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Cue Reactivity in Non-Smoking Electronic Cigarette Users

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ABSTRACT

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Electronic cigarettes (ECIGs) are among the most popular nicotine products in the United States, particularly among youth and young adults. Many individuals who use ECIGs report an interest in quitting or unsuccessful quit attempts. In addition to nicotine dependence, one factor that may contribute to continued ECIG use is an individual's response to ECIG-related environmental stimuli, or cues. Existing research demonstrates that exposure to ECIG cues increases craving for ECIGs among cigarette smokers, including those without previous ECIG experience. The purpose of this study was to examine effects of ECIG cue exposure in experienced ECIG users with minimal smoking history, thus eliminating the potential confound of pre-existing nicotine dependence and cue reactivity from cigarettes. Experienced ECIG users ($N = 34$) who were never established cigarette smokers (≤ 100 cigarettes lifetime) completed two within-subject cue exposure conditions that differed only by pictorial cue type: ECIG or neutral. Participants experienced two bouts of cue exposure per session, completing subjective measures of ECIG craving and mood before and after each bout. After both cue exposures, participants completed hypothetical delay-discounting and behavioral economic tasks. Two different versions of these tasks were completed, with ECIG use quantified in either puffs or minutes of use. Mixed-effects models and paired-samples t-tests assessed effects of cue type on these outcomes. Ratings of desire to vape (Questionnaire on Vaping Urges-Brief Factor 1, ECIG Schuh-Stitzer) increased significantly from pre- to post-cue exposure for ECIG cues relative to neutral cues, p's $< .05$. A similar pattern was observed for negative mood (Positive and Negative Affect Schedule), $p = .005$. ECIG cue exposure did not significantly affect ECIG delay discounting or increase demand for ECIGs, p's $> .05$. Results are largely consistent with those reported for cigarette smokers. Findings may inform the regulation of ECIG product advertising, as exposure to ECIG-related cues may promote continued ECIG use.

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Cue Reactivity in Non-Smoking Electronic Cigarette Users

Electronic cigarettes (ECIGs) are a class of products designed to deliver nicotine to the user through the inhalation of an aerosol. ECIGs are the second most popular nicotine product in the United States (U.S.), following only combustible cigarettes (Cornelius et al., 2022). Notably, however, rates of use are higher for ECIGs than cigarettes among some U.S. subpopulations, including young adults and adolescents. In 2020, among young adults aged 18-24, 9.4% used ECIGs whereas 7.4% used cigarettes (Cornelius et al., 2022). The difference in product use among adolescents is even more pronounced, with 13.1% of middle and high school students reporting use of ECIGs and only 3.3% reporting cigarette smoking in 2020 (Gentzke et al., 2020). ECIG use (also known as vaping) among these populations is concerning, as many youth and young adults have no history of cigarette smoking (Cornelius, 2020; Cullen et al., 2019), and ECIG use among nonsmokers may be associated with smoking initiation (Baenziger et al., 2021; Primack et al., 2018). Further, like many other nicotine products, ECIGs may be associated with negative health outcomes. ECIG aerosols are shown to contain harmful heavy metals (Williams et al., 2019), and ECIG use may result in increased risk of cardiovascular disease (Kennedy et al., 2019; Moheimani et al., 2017).

Given the possible negative effects of ECIG use, it is not surprising that ECIG users may want to quit. In fact, up to 76% of ECIG users report an interest in quitting (Alalwan et al., 2022; Cuccia et al., 2021; Rosen & Steinberg, 2019), and up to 75% report making at least one quit attempt (Pulvers et al., 2021; Simpson et al., 2021). These findings are largely based on samples of ECIG users who were current or former smokers. However, ECIG users with no history of cigarette smoking may also want or try to quit. Indeed, in our own work with ECIG users who had never smoked cigarettes, more than half (58%) reported making an attempt to quit or reduce

using ECIGs in the past year (Douglas et al., 2023). Motivations for quitting ECIGs include health concerns (51-75%) and "freedom from addiction" (20%), which are similar to those reported for quitting cigarettes (Amato et al., 2021; Klemperer & Villanti, 2021). Research also suggests that ECIG users often fail to quit vaping. ECIG users on the social media platform formerly known as Twitter have posted about their numerous unsuccessful quit attempts, as well as their pronounced difficulty quitting ECIGs (Unger et al., 2020). Barriers to quitting may include aversive emotional and physical withdrawal symptoms (Simpson et al., 2021; Struik & Yang, 2021), as well as dependency on high levels of nicotine (Struik & Yang, 2021).

ECIG Dependence

The observed high rates of ECIG use and unsuccessful quit attempts are likely explained in part by nicotine dependence. In fact, ECIG users who reported a past quit attempt had higher dependence scores than those who had not tried to quit (Garey et al., 2019). Nicotine dependence is recognized as a medical condition by the World Health Organization (2018) and American Psychiatric Association (APA; 2013). Symptoms include craving, tolerance, unsuccessful quit attempts, and continued use despite negative physical, psychological, or social consequences (APA, 2013). Existing research demonstrates that at least some ECIGs are capable of producing dependence (Boykan et al., 2019; Foulds et al., 2015; Morean et al., 2018), including among users who have minimal history of other tobacco product use (Douglas et al., 2022). The ability of ECIGs to produce nicotine dependence relies, in part, on the dose and speed at which nicotine is delivered. Tobacco products that deliver higher nicotine concentrations and/or at a more rapid speed (e.g., cigarettes) are more likely to produce dependence than products that deliver lower nicotine concentrations and/or at a slower speed (e.g., smokeless tobacco; Carter et al., 2009).

Cigarettes and ECIGs both deliver nicotine rapidly via inhalation; however, ECIG products are more heterogenous in the dose of nicotine they deliver.

Notably, the ability of ECIGs to deliver nicotine has improved since they were introduced to the U.S. marketplace in 2007 (Hajek et al., 2017). The first ECIGs to emerge were similar in appearance to combustible cigarettes. These devices, known as "cig-alikes," have low-voltage batteries, are prefilled with liquid, and may be discarded after use. They deliver low levels of nicotine relative to combustible cigarettes (Hajek et al., 2017). The next generation of ECIG, known as "vape pens" or "tanks," typically deliver nicotine at doses higher than cig-alike models, but still lower than cigarettes (Hajek et al., 2017). The next device type that emerged is referred to as a "mod." Mod-style devices allow the user to make adjustments to the heating element/coil and battery power to manipulate nicotine yield (Williams & Talbot, 2019). The nicotine delivery profile of these devices depends on user settings (e.g., coil resistance, nicotine concentration) but they are thought to be capable of delivering nicotine more efficiently than earlier-generation devices (Boykan et al., 2019; Hajek et al., 2017). Most recently, pod-based systems and modern disposable devices were introduced. These devices most commonly contain nicotine salt solutions (vs. freebase), which provide the user with a high, yet palatable, dose of nicotine (Eissenberg et al., 2018; Talih et al., 2019; Zhu et al., 2014). This evolution of ECIG products has resulted in some devices that are capable of delivering nicotine in doses similar to or exceeding that of a cigarette (Ramôa et al., 2016).

Cue Reactivity

Nicotine dependence is undoubtedly an important factor that maintains ECIG use. Interestingly, however, nicotine has been described as a weak reinforcer relative to other drugs of abuse (e.g., cocaine, amphetamine; Manzardo et al., 2002; Rupprecht et al., 2015). Support for

this idea comes from human and nonhuman models of nicotine self-administration, in which subjects respond (e.g., lever press, mouse click) to receive nicotine under controlled laboratory conditions (Barrett, 2010; Donny et al., 1995). In such work, responding for nicotine is low (Caggiula et al., 2002) unless high doses are available (Chaudhri et al., 2007). Notably, these same models reveal much higher levels of nicotine self-administration when nicotine delivery is paired with other external stimuli (e.g., visual or olfactory cues). An individual's response to such external stimuli, known as cue reactivity, is likely another important factor that maintains ECIG use. Cue reactivity is believed to be established through classical (i.e., Pavlovian) conditioning, the process by which a neutral stimulus becomes a conditioned stimulus that elicits a conditioned response through repeated pairings with an unconditioned stimulus that elicits an unconditioned response. As an example, stimuli that are reliably paired with ECIG use (e.g., sight and/or smell of exhaled vapor, ECIG device, context of use) are initially neutral stimuli that do not elicit a response on their own. After repeated pairings with the unconditioned stimulus (i.e., nicotine), these neutral stimuli become conditioned stimuli that elicit conditioned responses in the absence of the drug. Drug-paired conditioned stimuli have been shown to produce subjective (e.g., increased craving), and/or behavioral (e.g., increased drug seeking) effects (Carter & Tiffany, 1999).

Laboratory-based cue-reactivity paradigms have been used to systematically measure effects of exposure to smoking-related stimuli in cigarette smokers. Participants are presented with cues in one or more forms (e.g., in vivo, imaginal, picture, video, virtual reality) and their subjective, physiological, and/or behavioral responses are recorded. Some researchers have compared participants' responses to smoking-related (i.e., active) cues to their pre-exposure baselines; however, with this method it is impossible to conclude that any observed differences

are due to cue exposure (Carter & Tiffany, 1999). Thus, as a methodological control, participants are often also presented with stimuli that are not associated with nicotine (e.g., water, a toothbrush). Their responses to these neutral cues are recorded and compared with their responses to smoking-related cues. To maximize craving potential, participants are commonly required to remain abstinent from cigarettes for a certain duration of time before cue exposure.

Findings from cue-reactivity studies with cigarette smokers demonstrate reliable associations between exposure to smoking-related cues and increased levels of self-reported craving (see Carter & Tiffany, 1999 and Betts et al., 2020 for meta-analyses). Other observed outcomes include changes in mood (Wray et al., 2011), and increases in smoking-related behavior following exposure to smoking cues (e.g., increases in puff number and/or volume; Conklin et al., 2015, 2019; Heishman et al., 2010; Wray et al., 2011). Notably, cue effects on smoking have not been observed consistently. In a study by Shiffman et al. (2013), exposure to smoking cues had no effect on amount smoked, latency to smoke, or likelihood of smoking during a 15-min ad libitum smoking bout after cue exposure. Interestingly, however, higher craving intensity was predictive of positive smoking outcomes, and higher craving intensity was observed after exposure to smoking cues (Shiffman et al., 2013). Physiological responses (e.g., heart rate, skin temperature) are also sometimes measured in smoking cue-reactivity research, though smaller effect sizes are generally observed for physiological responses compared to craving (Carter & Tiffany, 1999). Research investigating effects of cue exposure on heart rate are mixed, with some studies demonstrating increases in current smokers' heart rate as a function of active cue exposure (Drobes & Tiffany, 1997; Tiffany & Drobes, 1990; Balter et al., 2015) and others showing no significant differences relative to neutral cues (Conklin et al., 2010; Tong et al., 2007).

ECIG Cue Reactivity

Similar to cigarette cues, exposure to ECIG-related cues may elicit craving, changes in mood, and/or ECIG use. Cues related to ECIG use may include the context or environment in which vaping commonly occurs, the sight and/or smell of the exhaled aerosol cloud, and the appearance of the device itself. The majority of studies using ECIG cues have examined how they affect cigarette smokers who may or may not have previous ECIG-use experience. Much of this research has been conducted by King and colleagues, and demonstrates that exposure to ECIG-related cues (vs. neutral cues) increases craving and desire for cigarettes among smokers (King et al., 2015, 2016, 2018, 2021; Vena et al., 2020, 2021). These effects have been observed regardless of cue modality (e.g., ECIG video advertisement, confederates puffing on an ECIG), or the ECIG device type depicted in the cue (e.g., cig-alike, tank, or pod styles).

A recent analysis by King et al. (2021) that combined data from five studies found that reactivity to ECIG cues was greater among cigarette smokers who did (dual cigarette-ECIG users) versus did not (exclusive smokers) also use ECIGs. Specifically, both subsamples were exposed to a confederate (disguised as a participant) either vaping an ECIG (i.e., active cue) or drinking water (i.e., neutral cue; results from a third condition – cigarette smoking cue – not reported here). The type of ECIG device that the confederate used varied between the studies; cig-alikes, vape pens, mod-style, and JUUL (i.e., pod-style) were used. Before and after each cue exposure, participants rated their desire for cigarettes and for ECIGs. Some also completed a 50-minute smoking latency task in which they were paid $0.20 for every five minutes of smoking abstinence, with the outcome measure being the number of minutes (i.e., latency) to smoke cigarettes. The ECIG cue (regardless of device type) resulted in an increased desire for cigarettes, and a shorter latency to smoke, for dual cigarette-ECIG users relative to exclusive

cigarette smokers. The ECIG cue also increased desire for an ECIG among dual cigarette-ECIG users. Interestingly, participants' level of desire for an ECIG varied as a function of the type of product the confederate used, such that products without a tank (i.e., cig-alike, JUUL) produced higher ratings of ECIG desire than products with a tank (e.g., vape pens, mod-style devices; King et al., 2021). Notably, dual cigarette-ECIG users' ECIG device types were not reported, so differences in cue reactivity as a function of preferred device type could not be determined.

Other researchers have also examined effects of ECIG cue exposure using samples of current or former smokers with varying levels of experience with ECIGs. In a between-subjects study designed by Blackwell and colleagues (2020), participants with varying smoking and vaping statuses were randomly assigned to view a one-min video of people having a conversation while: a) vaping a cig-alike device, b) vaping a mod-style device, c) smoking a traditional cigarette, or d) moving their hand to their mouth. Participants rated their level of desire to both smoke and vape before and after cue exposure. Study findings revealed no evidence that ECIG cues increased desire for cigarettes or vice versa. Further, there were no differences in desire to smoke cigarettes across cue groups. By contrast, urge and desire to vape were higher following ECIG cue exposure (i.e., both cig-alike and mod-style device cues) relative to neutral cues. Notably, this study was conducted online, so participants' attention to cues could not be verified. Moreover, participants were not required to remain abstinent from smoking or vaping before viewing the videos (i.e., they may not have been in withdrawal when viewing cues), and their level of nicotine dependence was not assessed (Blackwell et al., 2020). Still, this study provides some evidence that ECIG cues increase subjective ratings of urge and desire for ECIGs among current and/or former smokers.

Surprisingly little research has examined effects of ECIG-related cue exposure in experienced ECIG users who are not current cigarette smokers. Nichols et al. (2016) recruited a sample of experienced ECIG users who were former cigarette smokers to view videos of individuals vaping (i.e., active cue) and brushing their teeth with an electronic toothbrush (i.e., neutral cue). Cues were intermixed and were presented during two functional magnetic resonance imaging (fMRI) scans within a single study visit. Between scans, participants completed a standardized 10-min ECIG puffing bout. Before and after the puffing bout, participants self-reported their level of desire for an ECIG, as well as any withdrawal symptoms they were experiencing. They also verbally reported their level of desire for an ECIG while in the scanner before and after cue presentations. A cue-by-session interaction was observed, such that several brain regions (e.g., inferior temporal gyrus, bilateral cerebellum) were activated during exposure to ECIG cues, and these effects were greater after participants used their ECIG for 10-min before the scan. Not surprisingly, desire for an ECIG was higher before (vs. after) the ECIG puffing bout. Finally, verbal ratings of desire for an ECIG did not significantly differ before and after viewing the cue videos. Notably, this was a pilot study with a small sample size ($N = 7$) and participants had only low-to-moderate levels of ECIG dependence (Penn State Electronic Cigarette Dependence Index $M = 7.0$, $SD = 3.0$). Additionally, the ECIG device featured in the active-cue videos was a first-generation, cig-alike device, though all participants reported using a newer-generation device at the time of the study, and only $n = 3$ had ever owned a cig-alike (Nichols et al., 2016). Thus, the cues may not have been relevant for the ECIG users in the sample, as cig-alikes are quite different in appearance than modern devices.

