Another limitation is the inability to include device power in the current analyses due to the large amount of missing data (75% missing for self-report, 51% missing for pictures). As mentioned above, device power is shown to affect nicotine delivery (Hiler et al., 2020), and can interact with other ECIG features such as nicotine concentration. Unfortunately, however, it appears common for ECIG users to be largely unaware of the power level of their devices, regardless of the unit of measurement presented (e.g., voltage, wattage; Harvanko et al., 2018; Rudy et al., 2017). Thus, instead of assessing device
power continuously, we simply examined whether participants used devices with adjustable power capabilities.

Characteristics of the sample should also be considered. Approximately 44% of study participants were recruited through MTurk, an online crowdsourcing platform. The participants recruited via MTurk are likely to come from a wide variety of geographic locations in the United States (Buhrmester et al., 2011). In contrast, the majority of the remaining participants were recruited through WVU listservs, and may reside in more homogeneous geographic regions (e.g., sections of Appalachia). The sample is also limited in terms of racial, sexual, and gender diversity. Most participants were white, with only about 7% making up the next largest racial group (Multiracial). Due to the small sample size, race was dichotomized into white and racial minority. For this reason, results may not capture the unique experiences of the Black, Asian, Multiracial, and Puerto Rican participants included in this sample. Similarly, while survey items included response options for individuals identifying as a sexual and/or gender minority, these groups were not large enough to treat as separate in the analyses. Thus, the sample as a whole may not be representative of the US population of ECIG users. Future research should consider oversampling these minority groups for increased representation.

Conclusions and Future Directions

Results from the current study suggest that ECIG device/liquid features are not salient predictors of ECIG dependence in a sample of experienced ECIG users who are largely tobacco naïve. Nicotine delivery, and consequently ECIG dependence, are influenced by many factors that are not limited to characteristics of the ECIG device or liquid. Indeed, results of this study show that characteristics of the user (e.g., use duration, use frequency) are likely stronger indicators of ECIG dependence level. However, given the small size of the sample, these results
should be interpreted with caution. Future work should include a larger and more diverse sample to increase the generalizability of findings. Future work may also benefit from a more precise measure of nicotine delivery, such as nicotine flux, which is the amount of nicotine emitted per puff second (Shihadeh & Eissenberg, 2015). Additionally, due to limitations in ECIG users’ knowledge of their devices or discrepancies in the terminology used between ECIG users and researchers, future studies should consider verifying ECIG product characteristics by requiring participants to provide a picture of their ECIG and/or liquid. Employing focus groups or open-ended interviews with ECIG users to determine the clearest terminology to describe ECIG product features may also help to overcome these limitations.
References


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https://doi.org/10.1001/jamanetworkopen.2018.3535


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https://westat.confex.com/westat/trs21/general/eposter.cgi?eposterid=122


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https://doi.org/10.1136/tobaccocontrol-2014-051670
### Table 1

*Participant Demographic Characteristics*

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<th>Characteristic</th>
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<td>23.37 (5.63)</td>
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<tr>
<td>Gender</td>
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<tr>
<td>Female</td>
<td>76 (59.8%)</td>
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<tr>
<td>Male</td>
<td>51 (40.2%)</td>
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<tr>
<td>Race</td>
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<tr>
<td>White</td>
<td>107 (82.3%)</td>
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<tr>
<td>Minority</td>
<td>23 (17.7%)</td>
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<td># Cigarettes/Lifetime</td>
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<td>ECIG use</td>
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<td>Duration (years)</td>
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<tr>
<td>Days/week</td>
<td>6.51 (0.90)</td>
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<td>ECIG dependence score</td>
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<td>PSECDI</td>
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<tr>
<td>No/Mild</td>
<td>43 (32.1%)</td>
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<tr>
<td>Moderate</td>
<td>33 (24.6%)</td>
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<td>Severe</td>
<td>58 (43.3%)</td>
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<td>ECIG device type</td>
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<td>Cigalike/vape pen</td>
<td>31 (27.4%)</td>
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<tr>
<td>Mod</td>
<td>23 (20.4%)</td>
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<tr>
<td>Pod</td>
<td>59 (52.2%)</td>
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<td>Individual ECIG characteristics</td>
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<tr>
<td>Disposable</td>
<td>32 (24.6%)</td>
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<tr>
<td>Refill with liquid</td>
<td>60 (44.8%)</td>
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<tr>
<td>Adjustable power</td>
<td>38 (28.8%)</td>
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<tr>
<td>Nicotine salt ECIG liquid</td>
<td>52 (56.5%)</td>
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<tr>
<td>Flavor</td>
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<tr>
<td>Menthol/mint</td>
<td>59 (44.0%)</td>
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<tr>
<td>Non-menthol/mint</td>
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<td>Nicotine concentration (mg/mL)</td>
<td>35.87 (22.83)</td>
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**Note.** 1. PSECDI = Penn State Electronic Cigarette Dependence Index (range 0-20); EDS = Electronic Cigarette Dependence Scale (range 0-4); DSM-V = Diagnostic and Statistical Manual of Mental Disorders (5th ed.); 2. Self-reported ECIG device types and individual characteristics
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*Note. Bold values denote statistical significance, p < .05*
Table 3

Bivariate Pearson Correlations Among Key Study Variables - Picture-Based Outcomes

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Note. Bold values denote statistical significance, $p < .05$
Table 4
ECIG Dependence as a Function of Individual and Combined Device Characteristics

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Note. p-values reflect significance values from independent samples t-tests (individual characteristics) or one-way ANOVAs (device type).
Table 5

Multiple Linear Regressions Predicting PSECDI Score from Self-Reported ECIG Characteristics

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*Note. Significant items are bolded*

All models controlled for age, gender, race, ECIG use duration, and ECIG use days/week

1Pod-based systems is referent group for device type
Table 6

*Multiple Linear Regressions Predicting EDS Score from Self-Reported ECIG Characteristics*

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*Note.* Significant items are bolded

All models controlled for age, gender, race, ECIG use duration, and ECIG use days/week

^1Pod-based systems is referent group for device type
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Multiple Linear Regressions Predicting PSECDI Score from ECIG Picture Characteristics

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Note. Significant items are bolded
All models controlled for age, gender, race, ECIG use duration, and ECIG use days/week
$^1$Pod-based systems is referent group for device type
### Table 8

*Multiple Linear Regressions Predicting EDS Score from ECIG Picture Characteristics*

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*Note.* Significant items are bolded

All models controlled for age, gender, race, ECIG use duration, and ECIG use days/week

¹Pod-based systems is referent group for device type
Table 9
Multinominal Logistic Regressions Predicting DSM-V Dependence Level from ECIG Characteristics

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Self Reported ECIG Characteristics

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</tbody>
</table>

Model 131 - Device type

<table>
<thead>
<tr>
<th>Model 14 - Individual Characteristics</th>
<th>Moderate Dependence</th>
<th>Severe Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.05</td>
<td>-0.13</td>
</tr>
<tr>
<td>Female</td>
<td>-0.37</td>
<td>-0.25</td>
</tr>
<tr>
<td>Racial Minority</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>ECIG use duration (years)</td>
<td>-0.25</td>
<td>-0.01</td>
</tr>
<tr>
<td>ECIG use days/week</td>
<td>0.41</td>
<td>0.75</td>
</tr>
<tr>
<td>Cigalike/Vape pen</td>
<td>0.79</td>
<td>0.75</td>
</tr>
<tr>
<td>Mod</td>
<td>1.85</td>
<td>1.19</td>
</tr>
<tr>
<td>Nicotine concentration</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Note: Significant items are bolded; No/mild dependence is referent group for DSM-V dependence level
1Pod-based systems is referent group for device type
Appendix A

Eligibility Questions

1. Do you speak English?
   ○ Yes   ○ No

2. Do you currently live in the United States?
   ○ Yes   ○ No

3. What is your age in years? _____ years

4. Have you ever smoked a cigarette, even one or two puffs?
   ○ Yes   ○ No

5. Approximately how many cigarettes have you smoked in your lifetime? (There are 20 cigarettes in a pack.) _____ cigarettes

6. Have you used an e-cig/vape in the past 30 days?
   ○ Yes   ○ No

7. For how long have you used an e-cig/vape? Please respond in the appropriate box for months or years.
   ○ _____ months   ○ _____ years

8. On average over the past 3 months, how many days per week have you used an e-cig/vape?
   ○ 0…7

9. Does the e-cig/vape that you use most often contain nicotine?
   ○ Yes   ○ No   ○ Don’t know
Appendix B

Demographics

1. Which gender do you most identify with?
   o Male
   o Female
   o Transgender
   o Nonbinary/fluid queer/gender queer
   o Other. Please specify: __________
   o I prefer not to answer