The existing studies on ECIG cue reactivity are largely limited to subjective (e.g., ratings of desire, urge) and behavioral (e.g., latency to smoke, puff frequency) outcome measures. Other

measures that might be sensitive to cue reactivity are those behavioral economic in nature. For example, Dowd & Tiffany (2019) exposed dual users of cigarettes and ECIGs to in-vivo cues of a) a lit cigarette, b) their own ECIG, and c) water. After viewing a cue, participants self-reported their level of craving for cigarettes and ECIGs. They also selected the amount of money (range $0.01 to $0.25) they would spend to access each product. The amount of money corresponded to the probability (range 5% to 95%) that they could access the cue (i.e., take one puff from the cigarette or ECIG, or take a sip of water). Self-reported craving and money spent were highest after exposure to the lit cigarette relative to the ECIG. Further, craving and money spent were higher after exposure to the ECIG cue relative to the water cue (Dowd & Tiffany, 2019).

Behavioral economic measures are also commonly used to assess reinforcing efficacy of cigarettes and therefore may be relevant to ECIG use. One measure, the Cigarette Purchase Task, assesses demand for cigarettes by asking participants the number of cigarettes they would purchase on a typical day at increasing prices. A recent meta-analysis by González-Roz et al. (2019) demonstrates that Cigarette Purchase Task demand indices are associated with cigarette consumption and nicotine dependence. Further, purchase tasks are shown to be sensitive to experimental manipulations (Acuff et al., 2020), including cue exposure (Acker & MacKillop, 2013; MacKillop et al., 2012b). For example, Acker and MacKillop (2013) investigated effects of tobacco-related virtual reality cues on demand for cigarettes in smokers. They found that participants spent more money on cigarettes and were less sensitive to increasing prices after exposure to tobacco cues relative to neutral cues. Research of this nature should be extended to include ECIG users and ECIG cues.

Another behavioral measure that is associated with nicotine dependence is impulsivity, which may be operationally defined as steeper discounting of delayed rewards (Amlung &

MacKillop, 2014; Bickel et al., 1999; Reynolds et al., 2004). That is, when given the choice between a smaller, sooner reinforcer and a larger, later reinforcer, those with higher levels of nicotine dependence may choose the former (i.e., the "impulsive" choice). In addition to dependence, steeper delay discounting is associated with greater nicotine consumption (Ohmura et al., 2005) and a higher number of unsuccessful ECIG quit attempts (Pericot-Valverde et al., 2020). By contrast, lower delay-discounting rates are associated with greater intention to quit smoking (Athamneh et al., 2017). Weidberg et al. (2017) evaluated delay discounting with monetary rewards in excusive ECIG users, current smokers, and former smokers. They found that ECIG users discounted delayed rewards more steeply than former smokers but not current smokers. Białaszek et al. (2017) found that ECIG users and cigarette smokers discounted delayed rewards at similar rates, and their rates of discounting were higher compared to never smokers. Delay discounting is shown to be sensitive to some experimental manipulations such as episodic future thinking (Stein et al., 2018) and drug administration (de Wit & Mitchell, 2010). Still, a study with smokers and smoking cues revealed no cue effects on hypothetical delay discounting (Field et al., 2007). The current study included hypothetical behavioral economic and delay-discounting measures in addition to subjective ratings of craving, to provide a more comprehensive assessment of cue reactivity in ECIG users.

Statement of the Problem

In recent years, ECIGs have become one of the most popular nicotine products on the U.S. market. Rates of ECIG use are highest among youth and young adults, populations which are largely tobacco naïve (Cornelius, 2020; Cullen et al., 2019). A large proportion of ECIG users report an interest in quitting, and some have even reported unsuccessful quit attempts (Pulvers et al., 2021; Rosen & Steinberg, 2019; Unger et al., 2020). One factor that may maintain

ECIG use is an individual's response to ECIG-associated environmental stimuli, known as cue reactivity. Exposure to drug-associated cues is shown to increase drug craving among users of heroin, alcohol, cocaine, and cigarettes (Carter & Tiffany, 1999). Few studies, however, have evaluated effects of cue exposure among the growing population of ECIG users. Further, no known studies have evaluated these effects in ECIG users who have never smoked cigarettes. Such research is important, as it eliminates the potential confound of nicotine dependence and craving from cigarettes. Additionally, few studies have used behavioral economic and delay-discounting measures to assess the value of ECIGs as a function of cue exposure. To fill these gaps in the literature, this study used hypothetical behavioral economic and delay-discounting measures, in addition to subjective measures of craving and mood, to assess effects of ECIG-associated cue exposure in ECIG users with minimal smoking experience.

Implications

Evaluating effects of ECIG cues has implications related to public policy regulation and treatment development for ECIG users who want to quit. Cues related to ECIG use are present on television, social media, retail stores, billboards, and online. Advertisements for cigarettes are strictly regulated by the federal government (Centers for Disease Control and Prevention, 2020). The U.S. Food and Drug Administration (U.S. FDA) currently has regulatory control over ECIG products, which includes regulation of advertising, and marketing restrictions have begun to emerge (U.S. FDA, 2021). Thus, the current study has the potential to inform regulatory efforts. In addition, this research has implications for treatment development for ECIG cessation, which is necessary given the high proportion of ECIG users who want to quit.

Method

Participants

Experienced ECIG users were recruited through word-of-mouth and university-approved advertisements posted via flyers around the greater Morgantown, West Virginia area and on West Virginia University (WVU) survey listservs, social media (e.g., Facebook, Instagram), and Craigslist. Interested individuals completed a short screening survey, hosted on REDCap (Appendix A). A power analysis was conducted to determine an adequate sample size using G*Power 3.1 (Faul et al., 2007). The power analysis was calculated for the delay-discounting and behavioral economic outcomes. These measures were completed fewer times per session than the subjective measures and thus a larger sample size was required to power these outcomes. Assuming a medium effect size (Cohen's $f = 0.25$; Cohen, 1992), a power of .80, a Type 1 error rate of .05, and a moderate correlation among repeated measures ($r = .50$), a total sample of 34 participants was determined to be sufficient to power this study.

Inclusion Criteria

Participants were required to be at least 18 years of age to be eligible for this study. No upper age limit was imposed, though the overwhelming majority of ECIG users who are nonsmokers are young adults (Mirbolouk et al., 2018). Additional inclusion criteria included use of a nicotine-containing ECIG on an average of four or more days per week for the past three months and lifetime use of ≤ 100 cigarettes.

Exclusion Criteria

Individuals were excluded from study participation if they self-reported an uncontrolled medical or psychiatric condition, use of marijuana/THC (including vaping) or alcohol > 15 days in the past month, any use of illicit substances (e.g., cocaine, heroin) in the past month, or current

pregnancy (verified by urinalysis) or breastfeeding. Individuals also were excluded if they self-reported an intention to reduce or quit vaping within the next 30 days.

Informed Consent and In-person Screening Procedures

Individuals who appeared eligible based on their initial screening survey were invited to the laboratory for an in-person screening session. They were first guided through the informed consent form. The study purpose, procedures, risks, and benefits were described, and they had the opportunity to ask questions before consenting. After providing informed consent, individuals completed an additional screening questionnaire on the computer (Appendix B). These questions intentionally overlapped with those in the initial screening questionnaire to test for reliable reporting. Individuals were excluded from study participation if their responses were not comparable to those provided in the initial survey (i.e., they no longer met the inclusion or exclusion criteria described above). Current non-smoking status was verified through an exhaled-air carbon monoxide (CO) level of ≤ 5 ppm (piCO+ Smokerlyzer coVita; Haddonfield, NJ). ECIGs are noncombustible and therefore do not increase CO levels. Pregnancy was ruled out for females via a urine pregnancy test (QuickVue; San Diego, CA). Those who provided informed consent and met the study inclusion and exclusion criteria began the first session immediately.

Study Design

Using a within-subjects design, participants experienced two randomly ordered conditions that differed only by cue type: ECIG or neutral. Within each session, participants experienced two, 5-min cue exposures. They completed subjective questionnaires before and after each exposure, for a total of four timepoints. They also completed two batteries of delay-discounting and behavioral economic questionnaires per session. Because there is no gold-standard unit by which to quantify ECIG use, participants completed one set of tasks with ECIG

use quantified in puffs and one quantified in minutes of access to use ECIG products. The order of the questionnaires was counterbalanced across participants.

Session Procedure

Study sessions were conducted on WVU's Downtown Campus. The two sessions were separated by a minimum of 48 hours to avoid potential carryover effects of cue exposure. Participants were asked to abstain from ECIG use for at least eight hours before each session. Because ECIGs are noncombustible and therefore do not produce CO, abstinence from ECIGs could not be confirmed immediately in the laboratory. Thus, to maximize compliance with ECIG abstinence, a bogus pipeline method was used (Jones & Sigall, 1971). Prior to the session participants were told that a saliva sample would be used to confirm ECIG abstinence, and if they failed to abstain, they would be ineligible to participate in the study. Research staff collected a saliva sample from all participants before each session; however, no such testing occurred, and the sample was discarded. Bogus pipeline methods have been used to promote compliance with abstinence in prior studies with smokers (Donny & Jones, 2009; Shiffman et al., 1995) and ECIG users (Hiler et al., 2020).

Participants who met the abovementioned requirements then began the session; a diagram of the session procedures is provided in Figure 1. First, participants were connected to physiological equipment for continuous measurement of heart rate and blood pressure. Physiological responses were measured to monitor participant safety throughout the session, as well as to assess effects of cue exposure on heart rate. During the first session only, participants completed measures of hypothetical monetary delay discounting and impulsiveness 10 min after being connected to physiological recording equipment (Appendix C). After 35 min, participants were presented with the condition-assigned session cues, with assessment of subjective ratings

occurring before and after cue exposure. The second cue exposure took place 20 min later, with subjective ratings again occurring before and after. Next, participants completed one version of delay-discounting and behavioral economic tasks, followed 30 min later by the other version (i.e., puffs or minutes of access). An additional battery of subjective questionnaires was added to the protocol in September 2022, and thus was completed by 12 of the total 34 completers. Between tasks, participants were allowed to read or use activity booklets (e.g., word searches). To prevent exposure to other sources of cues, participants were not allowed to use their phones or have their ECIG devices out during the session. Participants were compensated with a $50 gift card after each session, for a total of $100 for study completion.

Cues

Cues were presented in the form of a picture slideshow twice per session. During one session, the cues were pictures of ECIGs and people vaping (i.e., active cues), and during the other session the cues were pictures of water and people drinking water (i.e., neutral cues; see King et al., 2016). A meta-analysis on smoking-related cue reactivity found that effect sizes were larger for pictorial cues (Hedges' g = .93) relative to other modalities (e.g., video g = .87, in vivo g = .47; Betts et al., 2020). Moreover, larger effect sizes were observed in work where cues were presented multiple times (g = .81) instead of only once (g = .53). These effect sizes were observed to be independent of a variety of factors, including smoking abstinence and cigarettes smoked per day. Thus, in this study, cues were presented in picture format and the same cues were presented at two different timepoints within each session. Specifically, cues were presented via 5-min slideshows of 50 pictures, presented for 6 s each and matched on salient characteristics, including the presence of a person and setting (e.g., outside vs. inside; see Figure 2 for examples). This method of cue presentation was similar to the method used by Shiffman et

al. (2013). Notably, research staff were blinded to cue type. Staff selected the slideshow to be presented (simply labeled A or B) and left the room before the cues were shown. The last screen on the slideshow was left blank so that research staff did not see the cue type when they re-entered the room.

Primary Outcome Measures

ECIG Craving and Mood

Participants completed subjective measures immediately before and after each cue presentation (Appendix D). The Tiffany-Drobes Questionnaire on Smoking Urges (QSU-Brief; Cox et al., 2001; Tiffany & Drobes, 1991) was used to assess nicotine craving. The measure consists of 10 items (e.g., "I have an urge for a cigarette" and "I am going to smoke as soon as possible") presented on a 7-point Likert scale ranging from 0 = *strongly disagree* to 6 = *strongly agree*. The QSU-Brief has a two-factor structure. Factor 1 items reflect a strong desire to smoke and perceived positive effects of smoking and Factor 2 items reflect anticipation of relief from perceived negative withdrawal symptoms (Cox et al., 2001). Items from each factor were summed and reported separately. The measure has demonstrated strong reliability and internal consistency, and is commonly used as a measure of nicotine craving and withdrawal (see Blackwell et al., 2020; Kang et al., 2012; King et al., 2016, 2018; Vena et al., 2019, 2020). Items on the QSU-Brief were adapted for ECIG use, such that smoking terms (i.e., "smoke," "cigarette") were replaced with vaping terms (i.e., "vape," "ECIG"). Participants completed both vaping (primary outcome) and smoking (secondary outcome) versions of this measure.

The Schuh–Stitzer craving measure consists of four questions presented on a visual analogue scale that ranges from 0 = *not at all* to 100 = *very much* (Schuh & Stitzer, 1995). Items are related to nicotine craving (e.g., "How pleasant would a puff be right now?" and "How much

of an urge or desire do you have to smoke/vape right now, just for the pleasure of smoking/vaping?"). Participants responded to each item by clicking a point on a visual analogue scale. Individual item scores were expressed as a percentage of the distance from the left anchor (i.e., 0) to the point selected. Scores on the four items were then averaged to create a composite score ranging from 0-100, with higher values indicating higher levels of craving. Measures derived from Schuh-Stitzer (1995) have been used previously in research assessing nicotine craving (Hanson et al., 2009; see Dallery et al., 2003; Donny et al., 2007; Eid et al., 2005). Participants completed two versions of the Schuh-Stitzer scale: one version assessed ECIG desire (primary outcome) and the other assessed cigarette desire (secondary outcome). Statements on the ECIG versions were adapted for ECIG use, such that terms like "cigarettes" and "smoke" were replaced with "ECIGs" and "vape."

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was used to assess participants' mood. Participants were asked to rate the extent to which they felt a certain way on a 5-point scale ranging from 1 = *very slightly or not at all* to 5 = *extremely*. The measure consists of 20 items; half refer to positive mood states (e.g., "excited," "inspired," "proud") and half refer to negative mood states (e.g., "upset," "hostile," "nervous"). Items from the positive- and negative-affect scales were summed separately. Scores on each scale range from 10-50 with higher scores indicating higher positive or negative affect. The measure has demonstrated strong internal consistency and sensitivity to fluctuations in mood (Watson et al., 1988).

Delay Discounting

Participants completed two sets of choice tasks per session: one with ECIG use quantified in number of puffs (Appendix E) and the other with ECIG use quantified in minutes of access to ECIG products (Appendix F). Adapted versions of the 27-item Monetary Choice Questionnaire

(MCQ; Kirby et al., 1999; Kirby & Maraković, 1996) were used to assess discounting of delayed ECIG use (i.e., impulsive choice). The original MCQ consists of a series of prompts that ask participants to choose between a hypothetical smaller, immediate reward and a hypothetical larger, delayed reward (e.g., "Would you rather have $19 today, or $25 in 53 days?"). Each question on the MCQ has an associated *k* value, calculated from the hyperbolic discounting equation (Mazur, 1987). The *k* value associated with each item corresponds to indifference between the response options. It can be inferred that a participant who chooses the smaller, immediate reward on a given item has a discounting rate equal to or higher than that item's *k* value. Conversely, a participant who chooses the larger, delayed reward has a discounting rate equal to or lower than that item's *k* value. To score the MCQ, the 27 items are ranked from smallest to largest based on their associated *k* values. An overall discounting rate (*k*) is calculated for each participant by taking the geometric mean of the item-associated *k* values surrounding the transition between smaller, immediate and larger, delayed rewards (Kaplan et al., 2016; Kirby et al., 1999). If a participant does not respond consistently (i.e., makes multiple transitions between smaller, immediate and larger, delayed rewards), the geometric mean of the item-associated *k* values surrounding the transitions is calculated (Kaplan et al., 2016). Larger overall *k* values represent steeper delay discounting (i.e., higher impulsivity) relative to smaller overall *k* values (i.e., higher self-control; Kaplan et al., 2016; Kirby et al., 1999). The MCQ is one of the most commonly used assessments of hypothetical delay discounting in human participants. For this study, the MCQ was adapted such that participants were asked to choose between a varying amount of ECIG use immediately and a larger amount of ECIG use after a varying delay. Participants were told that all choices were hypothetical, but they should respond as if they were

real. Moreover, they were instructed to assume that the puffs or minutes of access were for their own use and from their own ECIG.

Behavioral Economics

Participants completed hypothetical commodity purchase tasks to determine behavioral economic demand for ECIG use. Participants were presented with a vignette describing a typical day during which they could use only their preferred ECIG device. They were asked to enter the number of puffs or minutes of access they would purchase at given prices ($0.01, 0.03, 0.10, 0.30, 1.00, 3.00, 10.00, 30.00, 100.00). They were informed that purchases made at one price were independent of purchases made at other prices. Additionally, they were told that their purchases had to be used within 24 hours and that they could not be saved or given away. The prices were the same as in Johnson et al. (2017), a study in which participants completed hypothetical purchase tasks for cigarette and ECIG puffs. Several demand indices can be observed from commodity purchase tasks, including intensity (i.e., the amount of the commodity purchased at $0.01), breakpoint (i.e., the highest price at which any commodity was purchased), O_{max} (i.e., the maximum amount spent on the commodity), P_{max} (i.e., the price at which the maximum amount was spent), and elasticity (i.e., purchasing sensitivity as a function of increasing price; Aston & Cassidy, 2019). Higher values of intensity, breakpoint, O_{max}, and P_{max} indicate greater abuse liability. By contrast, lower values of elasticity indicate greater abuse liability. Commodity purchase tasks are shown to be valid measures of behavioral economic demand for a variety of substances (Strickland et al., 2020) including ECIGs (Cassidy et al., 2017, 2020).

Another behavioral economic task, the Multiple-Choice Procedure (MCP; Griffiths et al., 1993, 1996), was used to assess the reinforcing value of ECIGs after cue exposure. Participants

were asked to choose between a hypothetical fixed amount of ECIG use (10 puffs or 10 minutes of access) and an increasing amount of money ($0.01, 0.02, 0.04, 0.08, 0.16, 0.32, 0.64, 1.28, 2.56, 5.12). The outcome variable was the crossover point, which was defined as the last price at which ECIG use was chosen over money (see Barnes et al., 2017). For cases in which ECIG use was selected over money at all values, the crossover point was recorded as the highest amount of money available ($5.12). For cases in which money was always preferred over ECIG use, the crossover point was recorded as $0.00. The MCP has been used to assess the reinforcing value of ECIGs in previous work (Barnes et al., 2017; Felicione et al., 2022; McPherson et al., 2016; Vansickel et al., 2012).

Secondary Measures

ECIG Dependence

Participants completed two measures of ECIG dependence as part of the in-person screening questionnaire. One measure was the Penn State Electronic Cigarette Dependence Index (PSECDI; Foulds et al., 2015), which consists of 10 questions. Scores range from 0-20 with higher scores indicating greater levels of dependence. The PSECDI has been used to assess dependence among ECIG users who are former or current smokers (Du et al., 2019; Foulds et al., 2015; Yingst et al., 2021), as well as never smokers in our own work (Douglas et al., 2023). In addition, participants completed the four-item version of the E-Cigarette Dependence Scale (EDS-4; Morean et al., 2019). The EDS-4 was adapted from the Patient-Reported Outcomes Measurement Information System Item Bank v1.0, Smoking: Nicotine Dependence for All Smokers (Edelen et al., 2014; Shadel et al., 2014). Four items are presented on a 5-point scale with response options ranging from 0 = *never* to 4 = *almost always*. Higher mean scores indicate

higher levels of ECIG dependence. The EDS-4 is shown to have strong psychometric properties for evaluating ECIG dependence in adult ECIG users (Milstred et al., 2023; Morean et al., 2019).

Impulsivity

Participants completed two measures of impulsivity at the beginning of their first session. One was the monetary version of the MCQ delay-discounting assessment (described above). The other was the Barratt Impulsiveness Scale (BIS), a 30-item measure of impulsivity. It includes items such as "I do things without thinking" and "I change hobbies." Participants respond to each statement on a 4-point scale with response options of rarely/never, occasionally, often, and almost always/always. The original measure, which was developed by Barratt (1959), has been updated several times. The most recent version, the BIS-11, was published by Patton et al. (1995). It contains three factors related to impulsiveness: attentional, motor, and non-planning (Patton et al., 1995). The BIS-11 has been used to assess impulsiveness across a range of populations (Stanford et al., 2009), including cigarette smokers (Chase & Hogarth, 2011) and ECIG users (Grant et al., 2019).

Heart Rate

Participants' heart rate (beats per minute) was recorded every 20 s via finger pulse oximeter (Noninvasive Patient Monitor model 506 NP3, Criticare Systems, Inc., Waukesha, WI). Previous research with smokers shows mixed findings for effects of cue exposure on heart rate (Erblich et al., 2011). Therefore, heart rate was included as an exploratory outcome in this study.

Participant Safety and Rights

Participants' safety and rights were assured through an IRB-approved 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. To ensure

confidentiality, numbers were used to identify participants and data were stored securely on REDCap and password-protected computers. Signed consent forms were kept in a secure location separate from the data.

Data Analysis

Data Preparation

Data were examined to ensure they met the assumptions of the statistical models used. The spread of each dependent variable was examined using histograms and outliers were identified using boxplots. Where applicable, normal Q-Q plots were inspected to determine whether the model residuals and random effects were approximately normally distributed. Scatterplots of residual by predicted values were used to test the assumption of homogeneity of variance. For the ECIG-adapted versions of the MCQ, an Excel-based spreadsheet tool developed by Kaplan et al. (2016) was used to generate overall log-transformed *k* values for each participant and cue condition using the procedure described previously. Heart rate data were averaged into 5-min bins to create single values for pre-, during, and post-cue exposure timepoints.

Primary Outcomes

Data were analyzed using SPSS version 28 (IBM Corp, 2021) and R Statistical Software version 4.2.3 (R Core Team, 2023) with the libraries *lme4, lmerTest, emmeans,* and *beezdemand.* Mixed-effects models fitted by restricted maximum likelihood assessed effects of cue type (ECIG vs. neutral), bout (one vs. two), and time (pre- vs. post-cue exposure) on each of the subjective outcomes separately. Models assessed the main effects of these factors, as well as their interactive effects. Gender was included as a fixed covariate, as some studies suggest that gender affects cue reactivity (see Betts et al., 2020). Bout and time were entered as fixed factors.

Random intercepts were modeled for participants to account for the repeated-measures design. Additionally, random slopes were modeled for cue condition to allow the effects of cue type to vary across participants. Likelihood ratio tests revealed significant improvement in model fit when random slopes for cue condition were included in the models (p's < .05). Visual inspection of normal Q-Q plots indicated that the QSU-Brief Factor 2 and PANAS positive- and negative-affect scales did not meet the model assumption of normally distributed residuals. Neither logarithmic (log) nor square-root transformations improved the distributions. The models were then fitted with a gamma distribution and identity link function, which improved the fit of each model (i.e., AIC and BIC were lower). Post-hoc comparisons were conducted where applicable using *emmeans* with Tukey's p-value adjustment. Estimated marginal means from the mixed-effects models are reported for subjective outcomes. Paired-samples t-tests were used to determine if there were differences between subjective ratings at bout two, post-cue exposure and the final timepoint for the n = 12 participants who completed subjective measures at the end of the session.

Individual-level responses on the MCQ were first examined for consistency. Participants with consistency scores below the recommended cutoff of 75% were excluded from analyses (Kaplan et al., 2016). Data from the commodity purchase tasks were assessed for nonsystematic responding using the criteria outlined by Stein et al. (2015). Specifically, responses were checked to ensure they met the criteria of trend (i.e., a general reduction in consumption of the commodity from the lowest to highest price), bounce (i.e., consumption generally decreased with each consecutive price increase), and absence of reversals from zero (i.e., non-zero consumption at two consecutive prices followed by consumption at a higher price). Next, several demand indices were observed from the commodity purchase task data, including demand intensity,

breakpoint, O_{max}, and P_{max} (described above). Elasticity of demand was calculated using the exponentiated demand equation shown in (1) (Koffarnus et al., 2015), where Q = consumption, C = cost, α = demand elasticity, and k = a scaling parameter representing the span of the function in log units.

$$Q = Q_0 * 10^{k(e^{-\alpha Q_0 C}-1)} \quad (1)$$

Demand curves were fitted to individual subject data using the R package *beezdemand* (Kaplan et al., 2018). For the best fitting demand curves while being consistent across cue conditions and task versions, k was set to 4.

Linear mixed-effects models were used to determine differences in discounting rates as a function of cue condition. Cue type was included as a fixed factor, and random intercepts were modeled for participants to account for the repeated-measures design. To control for baseline level of impulsiveness, the monetary version of the MCQ was included as a covariate. Paired-samples t-tests were used to compare purchase task demand indices and MCP crossover points between cue conditions. Log or square root transformations were used to improve the distribution of highly skewed variables. Significance is reported at $p < .05$.

Secondary Outcomes

Bivariate correlations were used to explore associations between ECIG dependence, impulsivity via the BIS-11, and the other outcome measures. Correlations were also used to compare the puffs and minutes versions of the behavioral economic measures. Specifically, the significance and magnitude of the correlations between the behavioral economic outcomes and ECIG dependence were compared across task versions. A linear mixed-effects model was used to analyze heart rate data. Cue type (ECIG vs. neutral), bout (one vs. two), time (pre- vs. during vs. post-cue exposure) and their interactions were included as fixed factors. Random intercepts

were modeled for participants. Data obtained from the cigarette versions of the QSU-Brief Factors 1 and 2 and Schuh-Stitzer scale were highly positively skewed (skew > 2.90). The assumptions of mixed models were not met for these variables, including when log and square-root transformations were performed, and when data were modeled with a gamma distribution. Consequently, nonparametric Wilcoxon signed-rank tests were used to compare ratings of smoking desire between cue types. Where applicable, significance for secondary outcomes is reported at $p < .05$.

Study Hypotheses

For subjective outcomes, it was hypothesized that exposure to ECIG (vs. neutral) cues would significantly increase self-reported craving for an ECIG as measured by the QSU-Brief and Schuh–Stitzer craving questionnaire (King et al., 2016, 2018; Vena et al., 2020). It was also expected that exposure to ECIG cues would increase negative mood (Heishman et al., 2010; Wray et al., 2011) relative to exposure to neutral cues. Further, it was hypothesized that behavioral economic outcomes would be sensitive to cue type (see Dowd & Tiffany, 2019). Specifically, it was expected that participants would spend more on ECIG use following exposure to ECIG cues, and that demand elasticity would be lower (Acker & MacKillop, 2013; MacKillop et al., 2012b). Finally, delay discounting was expected to be steeper and MCP crossover points were expected to be higher following exposure to ECIG cues.

Results

Participant Recruitment and Enrollment

A total of 556 individuals completed the screening survey and provided their contact information. Of these, 149 (26.8%) appeared to meet the study inclusion/exclusion criteria and were contacted about scheduling a screening visit. Forty-one individuals attended an in-person

screening visit and consented to participate in the study. Of those who consented, five (12.2%) did not attend both sessions and one (2.4%) was deemed ineligible for no longer meeting inclusion criteria (i.e., reported too frequent marijuana use). Additionally, one participant (2.4%) was excluded from the final sample due to an inconsistency in study procedures. The remaining $N = 34$ (82.9%) completed both study sessions and were included in the final sample.

The most common reasons for ineligibility on the screening survey were intention to quit vaping within the next 30 days (27.9%), use of marijuana/THC > 15 days in the past 30 days (22.2%), lifetime use of > 100 cigarettes (19.6%), no ECIG use in the past 30 days (12.1%), and use of an ECIG on an average of < 4 days per week over the past three months (10.3%). Less common reasons for ineligibility were use of alcohol > 15 days in the past 30 days (5.0%), use of an ECIG for < 3 months (4.9%), not using an ECIG containing nicotine (3.6%), use of an illicit drug in the past 30 days (1.8%), and age < 18 (1.3%). These reported percentages are based on all 556 individuals who completed the screening survey and do not exclude participants deemed ineligible for more than one reason.

Participant Characteristics

Demographic characteristics of the final sample ($N = 34$) are shown in Table 1. Participants were primarily young adults, with a mean age of 21.47 ($SD = 3.39$) years. All participants identified as women (64.71%) or men (35.29%). The sample was 76.47% white, 2.94% Black, 8.82% multiracial, and 11.76% other or unknown race. Most were non-Hispanic (79.41%). Participants reported using an ECIG nearly every day ($M = 6.50$, $SD = 0.90$ days per week) over the past three months and had vaped for an average of 2.91 ($SD = 1.58$) years. The majority of the sample used modern disposables (67.65%) or pods (26.47%). Many participants reported using the ECIG brands Hyde (52.94%), ELF Bar, JUUL, and Vuse (11.76% each).

Participants were moderately dependent on ECIGs based on their scores on the PSECDI (M = 10.79, SD = 4.62) and the EDS-4 (M = 2.07, SD = 0.75). All participants reported smoking ≤ 100 cigarettes in their lifetime (M = 15.76, SD = 26.75).

Primary Outcomes

ECIG Craving and Mood

Results of the models predicting the subjective outcomes of ECIG craving and mood are provided in Table 2. For the ECIG QSU-Brief Factor 1 (i.e., desire to vape; Figure 3), a significant interaction between cue type and time was observed. Specifically, scores were comparable pre- (M = 17.17, SE = 1.49) and post-exposure (M = 17.10, SE = 1.49) for neutral cues, but increased from pre- (M = 17.80, SE = 1.62) to post-exposure (M = 19.48, SE = 1.62) for ECIG cues. Also observed were significant main effects of bout and time. For the main effect of bout, ratings of desire to vape were significantly higher at the second bout of cue exposure (M = 18.39, SE = 1.48) relative to the first (M = 17.38, SE = 1.48). For the main effect of time, ratings of desire to vape were significantly higher post cue exposure (M = 15.28, SE = 1.48) than pre cue exposure (M = 14.48, SE = 1.48). A gamma mixed-effects model investigated effects of cue type, bout, and time on ECIG QSU-Brief Factor 2 scores (i.e., anticipation of relief from ECIG withdrawal; Figure 4). There was a significant three-way interaction between these factors. For neutral cues only, QSU-Brief Factor 2 ratings decreased after bout one of cue exposure but increased after bout two of cue exposure. However, post-hoc tests revealed that these differences were not reliable. Also significant was an interaction between bout and time, though post-hoc tests revealed no reliable differences.

The linear mixed model predicting ECIG craving via the Schuh-Stitzer scale showed a significant three-way interaction between cue type, bout, and time, as well as significant main

effects for each of these same factors (Figure 5). For the interaction, ratings of craving increased significantly from pre- to post-exposure at bout one for ECIG cues (M = 53.97, SE = 5.17 vs. M = 60.35, SE = 5.17, respectively), but remained similar between timepoints for neutral cues (M = 50.47, SE = 4.90 vs. M = 51.13, SE = 4.90, respectively), Tukey's $p < .05$. For the main effect of cue type, ratings of ECIG craving were higher in the ECIG-cue condition than the neutral-cue condition (M = 59.07, SE = 5.06 vs. M = 53.19, SE = 4.78, respectively). For the main effect of bout, scores were significantly higher at bout two relative to bout one (M = 58.27, SE = 4.80 vs. M = 53.98, SE = 4.80, respectively). For the main effect of time, craving scores were significantly higher post-cue exposure than pre-cue exposure (M = 58.27, SE = 4.80 vs. M = 53.98, SE = 4.80, respectively).