2. What sexual identity do you most identify with?
   o Straight/Heterosexual
   o Gay or Lesbian
   o Bisexual
   o Other. Please specify: __________
   o I prefer not to answer

3. What is your ethnicity?
   o Hispanic or Latino
   o Not Hispanic or Latino
   o I prefer not to answer

4. What is your race?
   o American Indian or Alaska Native
   o Asian
   o Black or African American
   o Native Hawaiian or Pacific Islander
   o White
   o Other. Please specify: __________
   o I prefer not to answer

5. What is your marital status?
   o Single (never married)
   o Married
   o Widowed
   o Divorced
   o Separated

6. What is your highest level of education completed?
   o Some high school
   o High school diploma or equivalent (e.g., GED)
   o Some college
   o Trade/technical/vocational training
   o Associate degree
   o Bachelor’s degree
7. Are you currently…?
   - Employed full time
   - Employed part time
   - Unemployed
   - Homemaker
   - Student
   - Military
   - Retired
   - Unable to work

8. What is your annual household income?
   - Less than $20,000
   - $20,000 to $34,999
   - $35,000 to $49,999
   - $50,000 to $74,999
   - $75,000 to $99,000
   - Over $100,000
Appendix C

Tobacco and Other Drug Use

1. Besides e-cigs/vapes, have you used any tobacco products in the past 30 days?
   - Yes
   - No

2. Select all of the tobacco products that you have used in the past 30 days:
   - Cigars (like Macanudo, Romeo y Julieta, or Arturo fuente)
   - Cigarillos/small cigars (like Black & Mild, Swisher Sweets, or Phillies Blunt)
   - Hookah/waterpipe
   - Chewing tobacco or dip/snuff/snus (like Levi Garrett, Red Man, or Beech Nut, Skoal, or Copenhagen)
   - Nicotine replacement products (like gum, patches, lozenges, or inhalers)
   - Other. Please specify: ______
   - I have not used any of these products.
   - I prefer not to answer.

3. Of the past 30 days, on how many did you use [carry forward response(s) from previous question]?
   - 1…30

4. Have you used alcohol in the past 30 days?
   - Yes
   - No

5. Of the past 30 days, on how many have you used alcohol?
   - 1…30

6. In the past 30 days, have you used any of the following substances? Select all that you have used in the past 30 days.
   - Stimulants (e.g., cocaine, amphetamine, MDMA)
   - Opiates (e.g., heroin, fentanyl)
   - Cannabinoids (e.g., marijuana)
   - Benzodiazepines (e.g., Xanax, Valium)
   - Hallucinogens (e.g., LSD, mushrooms)
   - Other. Please specify: ______
   - I have not used any of these drugs in the past 30 days.
   - I prefer not to answer.
Appendix D

User Characteristics

7. How old were you when you first used an e-cig/vape? _____ years

8. Have you tried to cut down or quit using e-cigs in the past 12 months?
   ○ Yes ○ No

9. How many attempts have you made to cut down or quit using e-cigs/vapes in the past 12 months? _____ attempts

10. What methods have you tried to quit using e-cigs/vapes?
    □ Nicotine replacement therapy
    □ Chantix/varenicline or Zyban/bupropion
    □ Cold turkey
    □ Counselling
    □ Other. Please describe: _____

11. Do you intend to quit using e-cigs/vapes in the next 6 months?
    ○ Yes ○ No ○ Don’t know

12. Why did you start using an e-cig? Select all that apply.
    □ My friends/family members use e-cigs
    □ I was curious about e-cigs
    □ E-cigs enhance my social status
    □ E-cigs are more acceptable to nonsmokers
    □ E-cigs might be less harmful than cigarettes
    □ E-cigs are more affordable than other forms of tobacco
    □ E-cigs come in appealing flavors
    □ I wanted to perform vapor tricks
    □ Other. Please describe: _____
    ○ None of these

13. Do you use e-cigs/vapes containing THC, CBD, or synthetic cannabinoids?
    ○ Yes ○ No ○ Don’t know

14. Do you primarily vape…
    ○ Nicotine
    ○ THC
    ○ CBD
    ○ Synthetic cannabinoids (e.g., K2, spice)
    ○ Don’t know

15. Do you consider yourself addicted to e-cigs/vapes?
    ○ Yes ○ No
Appendix E

ECIG Device and Liquid Characteristics

1. How many types of **nicotine-containing** e-cig/vape devices do you use on a normal day? 

   

For the following questions, please answer based on the **nicotine-containing device you use most often**. Please note, the following questions are not referring to any cannabis/marijuana or aromatherapy e-cigs/vapes.