For the PANAS positive affect scale (Figure 6), there was a significant interaction between bout and time. Specifically, there was a significant decrease in positive affect from pre- to post-cue exposure at bout one (M = 23.83, SE = 1.48 vs. M = 22.24, SE = 1.48, respectively) but scores remained similar from pre- to post-bout two (M = 21.05, SE = 1.48 vs. M = 20.71, SE = 1.48, respectively). There were also significant main effects of both bout and time. Positive affect decreased from bout one to bout two (M = 23.04, SE = 1.47 vs. M = 20.88, SE = 1.47, respectively), as well as from pre- to post- cue exposure (M = 22.44, SE = 1.47 vs. M = 21.48, SE = 1.47, respectively). For PANAS negative affect (Figure 7), there was a significant interaction between cue type and time. Negative affect scores increased significantly from pre- to post-cue exposure in the ECIG-cue condition (M = 16.81, SE = 1.51 to M = 17.48, SE = 1.51) but remained comparable in the neutral-cue condition (M = 15.56, SE = 1.35 to M = 15.36, SE = 1.35). Additionally, significant main effects were observed for cue type and bout. Negative affect was higher for ECIG cues than neutral cues (M = 17.14, SE = 1.50 vs. M = 15.46, SE = 1.35,

respectively). Further, negative affect was higher at bout two relative to bout one (M = 16.47, SE = 1.38 vs. M = 16.13, SE = 1.38, respectively).

Paired-samples t-tests revealed no significant differences in subjective ratings on the QSU-Brief Factors 1 and 2 and PANAS scales between bout two, post-cue exposure and the final assessment, for the n = 12 with data at this final timepoint, t's(11) = -1.46 - 1.54, p's > .05.

Delay Discounting

Linear mixed models predicted effects of cue type on log-transformed delay-discounting k values. All models controlled for log k values derived from the monetary version of the MCQ that was completed at baseline. One participant on each task version was excluded for earning a consistency score of < 75%. Cue type did not significantly affect delay discounting on the puffs (b = 0.02, SE = 0.03, t = 0.57, p = .574) or minutes (b = 0.12, SE = 0.06, t = 1.99, p = .055) version of the task. Figure 8 shows the average log k values for each cue type and task version. Appendix G shows the proportion of participants who chose the larger, delayed option on the MCQ puffs and minutes, plotted by the k values associated with each of the 27 MCQ items.

Behavioral Economics

Nonsystematic responding on the commodity purchase tasks was observed for the same n = 7 participants on each task. Of these n = 7 participants, the majority (85.71%) failed the criterion of trend, and many (66.67%) who failed trend also failed bounce or reversals from zero on at least one task. These participants were excluded from the subsequent analyses. An additional participant was excluded from analyses involving the minutes task, as they reported purchasing 4800 minutes of ECIG access in a 24-hour (1400 min) period. The exponentiated demand equation fit the data well, with average R^2 values $\geq$ 0.96. Table 3 displays descriptive statistics and paired-samples t-tests comparing log-transformed demand indices as a function of

cue type. For the puffs version of the task, no significant differences were observed as a function of cue type for any demand indices. For the minutes version, there was a significant effect of cue type on demand intensity. Unexpectedly, demand intensity was significantly higher for neutral cues (M = 656.65, SE = 74.27) relative to ECIG cues (M = 450.96, SE = 72.61). No other demand indices differed as a function of cue type for the minutes version of the ECIG purchase task.

Paired-samples t-tests revealed no cue-related differences in log-transformed MCP crossover points on the puffs ($t(33) = 0.60$, p = .551, d = 1.03) or minutes ($t(33) = -0.73$, p = .471, d = -0.12) versions of the task. The average crossover point on the puffs MCP was $2.03 ($SE$ = 0.31) for ECIG cues and $1.75 ($SE$ = 0.27) for neutral cues. On the minutes MCP, the average crossover point was $1.91 ($SE$ = 0.32) for ECIG cues and $1.72 ($SE$ = 0.27) for neutral cues.

Secondary Outcomes

Correlations

Bivariate Pearson's correlations among variables of interest are provided in Table 4. Scores on the PSECDI were significantly correlated with all impulsivity measures (r's = .44 - .67, p's < .05) except for MCQ k. By contrast, scores on the EDS-4 were correlated only with the BIS-11 total score (r = .35, p < .05). PSECDI and EDS-4 scores were also significantly correlated with scores on the QSU-Brief Factor 1 and Factor 2, as well as the Schuh-Stitzer scale (r's = .52 - .75, p's < .05). Scores on the PSECDI, but not EDS-4, were significantly correlated with MCP crossover point (r's = .35 - .37, p's < .05). Few other behavioral economic outcomes were correlated with ECIG dependence level. The BIS-11 total score and most subscale scores were significantly associated with ECIG craving as assessed by the QSU-Brief Factor 1 and

Schuh-Stitzer scale (r's = .35 - .49, p's < .05). Interestingly, the BIS-11 total score and attentional and motor subscale scores were each positively associated with PANAS negative affect (r's = .36 - .37, p's < .05) but not positive affect. Correlations were also used to compare the puffs and minutes versions of the behavioral economic tasks. Few differences in statistical significance emerged between task types, and the magnitude of the correlation coefficients were similar for each.

Cigarette Craving

Wilcoxon signed-rank tests were used to compare ratings of smoking desire between ECIG and neutral cues, collapsed across bout and time. No differences were observed as a function of cue type on any of the measures, which included the smoking version of the QSU-Brief Factor 1 (Z = -1.62, p = .106) and Factor 2 (Z = -1.37, p = .172), and the Schuh-Stitzer cigarette craving scale (Z = -1.06, p = .291). Scores on each of these measures were notably low. Collapsed across cue type, bout, and time, the average QSU-Brief scores were 1.21 (SD = 2.58) for Factor 1 and 0.65 (SD = 1.31) for Factor 2, despite the scales ranging from 0-30. Likewise, the average Schuh-Stitzer cigarette craving score was 5.61 (SD = 10.65) on a scale ranging from 0-100.

Heart Rate

The linear mixed-effects model predicting heart rate (beats per minute) revealed significant main effects of cue type (b = 0.51, SE = 0.19, t = 2.73, p = .007), bout (b = -0.76, SE = 0.18, t = -4.30, p < .001), and time (b = 0.86, SE = 0.25, t = 3.41, p = .001). Specifically, heart rate was higher in the ECIG-cue condition (M = 70.96, SE = 1.52) relative to the neutral-cue condition (M = 69.95, SE = 1.52). Heart rate was also higher at bout one (M = 71.21, SE = 1.52) than bout two (M = 69.69, SE = 1.52). Finally, heart rate was observed to be higher pre-exposure

(*M* = 71.31, *SE* = 1.53) compared to during exposure (*M* = 70.37, *SE* = 1.53). Figure 9 shows heart rate across bout and time for ECIG- and neutral-cue conditions.

Discussion

The current study is the first to examine effects of ECIG cue exposure in experienced ECIG users with minimal smoking history. Using a within-subjects design, ECIG users experienced two sessions that differed only by the type of cues presented: ECIG or neutral. The primary aims were to examine effects of ECIG cue exposure on subjective ratings of ECIG craving and mood, as well as hypothetical delay discounting and behavioral economics. Secondary aims included assessing effects of ECIG cue exposure on craving for cigarettes and heart rate. Other secondary aims were to explore associations between ECIG dependence and impulsivity, and to compare puffs and minutes versions of ECIG behavioral economic tasks.

ECIG Craving and Mood

In support of study hypotheses, significant effects of ECIG cue exposure were observed for several of the subjective outcomes. Ratings of desire to vape, as measured by the QSU-Brief Factor 1, increased significantly from pre- to post-cue exposure for ECIG cues relative to neutral cues. A similar effect was observed for ratings of ECIG craving on the Schuh-Stitzer scale; however, significant increases in craving were observed only after the first bout of ECIG cue exposure. Previous work with ECIG users who are current or former smokers show similar findings of increased ECIG craving in response to ECIG-related cues (Blackwell et al., 2020; King et al., 2015, 2016, 2018, 2021; Vena et al., 2019, 2020, 2021). Notably, the smokers included in many of these prior studies had limited experience using ECIGs (King et al., 2015, 2018, 2021; Vena et al., 2019, 2020). Therefore, the results of the current study build upon prior

research by including experienced ECIG users with minimal smoking experience (i.e., ≤ 100 lifetime cigarettes).

The observed findings related to ECIG craving may have implications for the regulation of ECIG product advertising. Young adults, including non-smokers, are frequently exposed to ECIG marketing (Wagoner et al., 2019). Advertisements depicting ECIGs or people vaping are present on social media, television, retail stores, and online. These advertisements may function as cues, increasing ECIG users' desire to vape and potentially promoting continued use. Given the findings of this study and others, research is needed to elucidate the effects of exposure to advertisements on ECIG craving. Additionally, future research is needed to assess the relationship between craving and actual ECIG use.

Exposure to ECIG cues also significantly increased negative mood. Similar findings have been observed in previous work where smokers were exposed to smoking-related cues (Drobes & Tiffany, 1997; Wray et al., 2011). This pattern of results may be explained by participants experiencing adverse symptoms (e.g., irritability, difficulty concentrating, headache) when presented with tobacco cues in an environment that does not permit tobacco use. Support for this idea comes from research by Carter and Tiffany (2001), in which smokers were presented with a smoking cue as well as the probability (0%, 10%, 100%) of being able to access the cue (i.e., smoke the cigarette). Negative mood increased after viewing the smoking cue (vs. neutral cue) only when there was a 0% probability of accessing it. As the probability of accessing the cue increased, negative mood decreased (Carter & Tiffany, 2001). More research is needed to determine the degree to which vaping availability affects cue-induced negative mood. Nevertheless, the finding of increased negative mood after ECIG cue exposure may have important implications for relapse. In smokers, rapid increases in negative affect is associated

with smoking relapse (Shiffman & Waters, 2004). No known studies have investigated this phenomenon in ECIG users; however, this work may be warranted given the findings of the current study.

Delay Discounting

ECIG cue exposure did not significantly affect hypothetical delay discounting (i.e., impulsive choice). This study is the first to investigate delay discounting as a function of ECIG cue exposure, so direct comparisons to existing literature cannot be made. Only one known study has examined delay discounting in smokers after exposure to smoking-related cues. Similar to the current study, no significant differences in delay discounting were observed (Field et al., 2007). There are several possible explanations for our findings. First, it is possible that the delay discounting measures used in the current study were not sensitive enough to detect cue-induced effects. The standard (i.e., monetary) MCQ is a validated assessment of delay discounting, whereas the ECIG-adapted versions of the MCQ used in this study are not. It is not uncommon for researchers to adapt the MCQ to their commodity of interest (see Dassen et al., 2015; Lim & Bruce, 2015; MacKillop et al., 2012a). Still, the current study is the first to use an ECIG-adapted version of the MCQ, and further testing may be required to determine the quantities of ECIG use that are optimal for this measure. Moreover, the tasks were fully hypothetical, which may yield results that are inconsistent with those observed when rewards are real (see limitations section for a discussion of real vs. hypothetical tasks). A second possibility is that the conditions necessary to detect an effect were not met. Although, it is unlikely that the timing or order of task administration affected findings; both delay discounting tasks were administered within 40 min of the last cue exposure and the task order (i.e., puffs or minutes first) was counterbalanced across participants. Additionally, sensitivity analyses showed no significant effect of task order

on log *k* values when included as a covariate in the models. It is possible that ECIG abstinence impacted impulsive choice, washing out potential cue effects. Alternatively, the ECIG users in our sample may not have been in withdrawal due to our inability to enforce long-term abstinence with biochemical tests. However, in a recent study with exclusive ECIG users, 16-hour nicotine abstinence had no effect on delay discounting for ECIG liquid (Pericot-Valverde et al., 2023). Similar studies with smokers show mixed findings, with some suggesting nicotine deprivation increases impulsive choice for cigarettes (Field et al., 2006) and others finding no such effects (Yi & Landes, 2012). Third, it is possible that exposure to ECIG cues does not affect delay discounting in ECIG users. As suggested by Field et al. (2007), impulsive choice may not be sensitive to all manipulations that increase desire for tobacco products. Future research may provide further insight into effects of ECIG cue exposure on impulsive choice.

Behavioral Economics

Contrary to study hypotheses, exposure to ECIG cues did not significantly increase behavioral economic demand for ECIGs. No other known studies have used an ECIG purchase task or MCP to assess the reward value of ECIGs as a function of cue exposure. One published study, however, investigated effects of ECIG cue exposure on ECIG product purchasing. Dowd and Tiffany (2019) found that dual cigarette-ECIG users spent significantly more money to access a puff from their ECIG after viewing an ECIG cue than to access a sip of water after viewing a water cue. Notably, ECIG product purchasing was not assessed at baseline, nor after viewing a neutral cue, thereby limiting the ability to draw conclusions on cue-induced spending. Studies with smokers have used purchase tasks to assess the reward value of cigarettes after smoking cue exposure, though no known studies have used the MCP. In contrast to findings of the current study, studies with smokers and smoking-related cues have found significant

differences in some demand indices by cue type. For instance, using hypothetical rewards, Acker and MacKillop (2013) found demand indices of O_{max} and breakpoint to be higher, and elasticity to be lower, following exposure to smoking cues. Using real rewards, MacKillop et al. (2012b) found similar results for elasticity, but no other demand indices were sensitive to cue exposure. These results provide at least some evidence that exposure to smoking cues increases the abuse liability of cigarettes among smokers.

The ECIG users in our sample may have misunderstood or not attended to the purchase task, as evidenced by nonsystematic responding and unrealistic product purchasing by some participants. Indeed, nearly 21% of participants provided nonsystematic data and were thus excluded from analyses. An additional participant was excluded for reporting that they would purchase 4800 minutes of ECIG use in 24-hour (1400 min) period. This was likely the result of inattention to task instructions, which stated that all purchases had to be consumed within 24 hours and could not be saved or given away. Future work may aim to prevent unrealistic purchasing by verifying instructions with participants before the task, constraining the maximum amount available for purchase, or asking participants to confirm their response (Stein et al., 2015). The large proportion of missing data limited our statistical power to detect significant effects for demand indices. However, there were also no significant effects observed for the MCP, and no data were missing on this measure. Nonetheless, future work with larger samples may be warranted.

Secondary Outcomes

Cigarette Craving

A secondary outcome of this study was to assess effects of ECIG cue exposure on desire to smoke cigarettes. Overall, cigarette craving was notably low and unaffected by exposure to

ECIG cues. These findings contrast prior work with ECIG users who are, or have been, established smokers. Over half of the studies included in a systematic review by Keijsers et al. (2022) found that ECIG cue exposure increased desire for a combustible cigarette. It is likely that this effect is moderated by previous smoking experience. Despite never being regular smokers, the majority (76.5%) of the ECIG users in the current study reported taking at least one puff from a cigarette in their lifetime. Even so, the average number of cigarettes smoked was only 15.76 (*SD* = 26.75), which is likely too few to observe a cross-cue reactivity effect. Future work will need larger samples with greater variability in smoking experience to further elucidate this phenomenon.

Comparison of Puffs and Minutes Tasks

Another secondary outcome of this study was to compare the puffs and minutes versions of the delay discounting and behavioral economic tasks. Determining the best unit by which to quantify ECIG use on behavioral tasks is challenging, as there is no standardized unit of ECIG consumption (Soule et al., 2023). Researchers have proposed the use of various units, including puffs, mL of liquid, number of cartridges or pods, and frequency of product purchasing. In this study, puffs and minutes of access were compared, as both units are applicable to users regardless of their ECIG device type. Interestingly, no reliable differences emerged between task versions. Further, correlation coefficients between task outcomes and ECIG dependence measures were of similar magnitude for both task versions. Also notable is that the proportion of nonsystematic responses was the same for both task versions.

Although there were no systematic differences observed between units of consumption, there are some notable benefits and drawbacks of each. For instance, for tasks with preset quantities of ECIG use – like the delay discounting task and MCP in this study – the number of

puffs may exceed the amount desired by the user. ECIG users vary widely on the number of puffs taken per day and per vaping session (Dowd et al., 2023; St.Helen et al., 2016), likely due in part to the heterogeneity among ECIG devices (Soule et al., 2023). User puffing behavior (i.e., puff number, volume, duration) interacts with various device features (e.g., device power, liquid nicotine concentration) to affect the amount of nicotine delivered to the user (Voos et al., 2019). Consequently, to obtain a comparable amount of nicotine, an ECIG user may need to take more frequent, larger, or longer puffs from a device that yields low levels of nicotine (e.g., cig-alike) relative to one that yields high levels of nicotine (e.g., mod- or pod-style devices). The wide variation in the number of puffs that are reinforcing to ECIG users complicates task development. It may therefore be beneficial to quantify ECIG use in units that allow for more flexibility, such as minutes. At the same time, a minute of ECIG use provides no information on how much the ECIG is actually used, which may make it an unattractive unit of consumption for many researchers. It is also important for ECIG users to be able to accurately estimate their consumption in the units of ECIG use provided. Research shows that some ECIG users have trouble estimating their consumption in puffs (Cassidy et al., 2017). Similar issues may be present when measured in minutes, though there is no known research on this topic. More work is ultimately needed to determine whether minutes is an appropriate unit by which to quantify ECIG use. Meanwhile, researchers may opt to use a unit that is more specific to their population of ECIG users. For example, if the sample is comprised of users of refillable tank-based devices (e.g., vape pens, mod-style devices), then mL of liquid may provide the greatest accuracy when assessing consumption (Cassidy et al., 2020; Strickland et al., 2020). If the sample uses only pod-based devices, then number of pods may be a more accurate unit of consumption.

Alternatively, if the device types used by the sample are varied or unknown, a universally applicable unit, such as puffs, may be preferred (Strickland et al., 2020).

Heart Rate

The current study also investigated effects of cue exposure on heart rate, finding significantly higher heart rate in response to ECIG versus neutral cues. Additionally, heart rate was lower during (vs. pre-) cue exposure, and lower at bout two than bout one. No known studies have examined effects of ECIG cues on ECIG users' heart rate, and findings from studies with smokers and smoking cues are mixed. Some studies with smokers have found increased heart rate as a function of active cue exposure (Drobes & Tiffany, 1997; Tiffany & Drobes, 1990; Balter et al., 2015), whereas others have found no such differences (Conklin et al., 2010; Tong et al., 2007). Even when significant effects are observed, effect sizes for cue-induced physiological responses tend to be small (Carter & Tiffany, 1999; Drobes & Tiffany, 1997). Results of this study showed a similarly small effect, as average heart rate for ECIG- and neutral-cue conditions differed only by approximately 1 beat per minute. Similarly small (i.e., < 2 beat per minutes) differences were observed for the main effects of both bout and time. These latter effects may be best explained by habituation to the environment and cue presentations.

Strengths

Strengths of this study include the population of ECIG users sampled and features of the experimental design. Sampling ECIG users with minimal smoking history allowed for the assessment of cue effects in this growing population, without the potential confound of pre-existing nicotine dependence or cross-cue reactivity from cigarettes. A study strength related to the experimental design includes the controlled environment, which contained no proximal ECIG cues beyond those presented during the session. Another strength was the counterbalanced order

of the cue conditions across subjects. The inclusion of two bouts of cue exposure (vs. a single bout) is also a strength, as multiple bouts of cue exposure is shown to generate larger effect sizes in studies with smokers (Betts et al., 2020).

Limitations and Future Directions

There are several notable limitations of the present study. One limitation is that pre-session ECIG abstinence was not biochemically verified. The bogus pipeline procedure was implemented to increase compliance with abstinence; however, it is unknown whether participants truly abstained before each session. Cue-induced craving is not likely moderated by nicotine abstinence in smokers (Betts et al. 2020), though no known studies have investigated these effects in ECIG users. Still, future work requiring participants to remain abstinent may benefit from blood or saliva sampling verification, or a prolonged in-person abstinence period. Additionally, study findings may not generalize to a natural environment. Although the laboratory setting minimized confounds such as distractions and exposure to additional environmental cues, it is unlikely that an ECIG user would encounter a similar environment in their everyday life. Further, the cues present in a natural environment (i.e., advertisements, other people vaping) may be qualitatively different than the picture slideshows presented in this study. Future work may opt to use product advertisements (as in Garrison et al., 2018; Maloney & Cappella, 2016) or cues delivered by confederates (as in Vena et al., 2019, 2020, 2021) if the goal is to mimic a more naturalistic setting.

Another limitation is that the current study relied on hypothetical measures of delay discounting and behavioral economics. Hypothetical choice tasks are commonly used in studies with human subjects, as they avoid the financial burden and ethical dilemma of providing real rewards, like cigarettes, to participants. In delay-discounting assessments, they also allow for the

use of longer delays (e.g., many hours to days) which might otherwise be impractical (Green & Lawyer, 2014). Nevertheless, purely hypothetical tasks may not accurately reflect the choices made if the outcomes were real or had been previously experienced. With regard to hypothetical measures of delay discounting, choice is not modified by the outcomes of previous choices on the task (Steele et al., 2019). Participants are unlikely to have had to choose between similar outcomes in the past, thereby limiting their ability to make choices that would reflect their real-world behavior. These concerns have led researchers to investigate the degree of correspondence between real or potentially real (i.e., a participant receives one or more of their selected outcomes at random) and hypothetical discounting tasks. These studies have typically demonstrated high correspondence between task types when the rewards are monetary (Johnson & Bickel, 2002; Lawyer et al., 2011; Madden et al., 2003, 2004, but see Kirby, 1997). However, when cigarette rewards are used, smokers are shown to discount delayed cigarettes more steeply when they are potentially real than when they are purely hypothetical (Green & Lawyer, 2014; Lawyer et al., 2022). Hypothetical ECIG use was used as the reinforcer for the delay-discounting tasks in the current study, so it is possible that discounting was shallower than it would be with real outcomes. Similar concerns exist regarding the validity of hypothetical behavioral economic tasks. Thus far, researchers have found high correspondence between real and hypothetical purchase tasks (Amlung et al., 2012; Wilson et al., 2016). Still, given the discussed limitations, the results of the hypothetical choice tasks used in this study should be interpreted with caution.

Finally, results should be considered in light of the ECIG users sampled. Participants were near-daily ECIG users with moderate levels of dependence (PSECDI M = 10.79, SD = 4.62), and thus results may not generalize to less frequent or less dependent users. Moreover, participants were predominantly young adults (M_{age} = 21.47, SD_{age}= 3.39). Young adults make

up the largest group of adult ECIG users (Bandi et al., 2021; Obisesan et al., 2020) and ECIG use in never smokers is most common among individuals aged 18 to 29 years (Bandi et al., 2021; Kramarow & Elgadda, 2023). Still, results may not generalize to adolescents or older adult users.

Conclusions

Understanding effects of ECIG cue exposure in the growing population of never smokers is important, as many ECIG users want to quit, and exposure to ECIG cues may promote continued use. Research with this unique population eliminates the potential confound of pre-existing nicotine dependence and cross-cue reactivity from cigarettes. Study findings demonstrate significant increases in desire to vape and negative mood after ECIG cue exposure, replicating and extending prior research with cigarette smokers. However, exposure to ECIG cues did not significantly impact ECIG delay discounting or increase behavioral economic demand for ECIG products. Taken together, the results of this study provide evidence of cue reactivity in ECIG users with minimal smoking history, though continued research will be necessary to confirm and expand upon study findings.

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Table 1

Participant Demographic Characteristics (N=34)

	M (SD) or *N* (%)
Age (years)	21.47 (3.39)
Gender	
Women	22 (64.71%)
Men	12 (35.29%)
Race	
White	26 (76.47%)
Black	1 (2.94%)
Multiracial	3 (8.82%)
Other/Unknown	4 (11.76%)
Ethnicity	
Hispanic	7 (20.59%)
Non-Hispanic	27 (79.41%)
Education (years)	15.06 (2.74)
# Cigarettes in Lifetime	15.76 (26.75)
ECIG use	
Duration (years)	2.91 (1.58)
Days/week	6.50 (0.90)
ECIG Device Type	
Pod	9 (26.47%)
Modern Disposable	23 (67.65%)
Multiple Types	1 (2.94%)
Undetermined[1]	1 (2.94%)
ECIG Brand	
Hyde	18 (52.94%)
ELF Bar	4 (11.76%)
JUUL	4 (11.76%)
Vuse	4 (11.76%)
Geekvape	1 (2.94%)
Vaporesso	1 (2.94%)
Multiple brands	2 (5.88%)
Nicotine concentration (mg/mL)	49.68 (4.07)
ECIG Dependence	
PSECDI[2]	10.79 (4.62)
EDS-4[3]	2.07 (0.75)
BIS-11[4] Total	65.26 (10.33)

Note. [1]ECIG device type unable to be determined from self-reported brand; [2]PSECDI = Penn State Electronic Cigarette Dependence Index (range 0-20); [3]EDS-4 = Electronic Cigarette Dependence Scale (range 0-4); [4]Barratt Impulsiveness Scale-11 (range 30-120).

Table 2

Mixed-effects Models Predicting Subjective Outcomes

Outcome Measure	Estimate	*SE*	*t*	*p*
QSU-Brief Factor 1 (ECIG desire)				
Intercept	17.89	1.46	12.22	<.001
Cue type (ECIG)	0.75	0.47	1.60	.119
Bout (2)	**0.50**	**0.16**	**3.07**	**.002**
Time (Post)	**0.40**	**0.16**	**2.44**	**.015**
Gender (Female)	-0.88	1.45	-0.61	.550
Cue type (ECIG) × Bout (2)	0.00	0.16	-0.02	.982
Cue type (ECIG) × Time (Post)	**0.44**	**0.16**	**2.67**	**.008**
Bout (2) × Time (Post)	0.16	0.16	0.96	.336
Cue type (ECIG) × Bout (2) × Time (Post)	-0.23	0.16	-1.41	.159
QSU-Brief Factor 2 (Relief from ECIG withdrawal)				
Intercept	13.05	1.78	7.32	<.001
Cue type (ECIG)	0.73	0.48	1.52	.128
Bout (2)	-0.03	0.05	-0.64	.522
Time (Post)	0.03	0.05	0.56	.577
Gender (Female)	-1.55	1.68	-0.93	.355
Cue type (ECIG) × Bout (2)	-0.01	0.05	-0.26	.795
Cue type (ECIG) × Time (Post)	0.04	0.05	0.87	.383
Bout (2) × Time (Post)	**0.12**	**0.05**	**2.44**	**.015**
Cue type (ECIG) × Bout (2) × Time (Post)	**-0.11**	**0.05**	**-2.24**	**.025**
Schuh-Stitzer ECIG Craving				
Intercept	56.13	4.77	11.76	<.001
Cue type (ECIG)	**2.94**	**1.15**	**2.55**	**.016**
Bout (2)	**2.15**	**0.43**	**4.96**	**<.001**
Time (Post)	**1.29**	**0.43**	**2.98**	**.003**
Gender (Female)	-2.86	4.74	-0.60	.550
Cue type (ECIG) × Bout (2)	-0.24	0.43	-0.55	.580
Cue type (ECIG) × Time (Post)	0.56	0.43	1.29	.197
Bout (2) × Time (Post)	-0.47	0.43	-1.09	.277
Cue type (ECIG) × Bout (2) × Time (Post)	**-0.87**	**0.43**	**-2.01**	**.046**
PANAS Positive Affect				
Intercept	21.96	1.46	15.00	<.001
Cue type (ECIG)	1.19	0.72	1.65	.099
Bout (2)	**-1.08**	**0.12**	**-8.79**	**<.001**
Time (Post)	**-0.48**	**0.12**	**-3.95**	**<.001**
Gender (Female)	0.46	1.34	0.34	.732
Cue type (ECIG) × Bout (2)	0.05	0.12	0.37	.709
Cue type (ECIG) × Time (Post)	0.13	0.12	1.04	.301
Bout (2) × Time (Post)	**0.31**	**0.12**	**2.56**	**.010**
Cue type (ECIG) × Bout (2) × Time (Post)	-0.09	0.12	-0.73	.463

PANAS Negative Affect				
Intercept	16.30	1.38	11.83	<.001
Cue type (ECIG)	**0.84**	**0.37**	**2.29**	**.022**
Bout (2)	**0.17**	**0.08**	**2.22**	**.027**
Time (Post)	0.12	0.08	1.54	.123
Gender (Female)	1.58	1.34	1.18	.239
Cue type (ECIG) × Bout (2)	0.12	0.08	1.57	.116
Cue type (ECIG) × Time (Post)	**0.22**	**0.08**	**2.81**	**.005**
Bout (2) × Time (Post)	0.06	0.08	0.80	.424
Cue type (ECIG) × Bout (2) × Time (Post)	-0.01	0.08	-0.07	.941

Note. Significant items are bolded.

Table 3

Paired-samples t-tests Comparing Demand Indices across ECIG and Neutral Cues

	ECIG Cues	Neutral Cues	ECIG - Neutral		
	M (SE)	*M (SE)*	*t*	*p*	*d*
Puffs Version					
Intensity	515.74 (72.76)	529.63 (66.84)	-0.53	.603	-0.10
Breakpoint	19.23 (5.98)	15.22 (4.06)	-0.26	.800	-0.05
O_{max}	37.14 (11.41)	27.13 (7.08)	0.78	.444	0.15
P_{max}	15.43 (6.13)	12.15 (4.09)	-0.90	.378	-0.17
Elasticity (α)	0.0078 (0.0017)	0.0077 (.0016)	-0.35	.726	-0.07
Minutes Version					
Intensity	**450.96 (72.61)**	**656.65 (74.27)**	**-2.53**	**.018**	**-0.50**
Breakpoint	17.83 (5.33)	18.19 (5.29)	-1.08	.292	-0.21
O_{max}	34.94 (11.55)	31.58 (7.78)	-0.59	.562	-0.12
P_{max}	16.03 (5.41)	17.72 (5.34)	-0.71	.484	-0.14
Elasticity (α)	0.0063 (0.0010)	0.0056 (0.0012)	0.90	.378	0.18

Note. Significant items are bolded. $df = 26$ (puffs) or 25 (minutes). Intensity, breakpoint, O_{max}, and P_{max} were observed from the data. Elasticity was calculated using exponentiated demand equation (Koffarnus et al., 2015). Raw values are described in table.