2. What brand of e-cig/vape do you use most often?
   - Aspire
   - blu
   - Horizon
   - Innokin
   - Joytech
   - JUUL
   - KangerTech
   - Mig Vapor
   - NJOY
   - Puff Bar
   - RipTide
   - Sigelei
   - SMOK
   - Suorin
   - SXMini
   - VandyVape
   - Vaporti
   - VooPoo
   - Other. Please specify: _____

3. What does your e-cig/vape look like? Please be as descriptive as possible.

4. Which of the following best describes the style of your e-cig/vape?
   - Cigalike
   - Pen
   - Mod
   - Pod
   - Don’t know

5. Is your e-cig/vape fully disposable (i.e., are all parts of your device intended to be thrown away after use)?
   - Yes
   - No
   - Don’t know
6. Can you change (increase or decrease) the power of your device?
   ○ Yes   ○ No   ○ Don’t know

7. At what wattage (measured in watts, W) do you typically vape?
   ○ _____   ○ Don’t know

8. At what voltage (measured in volts, V) do you typically vape?
   ○ _____   ○ Don’t know

9. What is the resistance (measured in ohms, Ω) of your device/atomizer?
   ○ _____   ○ Don’t know

10. Is your device a “regulated mod” (one that has been modified from a standard cigarette-shaped style of e-cig with the aim of producing more consistent device power and/or wattage)?
    ○ Yes   ○ No   ○ Don’t know

11. Is your device a “mechanical/unregulated mod” (one where the battery connects directly to the atomizer with no connecting wires)?
    ○ Yes   ○ No   ○ Don’t know

12. Did you build your own atomizer?
    ○ Yes   ○ No   ○ Don’t know

13. Is the e-cig you use most often a sub-ohm device (i.e., the resistance of the coils is < 1 ohm)?
    ○ Yes   ○ No   ○ Don’t know

14. How is the liquid stored in your device?
    ○ Pods/cartridges/cartomizers prefilled with liquid
    ○ Refillable pods/cartridges/cartomizers
    ○ Tank system
    ○ I usually drip feed

15. When your e-cig/vape runs out of liquid, do you typically...
    ○ Discard the empty cartridge or pod and replace with a new and unused cartridge or pod pre-filled with liquid
    ○ Refill the empty tank, cartridge, or pod with liquid from a larger container

16. How many mL of liquid do you use per day? (One JUUL pod contains 0.7mL of liquid.) Please round your answer to the nearest tenth (one decimal place, such as 0.2, 0.5, or 1.1).
    ○ _____   ○ Don’t know
17. How many mL of liquid do you use per week? (One JUUL pod contains 0.7 mL of liquid.) Please round your answer to the nearest tenth (one decimal place, such as 0.2, 0.5, or 1.1).
   ○ _____  ○ Don’t know

18. Approximately how many days does it take for you to finish your most used cartridge or pod?
   ○ Less than one day  ○ At least one day

19. Is the nicotine in your liquid a nicotine salt?
   ○ Yes  ○ No  ○ Don’t know

20. For the liquid that you use most often, how is the nicotine concentration described on the label/bottle?
   ○ mg/mL
   ○ Percentage (%)
   ○ high/medium/low
   ○ Don’t know

21. What is the nicotine concentration of the liquid you typically use?
   ○ _____  ○ Don’t know

22. Liquids are often described as containing a percentage of vegetable glycerin (VG) and/or propylene glycol (PG). For instance, liquids might be 0% VG and 100% PG, or 30% VG and 70% PG. Do you know the percentage of VG or PG in your liquid?
   ○ Yes  ○ No

23. Please use the boxes below to write in the percentages of VG and PG for the liquid that you use most often.
   vegetable glycerin (VG) _____
   propylene glycol (PG) _____

24. Do you regularly use more than one liquid flavor?
   ○ Yes  ○ No

25. What flavors of liquid have you tried? Select all that apply.
   □ Tobacco
   □ Mint/menthol
   □ Fruit
   □ Sweet/candy
   □ Alcoholic drink
   □ Non-alcoholic drink
   □ Clove/spice
   □ Chocolate
   □ Other. Please specify: _____
26. Which flavor of liquid do you use most often?
   ► *Carry forward choices from previous question.*