Table 4

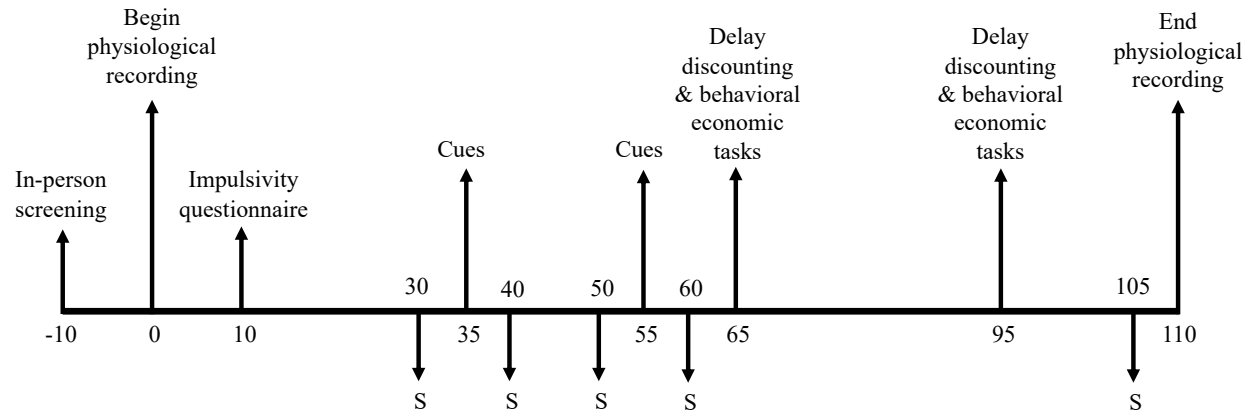
Bivariate Pearson Correlations Among Key Study Variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
ECIG Dependence																										
1. PSECDI	--																									
2. EDS	**.62**	--																								
Impulsivity Measures																										
3. MCQ *k* (monetary)	.30	.24	--																							
4. BIS-11 Total	**.67**	**.35**	.00	--																						
5. BIS-11 Attentional[1]	**.44**	.25	-.05	**.74**	--																					
6. BIS-11 Motor[1]	**.53**	.34	-.08	**.79**	**.41**	--																				
7. BIS-11 Non-planning[1]	**.63**	.27	.08	**.88**	**.41**	**.62**	--																			
Subjective Outcomes																										
8. QSU F1: ECIG	**.65**	**.65**	.13	**.49**	**.47**	.31	**.40**	--																		
9. QSU F2: ECIG	**.52**	**.64**	.30	.24	.13	.25	.20	**.76**	--																	
10. Schuh-Stitzer ECIG	**.71**	**.75**	.27	**.48**	**.43**	**.35**	**.39**	**.86**	**.81**	--																
11. PANAS Positive	-.04	.01	.16	-.11	.06	.08	-.30	.13	.10	-.01	--															
12. PANAS Negative	.26	**.51**	.14	**.36**	**.36**	**.37**	.19	**.49**	**.66**	**.57**	.23	--														
Delay Discounting																										
13. MCQ *k* (puffs)	.21	-.04	**.50**	-.21	-.19	-.26	-.10	.19	.18	.23	.07	-.18	--													
14. MCQ *k* (min)	.07	.02	**.39**	-.26	-.23	-.29	-.15	.08	.24	.20	-.08	-.18	**.79**	--												
Behavioral Economics																										
15. MCP Crossover (puffs)	**.35**	.13	.06	.30	.02	**.39**	.33	.31	**.42**	**.41**	-.15	.20	.07	.16	--											
16. MCP Crossover (min)	**.37**	.20	.04	.27	.03	**.38**	.28	.33	**.47**	**.50**	-.12	.20	.04	.21	**.96**	--										
17. PT Intensity (puffs)	.07	.06	.13	-.11	-.32	.20	-.07	-.06	.19	.09	.06	.04	.17	.24	.11	.11	--									
18. PT Breakpoint (puffs)	.31	.16	-.22	.10	.07	.30	-.05	.31	.34	.26	.34	.24	.00	-.07	**.50**	**.47**	-.05	--								
19. PT Omax (puffs)	.16	.08	-.09	.06	.13	.18	-.10	.31	.32	.27	**.51**	**.39**	.03	-.01	**.49**	**.48**	-.06	**.86**	--							
20. PT Pmax (puffs)	.26	.08	-.24	.11	-.01	.34	.01	.26	.31	.22	.29	.24	-.05	-.11	**.57**	**.54**	-.01	**.96**	**.84**	--						
21. PT Elasticity (puffs)	-.31	**-.40**	-.10	-.04	-.02	-.28	.11	-.13	-.36	-.36	-.21	-.25	-.11	-.25	-.19	-.29	**-.63**	-.28	-.33	-.21	--					
22. PT Intensity (min)	.24	.01	.12	.01	-.12	.21	-.01	.06	.24	.18	.09	.01	.16	.18	.27	.25	**.85**	.10	.14	.12	**-.62**	--				
23. PT Breakpoint (min)	.25	.28	-.18	.11	.10	.29	-.05	.36	.36	.31	.28	.38	-.06	-.08	**.43**	**.42**	-.11	**.91**	**.81**	**.86**	-.25	-.05	--			
24. PT Omax (min)	.12	.09	-.16	.07	.13	.20	-.09	.31	.29	.25	**.47**	**.42**	-.01	-.06	**.44**	**.45**	-.07	**.86**	**.98**	**.85**	-.31	.09	**.85**	--		
25. PT Pmax (min)	.23	.29	-.16	.10	.09	.29	-.05	.34	.37	.30	.26	**.40**	-.11	-.11	**.46**	**.44**	-.11	**.89**	**.79**	**.86**	-.22	-.05	**.99**	**.83**	--	
26. PT Elasticity (min)	-.33	**-.43**	-.04	-.09	-.12	-.27	.09	-.16	-.32	-.38	-.16	-.29	-.11	-.18	-.13	-.21	**-.53**	-.28	-.36	-.19	**.93**	**-.54**	-.34	**-.40**	-.31	--

Note. Table displays correlations of items averaged across cue type, bout, and time, if applicable. Significant items are bolded. [1]BIS-11 subscale.

Figure 1

Session Procedure



Note. Timeline (min) of each of two sessions, which differ by the type of cue presented. S = subjective measures. In-person screening and impulsivity questionnaire completed at the first session only.

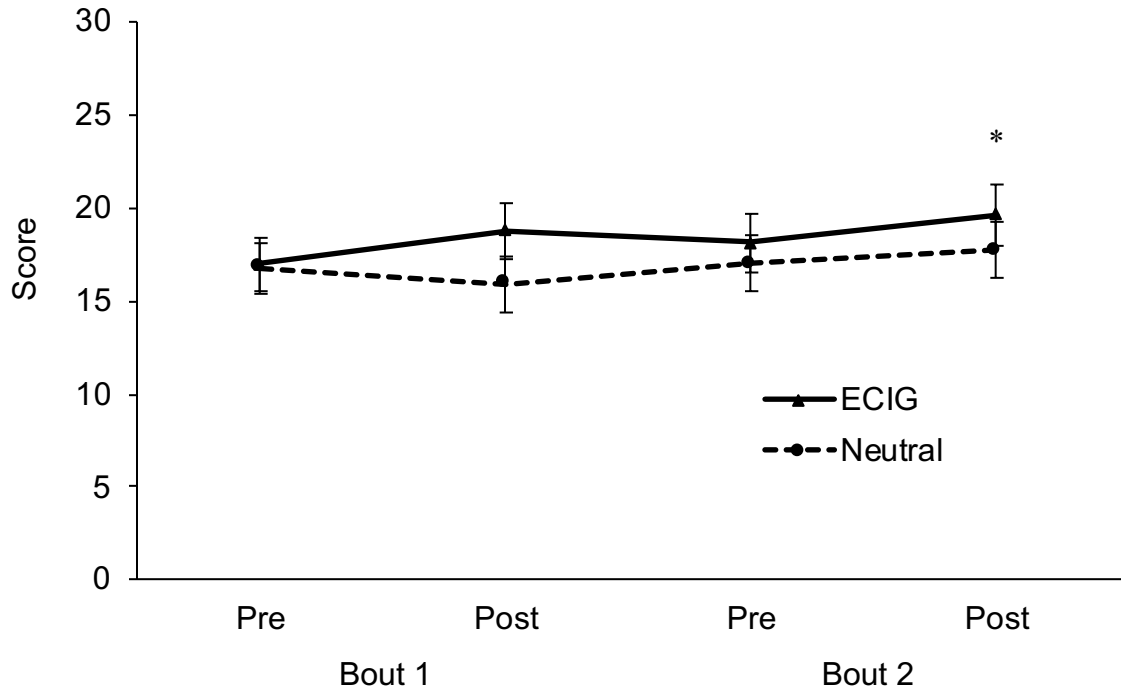
Figure 2

Cues

Note. Examples of ECIG cues (left) and neutral cues (right).

Figure 3

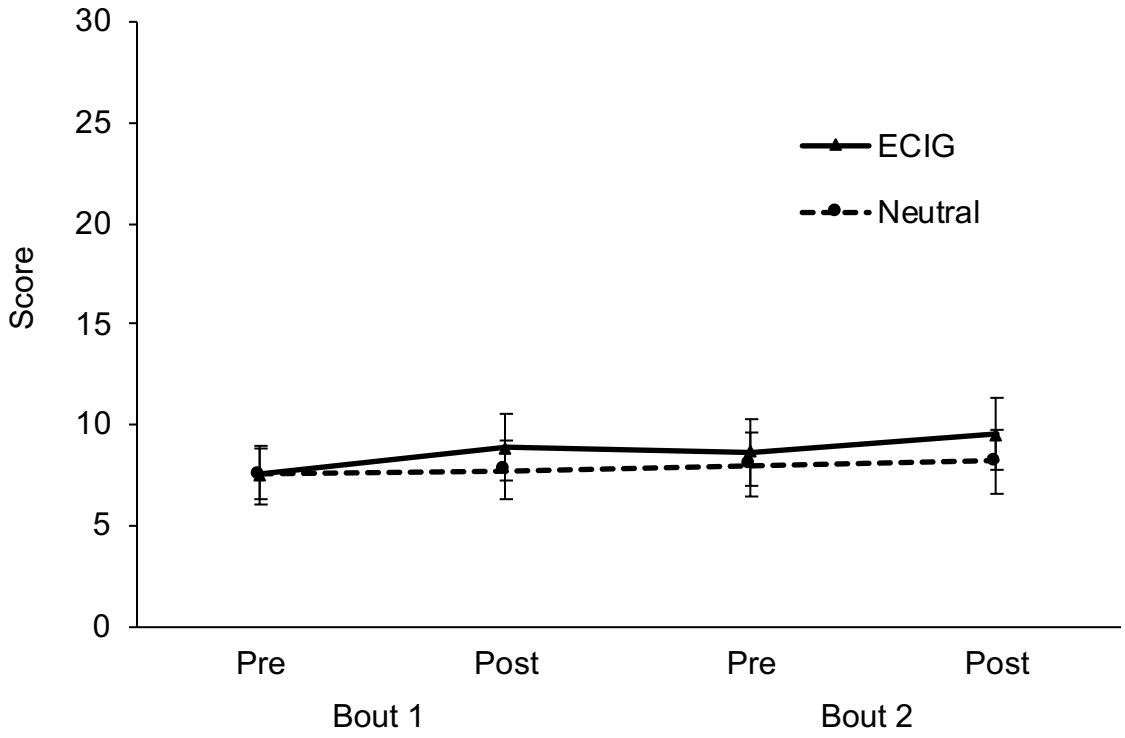
QSU-Brief Factor 1 (Desire to Vape) Ratings by Cue Type



Note. Mean (+/- SEM) ratings on the QSU-Brief Factor 1 (desire to vape) for ECIG and neutral cues. * Denotes significant difference between bout 1 pre-exposure and indicated timepoint within ECIG cue condition.

Figure 4

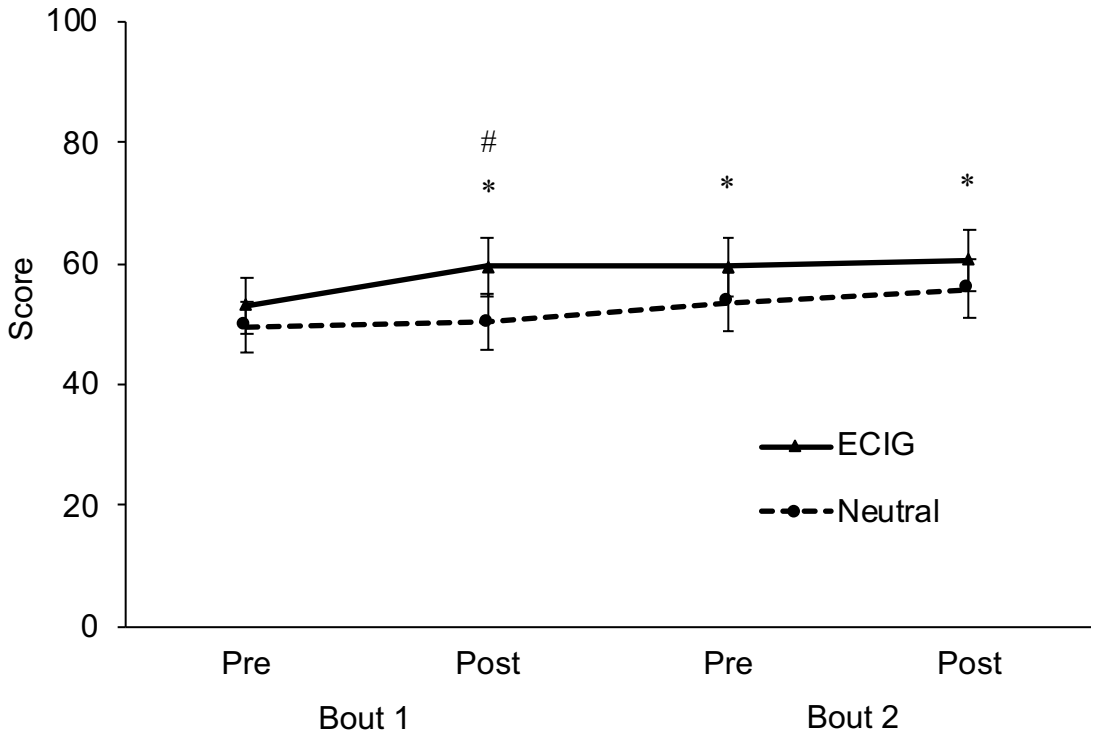
QSU-Brief Factor 2 (Anticipation of Relief from ECIG Withdrawal) Ratings by Cue Type



Note. Mean (+/- SEM) ratings on the QSU-Brief Factor 2 (anticipation of relief from ECIG withdrawal) for ECIG and neutral cues.

Figure 5

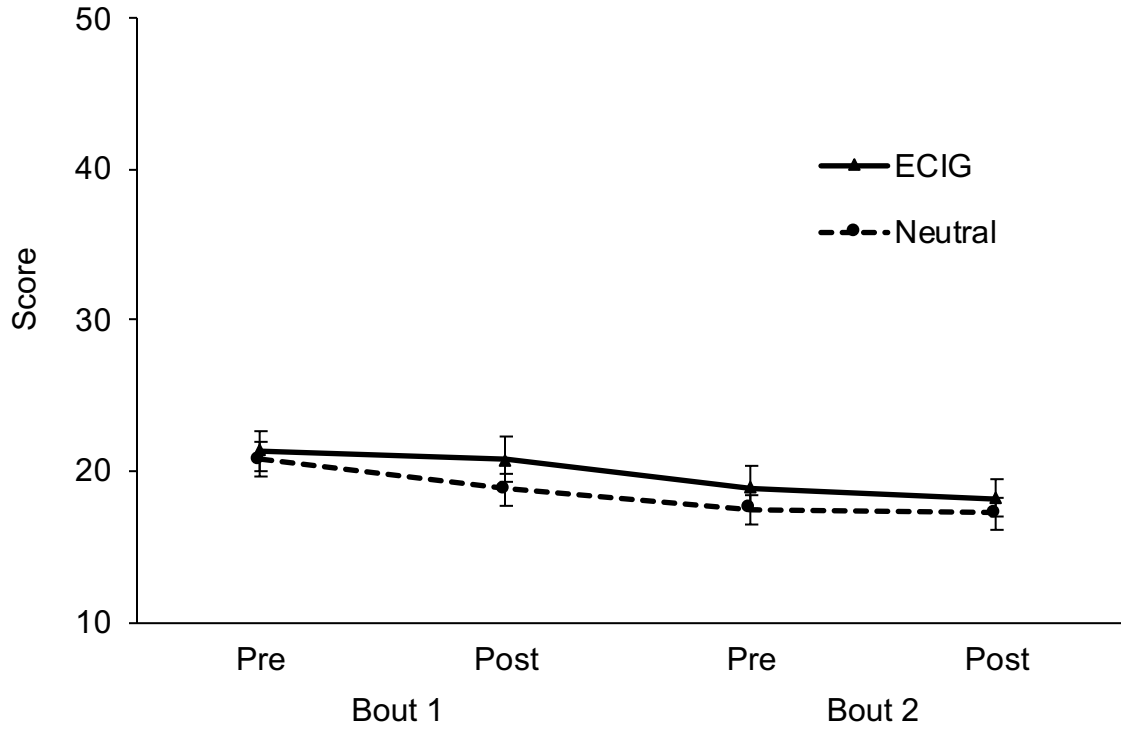
Schuh-Stitzer ECIG Craving Scores by Cue Type



Note. Mean (+/- SEM) ratings of Schuh-Stitzer ECIG craving for ECIG and neutral cues. * Denotes significant difference between bout 1 pre-exposure and indicated timepoint within ECIG cue condition. # Denotes significant difference at indicated timepoint between cue conditions (Tukey's $p < .05$)

Figure 6

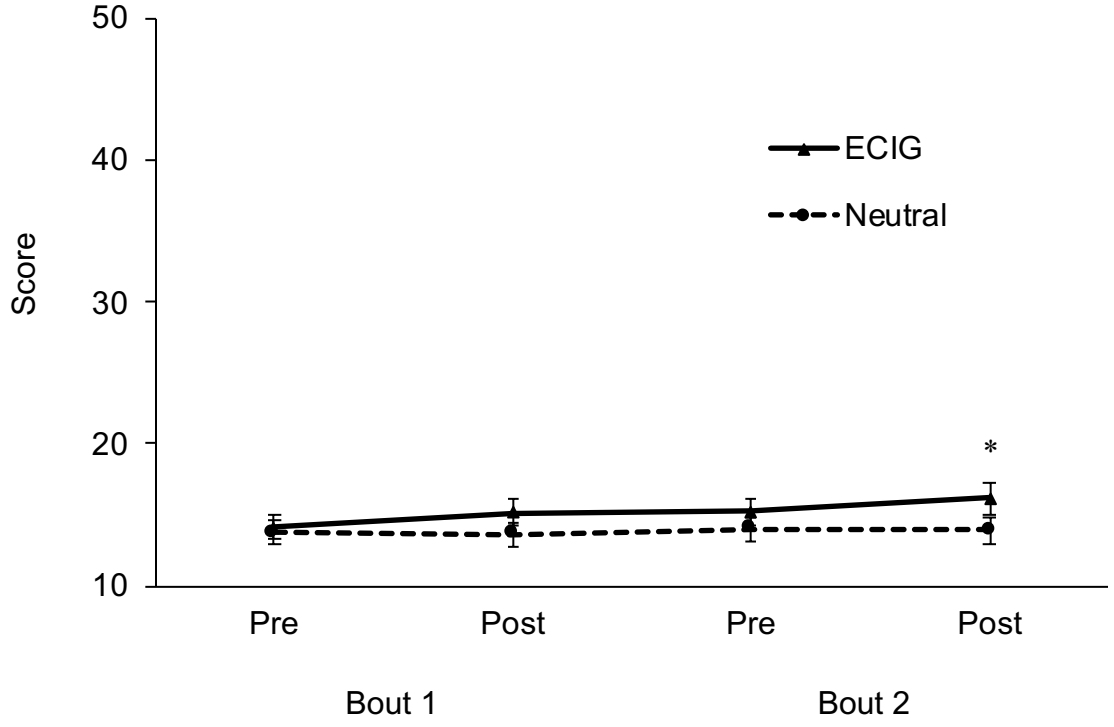
PANAS Positive Affect Scores by Cue Type



Note. Mean (+/- SEM) ratings of PANAS positive affect for ECIG and neutral cues.

Figure 7

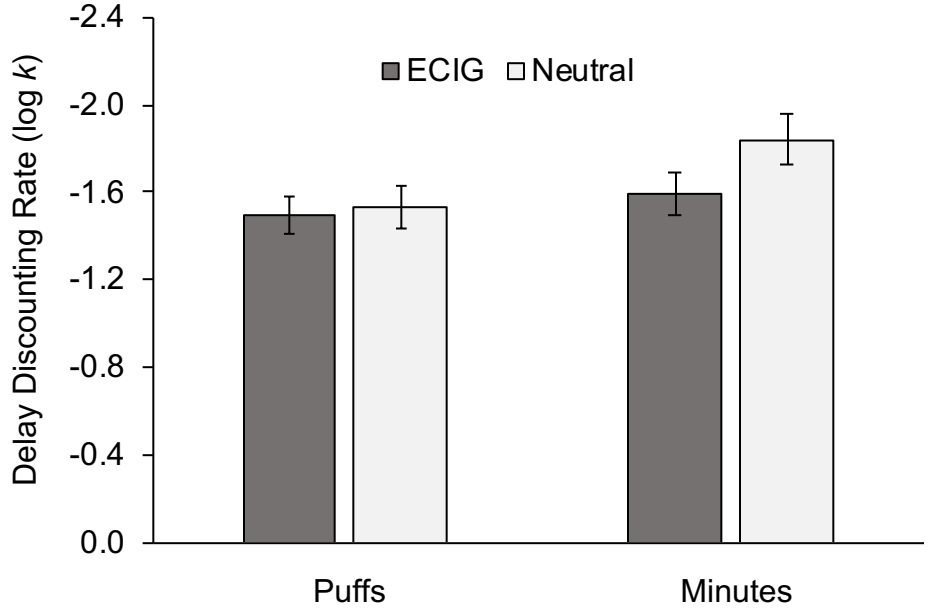
PANAS Negative Affect Scores by Cue Type



Note. Mean (+/- SEM) ratings of PANAS negative affect for ECIG and neutral cues. * Denotes significant difference between bout 1 pre-exposure and indicated timepoint within ECIG cue condition.

Figure 8

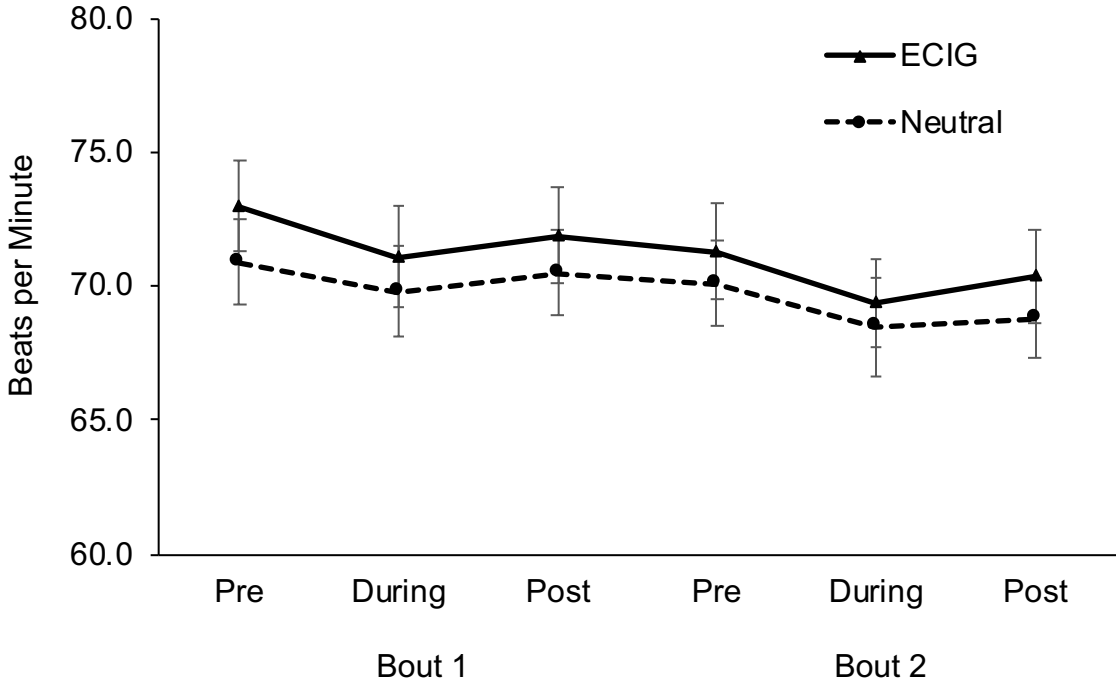
Mean Delay Discounting (*log* k) *Values by Cue Type*



Note. Mean (+/- SEM) log *k* values from the ECIG puffs and minutes MCQ. The y-axis is inverted.

Figure 9

Heart Rate during ECIG and Neutral Cue Conditions



Note. Mean (+/- SEM) heart rate during ECIG and neutral cue conditions.

Appendix A

Prescreening Questionnaire

Thank you for your interest in our research study. Electronic cigarettes are battery-operated nicotine delivery devices. They may be referred to as e-cigs, vapes, vape pens, ECIGs, or mods, but the term ECIG or vape will be used throughout this survey. This survey will ask you about the types of ECIGs/vapes that you use and how you use them.

1. What is your age in years? _____

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

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

4. For how many months have you used an e-cig/vape? _____

5. On average, over the past 3 months, how many days per week did you use an e-cig/vape? _____

6. Does the e-cig/vape that you use most often contain nicotine?
   - ○ Yes ○ No

7. Do you have plans to quit using an e-cig/vape within the next month?
   - ○ Yes ○ No

8. How did you hear about this research study?
   - ○ Facebook
   - ○ Craigslist
   - ○ Flyer on campus
   - ○ Flyer off campus
   - ○ WVU Survey Tuesday or eNews
   - ○ Other. Please describe: _____

9. Are you currently under a doctor's care for a medical condition?
   - ○ Yes ○ No
   - ➢ If yes, please describe: _____

10. Are you taking any prescription medications?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

11. Do you have any chronic health concerns or problems?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

12. Do you have any diagnosed psychiatric conditions, like schizophrenia or bipolar disorder?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

13. Are you currently pregnant or breastfeeding?
    - ○ Yes ○ No

14. Have you used alcohol in the past month?
    - ○ Yes ○ No

15. How many days out of the past 30 have you used alcohol? _____

16. Have you used marijuana in the past month?
    - ○ Yes ○ No

17. How many days out of the past 30 have you used marijuana? _____

18. Have you used any other drugs in the past month?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

19. Based on your responses, you may be eligible to participate in our research study. Please enter your email address or phone number if you are still interested and would like to be contacted about participating: _____

Appendix B

In-person Screening Questionnaire

Sociodemographic Questions

1. What is your age in years? _____

2. Are you Hispanic or Latino?
   - ○ Yes ○ No

3. What is your race?
   - o White or Caucasian
   - o Black or African American
   - o American Indian or Alaska Native
   - o Asian
   - o Native Hawaiian or other Pacific Islander
   - o More than one race
   - o Other/unknown. Please describe: _____

4. What is your gender?
   - o Female
   - o Male
   - o Transgender
   - o Other/wish not to report.

5. What is your current marital status?
   - o Single
   - o Married
   - o Separated
   - o Divorced
   - o Widowed
   - o Other. Please describe: _____

6. Please enter your education in years. High school = 12, college degree = 16, etc. _____

7. What is your current employment status?
   - o Unemployed
   - o Employed part time (0-30 hours/week)
   - o Employed full time (> 30 hours/week)
   - o Student
   - o Other. Please describe: _____

8. Are you currently under a doctor's care for a medical condition?
   - ○ Yes ○ No
   - ➢ If yes, please describe: _____

9. Are you taking any prescription medications?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

10. Do you have any chronic health concerns or problems?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

11. Do you have any diagnosed psychiatric conditions, like schizophrenia or bipolar disorder?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

Smoking and Vaping History

1. Have you ever tried a cigarette, even just one or two puffs?
    - ○ Yes ○ No

2. Do you currently smoke cigarettes?
    - ○ Yes ○ No

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

4. Approximately how many cigarettes have you smoked in the past year? (There are 20 cigarettes in one pack). _____

5. Approximately how many cigarettes have you smoked in the past month? (There are 20 cigarettes in one pack). _____

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

7. On average, over the past 3 months, how many days per week did you use an e-cig/vape? _____

8. Does the e-cig/vape that you use most often contain nicotine?
    - ○ Yes ○ No

9. What nicotine concentration of liquid do you use most often? (Please specify whether it is in % or mg/mL). _____

10. What brand and model of e-cig/vape do you use most often? _____

11. What flavor e-cig/vape liquid do you use most frequently? _____

Penn State Electronic Cigarette Dependence Index (Foulds et al., 2015)

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.)
   - o 0-4
   - o 5-9
   - o 10-14
   - o 15-10
   - o 20-29
   - o 30+

2. How soon after you wake up do you first use your e-cig/vape?
   - o 0-5 min
   - o 6-15 min
   - o 16-30 min
   - o 31-60 min
   - o 61-120 min
   - o 121+ minutes

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?
   - o 0-1 night(s)
   - o 2-3 nights
   - o 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?
   - o None/slight
   - o Moderate/strong
   - o Very/extremely strong

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

9. Do you feel more irritable because you couldn't use an e-cig/vape?
   - ○ Yes ○ No

10. Do you feel nervous, restless, or anxious because you couldn't use an e-cig/vape?
    - ○ Yes ○ No

E-cigarette Dependence Scale 4-item (Morean et al., 2019)

	0 Never	1 Rarely	2 Sometimes	3 Often	4 Almost always
1. I find myself reaching for my e-cig without thinking about it.	○	○	○	○	○
2. I drop everything to go out and get e-cigs or e-juice.	○	○	○	○	○
3. I vape more before going into a situation where vaping is not allowed.	○	○	○	○	○
4. When I haven't been able to vape for a few hours, the craving gets intolerable.	○	○	○	○	○

Other Tobacco and Drug use History

1. Do you currently use any other nicotine or tobacco products?
   ○ Yes ○ No

2. Select all products that you have used in the past 30 days.
   ☐ Cigars, cigarillos, or small cigars
   ☐ Hookah or waterpipe
   ☐ Smokeless tobacco (snus, dip, chew)
   ☐ Nicotine gum, patch, lozenge, or inhaler
   ☐ Cigarettes
   ☐ Other. Please describe: _____

3. Have you used alcohol in the past month?
   ○ Yes ○ No

4. How many days out of the past 30 have you used alcohol? _____

5. Have you ever been treated for alcohol abuse or dependence?
   ○ Yes ○ No

6. Have you used marijuana in the past month?
   ○ Yes ○ No

7. How many days out of the past 30 have you used marijuana? _____

8. Have you ever been treated for marijuana abuse or dependence?
    - ○ Yes ○ No

9. Have you used any other drugs in the past month?
    - ○ Yes ○ No
    - ➢ If yes, please describe: _____

10. How many days out of the past 30 have you used other drugs? _____

Appendix C

Impulsivity Questionnaire

Monetary Choice Questionnaire (Kirby et al., 1999)

The following questions will ask you to choose between a smaller amount of money now and a larger amount of money later. All questions are hypothetical, but you should respond as if the choices are real.

1. Would you rather have:
   - $54.00 now OR
   - $55.00 after 117 days
2. Would you rather have:
   - $55.00 now OR
   - $75.00 after 61 days
3. Would you rather have:
   - $19.00 now OR
   - $25.00 after 53 days
4. Would you rather have:
   - $31.00 now OR
   - $85.00 after 7 days
5. Would you rather have:
   - $14.00 now OR
   - $25.00 after 19 days
6. Would you rather have:
   - $47.00 now OR
   - $50.00 after 160 days
7. Would you rather have:
   - $15.00 now OR
   - $35.00 after 13 days
8. Would you rather have:
   - $25.00 now OR
   - $60.00 after 14 days
9. Would you rather have:
   - $78.00 now OR
   - $80.00 after 162 days
10. Would you rather have:
    - $40.00 now OR
    - $55.00 after 62 days
11. Would you rather have:
    - $11.00 now OR
    - $30.00 after 7 days
12. Would you rather have:
    - $67.00 now OR
    - $75.00 after 119 days

13. Would you rather have:
    - $34.00 now OR
    - $35.00 after 186 days

14. Would you rather have:
    - $27.00 now OR
    - $50.00 after 21 days

15. Would you rather have:
    - $69.00 now OR
    - $85.00 after 91 days

16. Would you rather have:
    - $49.00 now OR
    - $60.00 after 89 days

17. Would you rather have:
    - $80.00 now OR
    - $85.00 after 157 days

18. Would you rather have:
    - $24.00 now OR
    - $35.00 after 29 days

19. Would you rather have:
    - $33.00 now OR
    - $80.00 after 14 days

20. Would you rather have:
    - $28.00 now OR
    - $30.00 after 179 days

21. Would you rather have:
    - $34.00 now OR
    - $50.00 after 30 days

22. Would you rather have:
    - $25.00 now OR
    - $30.00 after 80 days

23. Would you rather have:
    - $41.00 now OR
    - $75.00 after 20 days

24. Would you rather have:
    - $54.00 now OR
    - $60.00 after 111 days

25. Would you rather have:
    - $54.00 now OR
    - $80.00 after 30 days

26. Would you rather have:
    - $22.00 now OR
    - $25.00 after 136 days

27. Would you rather have:
    - $22.00 now OR
    - $55.00 after 7 days

Barratt Impulsiveness Scale (Patton et al., 1995)

People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and select the response option that best represents how you act or think. Do not spend too much time on any statement. Answer quickly and honestly.