27. Specifically, what is your preferred flavor called? _____

28. From where did you purchase the e-cig device that you use most often?
   o Online
   o Gas station or convenience store
   o Supermarket, grocery store, or drug store
   o Vape shop
   o Liquor store
   o From someone else (e.g., family member, friend)
   o Other. Please specify: _____
   o Did not purchase/was given to me

29. In **U.S dollars**, how much did your e-cig/vape (battery, tank, etc.) cost in U.S. dollars, not including extras such as extra cartridges, chargers, etc.? $_____

30. In **U.S. dollars**, how much do you spend on liquid per month? $_____

31. Which of the following pictures most closely resembles the type of device that you use most often?
   o
   o
   o
   o
   o
   o None of these resemble my device.
Appendix F

Photo Upload

Please take a moment to get your most used e-cig/vape and your most used liquid from the past week. The next 2-3 prompts will ask you to upload PHOTOS of each.

**These pictures are required to be uploaded and to be clear in order for your survey participation to be considered complete and to receive compensation. Photos uploaded must be of your own e-cig.**

---

**You will first upload a picture of your device on this page, and then you will upload a picture of your liquid on the next page.**

Use the box below to upload a picture of your device. Make sure that you follow these steps before the picture is uploaded:

1. Make sure that any brand name/logo or other information can easily be seen.
2. If your e-cig/vape has a visual display, make sure it is turned on.
3. If you have the original box that the e-cig/vape came in, please include it in the picture.
4. Write this code, ECIG{random number}, on a piece of paper and include it in the picture.

Below are some examples of the photo you should upload.

![Example of device photo](image)

Now that you have uploaded a picture of your device, please upload a picture of your liquid.

Use the box below to upload a picture of your liquid. Make sure that you follow these steps before the picture is uploaded:

1. Make sure that any brand name/logo or other information can easily be seen.
2. If you have the original box that the liquid came in, please include it in the picture.
3. Write this code, ECIG{random number}, on a piece of paper and include it in the picture.

Below are some examples of the photo you should upload.

![Example of liquid photo](image)
Appendix G

Penn State Electronic Cigarette Dependence Index (PSECDI)

1. How many times per day do you usually use your e-cig/vape? (assume that one “time” consists of around 15 puffs or lasts around 10 minutes)
   - 0-4 times
   - 5-9 times
   - 10-14 times
   - 15-19 times
   - 20-29 times
   - 30+ times

2. On days that you can use your e-cig/vape freely, how soon after you wake up do you first use your e-cig/vape?
   - 0-5 min
   - 6-15 min
   - 16-30 min
   - 31-60 min
   - 61-120 min
   - 121+ min

3. Do you sometimes awaken at night to use your e-cig/vape?
   - Yes
   - No

4. How many nights per week do you typically awaken to use your e-cig/vape?
   - 0-1 nights
   - 2-3 nights
   - 4+ nights

5. Do you use an e-cig/vape now because it is really hard to quit?
   - Yes
   - No

6. Do you ever have strong cravings to use an e-cig/vape?
   - Yes
   - No

7. Over the past week, how strong have the urges to use an e-cig/vape been?
   - None/Slight
   - Moderate/Strong
   - Very strong/Extremely strong

8. Is it hard to keep from using an e-cig/vape in places where you are not supposed to?
   - Yes
   - No

9. Do you feel more irritable when you can’t use an e-cig/vape?
   - Yes
   - No

10. Do you feel nervous, restless, or anxious when you can’t use an e-cig/vape?
## Appendix H

Four-item E-Cigarette Dependence Scale (EDS)

Please respond to each question by marking one box per row.

<table>
<thead>
<tr>
<th></th>
<th>0 never</th>
<th>1 rarely</th>
<th>2 sometimes</th>
<th>3 often</th>
<th>4 almost always</th>
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</thead>
<tbody>
<tr>
<td>I find myself reaching for my e-cig without thinking about it.</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>I drop everything to go out and get e-cigs or e-juice.</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>I vape more before going into a situation where vaping is not allowed.</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>When I haven’t been able to vape for a few hours, the craving gets intolerable.</td>
<td>○</td>
<td></td>
<td></td>
<td></td>
<td>○</td>
</tr>
</tbody>
</table>