	Rarely/ never	Occasionally	Often	Almost always/ Always
1. I plan tasks carefully.	○	○	○	○
2. I do things without thinking.	○	○	○	○
3. I make up my mind quickly.	○	○	○	○
4. I am happy-go-lucky.	○	○	○	○
5. I don't "pay attention."	○	○	○	○
6. I have "racing thoughts."	○	○	○	○
7. I plan trips well ahead of time.	○	○	○	○
8. I am self-controlled.	○	○	○	○
9. I concentrate easily.	○	○	○	○
10. I save regularly.	○	○	○	○
11. I "squirm" at plays or lectures.	○	○	○	○
12. I am a careful thinker.	○	○	○	○
13. I plan for job security.	○	○	○	○
14. I say things without thinking.	○	○	○	○
15. I like to think about complex problems.	○	○	○	○
16. I change jobs.	○	○	○	○
17. I act "on impulse."	○	○	○	○
18. I get easily bored when solving thought problems.	○	○	○	○

19. I act on the spur of the moment.	○	○	○	○
20. I am a steady thinker.	○	○	○	○
21. I change residences.	○	○	○	○
22. I buy things on impulse.	○	○	○	○
23. I can only think about one thing at a time.	○	○	○	○
24. I change hobbies.	○	○	○	○
25. I spend or charge more than I earn.	○	○	○	○
26. I often have extraneous thoughts when thinking.	○	○	○	○
27. I am more interested in the present than the future.	○	○	○	○
28. I am restless at the theater or lectures.	○	○	○	○
29. I like puzzles.	○	○	○	○
30. I am future oriented.	○	○	○	○

Appendix D

Subjective Questionnaire

Positive and Negative Affect Schedule (Carter & Tiffany, 2001)

Indicate the extent to which you feel this way RIGHT NOW.

	Very slightly or not at all	A little	Moderately	Quite a bit	Extremely
Interested	○	○	○	○	○
Distressed	○	○	○	○	○
Excited	○	○	○	○	○
Upset	○	○	○	○	○
Strong	○	○	○	○	○
Guilty	○	○	○	○	○
Scared	○	○	○	○	○
Hostile	○	○	○	○	○
Enthusiastic	○	○	○	○	○
Proud	○	○	○	○	○
Irritable	○	○	○	○	○
Alert	○	○	○	○	○
Ashamed	○	○	○	○	○
Inspired	○	○	○	○	○
Nervous	○	○	○	○	○
Determined	○	○	○	○	○
Attentive	○	○	○	○	○
Jittery	○	○	○	○	○
Active	○	○	○	○	○
Afraid	○	○	○	○	○

Schuh and Stitzer (1995) Craving Scale

For the following questions, answer by placing a mark on the scale below.

Vaping

1. How much do you want to vape right now?
   Not at all Moderately Very much

2. How pleasant would using your ECIG/vape be right now?
   Not at all Moderately Very much

3. How much of an urge or desire do you have to vape right now, just for the pleasure of vaping?
   Not at all Moderately Very much

4. How much do you need to vape right now, for relief?
   Not at all Moderately Very much

Smoking

1. How much do you want to smoke a cigarette right now?
   Not at all Moderately Very much

2. How pleasant would a cigarette be right now?
   Not at all Moderately Very much

3. How much of an urge or desire do you have to smoke right now, just for the pleasure of smoking?
   Not at all Moderately Very much

4. How much do you need to smoke right now, for relief?
   Not at all Moderately Very much

Questionnaire on Smoking Urges-Brief (Cox et al., 2001)

Vaping

For each item, please indicate how you feel RIGHT NOW.

	Strongly disagree						Strongly Agree
I have a desire to use my ECIG/vape right now.	○	○	○	○	○	○	○
Nothing would be better than using my ECIG/vape right now.	○	○	○	○	○	○	○
If it were possible, I probably would vape now.	○	○	○	○	○	○	○
I could control things better right now if I could vape.	○	○	○	○	○	○	○
All I want right now is to use my ECIG/vape.	○	○	○	○	○	○	○
I have an urge to use my ECIG/vape.	○	○	○	○	○	○	○
My ECIG/vape would taste good now.	○	○	○	○	○	○	○
I would do almost anything for my ECIG/vape now.	○	○	○	○	○	○	○
Vaping would make me less depressed.	○	○	○	○	○	○	○
I am going to vape as soon as possible.	○	○	○	○	○	○	○

Smoking

For each item, please indicate how you feel RIGHT NOW.

	Strongly disagree						Strongly Agree
I have a desire for a cigarette right now.	○	○	○	○	○	○	○
Nothing would be better than smoking a cigarette right now.	○	○	○	○	○	○	○
If it were possible, I probably would smoke now.	○	○	○	○	○	○	○
I could control things better right now if I could smoke.	○	○	○	○	○	○	○
All I want right now is a cigarette.	○	○	○	○	○	○	○
I have an urge for a cigarette.	○	○	○	○	○	○	○
A cigarette would taste good now.	○	○	○	○	○	○	○
I would do almost anything for a cigarette now.	○	○	○	○	○	○	○
Smoking would make me less depressed.	○	○	○	○	○	○	○
I am going to smoke as soon as possible.	○	○	○	○	○	○	○

Appendix E

Delay Discounting and Behavioral Economics – ECIG Puffs

27-item ECIG Puffs Choice Questionnaire (Kirby et al., 1999)

Think about how you're feeling right now. The following questions will ask you to choose between a specified number of e-cigarette puffs now and a specified number of e-cigarette puffs later. All questions are hypothetical, but you should respond as if the choices are real. Assume that puffs are for your own use and using your own e-cigarette with your preferred liquid nicotine concentration and flavor. You do not have to consume all of the puffs at once.

1. Would you rather have:
   - 12 puffs now OR
   - 13 puffs after 117 minutes

2. Would you rather have:
   - 13 puffs now OR
   - 20 puffs after 61 minutes

3. Would you rather have:
   - 1 puff now OR
   - 2 puffs after 53 minutes

4. Would you rather have:
   - 5 puffs now OR
   - 22 puffs after 7 minutes

5. Would you rather have:
   - 1 puff now OR
   - 2 puffs after 19 minutes

6. Would you rather have:
   - 8 puffs now OR
   - 11 puffs after 160 minutes

7. Would you rather have:
   - 1 puff now OR
   - 6 puffs after 13 minutes

8. Would you rather have:
   - 2 puffs now OR
   - 15 puffs after 14 minutes

9. Would you rather have:
   - 19 puffs now OR
   - 21 puffs after 162 minutes

10. Would you rather have:
    - 7 puffs now OR
    - 13 puffs after 62 minutes

11. Would you rather have:
    - 1 puff now OR
    - 4 puffs after 7 minutes

12. Would you rather have:
    - 17 puffs now OR
    - 20 puffs after 119 minutes

13. Would you rather have:
    - 5 puffs now OR
    - 6 puffs after 186 minutes

14. Would you rather have:
    - 3 puffs now OR
    - 11 puffs after 21 minutes

15. Would you rather have:
    - 18 puffs now OR
    - 22 puffs after 91 minutes

16. Would you rather have:
    - 10 puffs now OR
    - 15 puffs after 89 minutes

17. Would you rather have:
    - 21 puffs now OR
    - 22 puffs after 157 minutes

18. Would you rather have:
    - 1 puff now OR
    - 6 puffs after 29 minutes

19. Would you rather have:
    - 5 puffs now OR
    - 21 puffs after 14 minutes

20. Would you rather have:
    - 3 puffs now OR
    - 4 puffs after 179 minutes

21. Would you rather have:
    - 6 puffs now OR
    - 11 puffs after 30 minutes

22. Would you rather have:
    - 2 puffs now OR
    - 4 puffs after 80 minutes

23. Would you rather have:
    - 8 puffs now OR
    - 20 puffs after 20 minutes

24. Would you rather have:
    - 12 puffs now OR
    - 15 puffs after 111 minutes

25. Would you rather have:
    - 12 puffs now OR
    - 21 puffs after 30 minutes

26. Would you rather have:
    - 1 puff now OR
    - 2 puffs after 136 minutes

27. Would you rather have:
    - 1 puff now OR
    - 13 puffs after 7 minutes

ECIG Puffs Multiple-Choice Procedure

Please choose between the two options:

1. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.01
2. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.02
3. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.04
4. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.08
5. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.16
6. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.32
7. Would you rather have:
   - 10 puffs from your e-cig OR ○ $0.64
8. Would you rather have:
   - 10 puffs from your e-cig OR ○ $1.28
9. Would you rather have:
   - 10 puffs from your e-cig OR ○ $2.56
10. Would you rather have:
    - 10 puffs from your e-cig OR ○ $5.12

ECIG Puffs Commodity Purchase Task

Imagine that electronic cigarettes are sold by the puff and the puffs available are your preferred brand, nicotine concentration, and flavor.

Imagine a typical day during which you can only use your electronic cigarette by purchasing individual puffs at the prices specified below. You should consider your current financial circumstances and that any puffs you purchase must be consumed within 24 hours and cannot be saved or given away.

Please treat individual prices of puffs as if they are unrelated to other prices (puffs purchased at one price are completely independent of purchasing puffs at another price). Please answer all questions as if they were real.

Please enter how many puffs you would purchase at each price into the textbox below each price.

1. $0.01 _____
2. $0.03 _____
3. $0.10 _____
4. $0.30 _____
5. $1.00 _____
6. $3.00 _____
7. $10.00 _____
8. $30.00 _____
9. $100.00 _____

Appendix F

Delay Discounting and Behavioral Economics – ECIG Minutes of Access

27-item ECIG Minutes of Access Choice Questionnaire (Kirby et al., 1999)

Think about how you're feeling right now. The following questions will ask you to choose between minutes of free access to your e-cigarette now versus minutes of free access to your e-cigarette later. All questions are hypothetical, but you should respond as if the choices are real. Assume that the minutes of free access are consecutive and that you can use your own e-cigarette as much as you'd like with your preferred liquid nicotine concentration and flavor during the time chosen.

1. Would you rather have:
   - 54 minutes of access now OR
   - 55 minutes of access after 117 minutes
2. Would you rather have:
   - 55 minutes of access now OR
   - 75 minutes of access after 61 minutes
3. Would you rather have:
   - 19 minutes of access now OR
   - 25 minutes of access after 53 minutes
4. Would you rather have:
   - 31 minutes of access now OR
   - 85 minutes of access after 7 minutes
5. Would you rather have:
   - 14 minutes of access now OR
   - 25 minutes of access after 19 minutes
6. Would you rather have:
   - 47 minutes of access now OR
   - 50 minutes of access after 160 minutes
7. Would you rather have:
   - 15 minutes of access now OR
   - 35 minutes of access after 13 minutes
8. Would you rather have:
   - 25 minutes of access now OR
   - 60 minutes of access after 14 minutes
9. Would you rather have:
   - 78 minutes of access now OR
   - 80 minutes of access after 162 minutes
10. Would you rather have:
    - 40 minutes of access now OR
    - 55 minutes of access after 62 minutes
11. Would you rather have:
    - 11 minutes of access now OR
    - 30 minutes of access after 7 minutes

12. Would you rather have:
    - 67 minutes of access now OR
    - 75 minutes of access after 119 minutes

13. Would you rather have:
    - 34 minutes of access now OR
    - 35 minutes of access after 186 minutes

14. Would you rather have:
    - 27 minutes of access now OR
    - 50 minutes of access after 21 minutes

15. Would you rather have:
    - 69 minutes of access now OR
    - 85 minutes of access after 91 minutes

16. Would you rather have:
    - 49 minutes of access now OR
    - 60 minutes of access after 89 minutes

17. Would you rather have:
    - 80 minutes of access now OR
    - 85 minutes of access after 157 minutes

18. Would you rather have:
    - 24 minutes of access now OR
    - 35 minutes of access after 29 minutes

19. Would you rather have:
    - 33 minutes of access now OR
    - 80 minutes of access after 14 minutes

20. Would you rather have:
    - 28 minutes of access now OR
    - 30 minutes of access after 179 minutes

21. Would you rather have:
    - 34 minutes of access now OR
    - 50 minutes of access after 30 minutes

22. Would you rather have:
    - 25 minutes of access now OR
    - 30 minutes of access after 80 minutes

23. Would you rather have:
    - 41 minutes of access now OR
    - 75 minutes of access after 20 minutes

24. Would you rather have:
    - 54 minutes of access now OR
    - 60 minutes of access after 111 minutes

25. Would you rather have:
    - 54 minutes of access now OR
    - 80 minutes of access after 30 minutes

26. Would you rather have:
    - 22 minutes of access now OR
    - 25 minutes of access after 136 minutes

27. Would you rather have:
    - 20 minutes of access now OR
    - 55 minutes of access after 7 minutes

ECIG Minutes of Access Multiple-Choice Procedure

Please choose between the two options:

1. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.01
2. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.02
3. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.04
4. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.08
5. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.16
6. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.32
7. Would you rather have:
   - 10 min of access to your e-cig OR ○ $0.64
8. Would you rather have:
   - 10 min of access to your e-cig OR ○ $1.28
9. Would you rather have:
   - 10 min of access to your e-cig OR ○ $2.56
10. Would you rather have:
    - 10 min of access to your e-cig OR ○ $5.12

ECIG Minutes of Access Commodity Purchase Task

Imagine that electronic cigarettes are sold by minutes of access and the minutes available are your preferred brand, nicotine concentration, and flavor.

Imagine a typical day during which you can only use your electronic cigarette by purchasing individual minutes of access at the prices specified below. You should consider your current financial circumstances and that any minutes of access you purchase must be consumed within 24 hours and cannot be saved or given away.

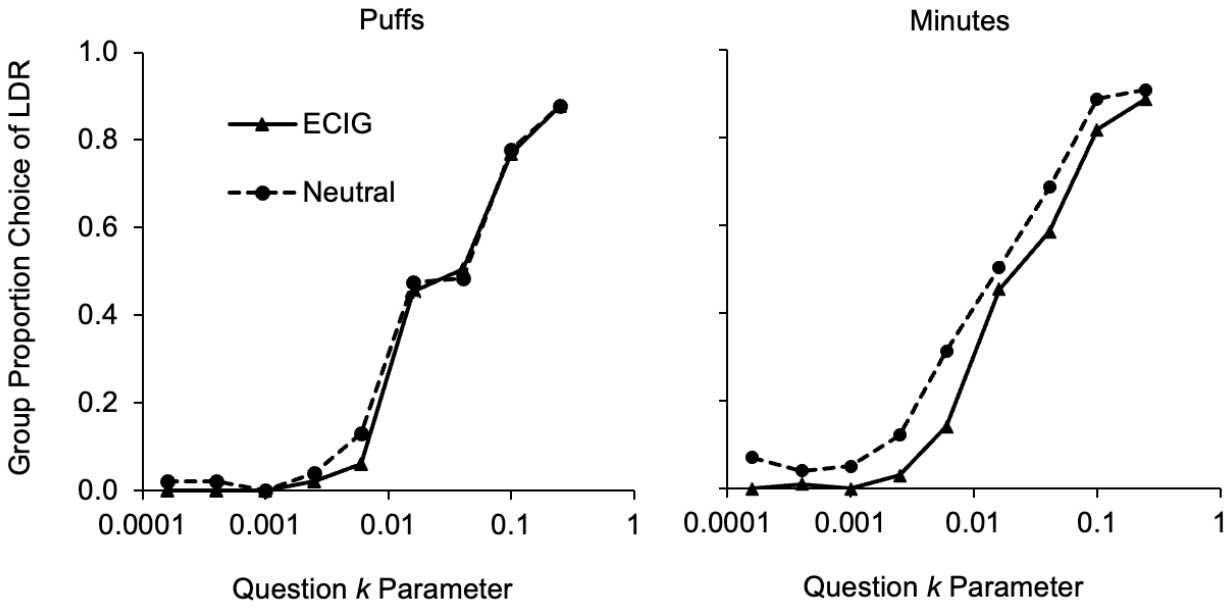
Please treat individual prices as if they are unrelated to other prices (minutes of access purchased at one price are completely independent of purchasing minutes at another price).
Please answer all questions as if they were real.

Please enter how many minutes of access you would purchase at each price into the textbox below each price.

1. $0.01 _____
2. $0.03 _____
3. $0.10 _____
4. $0.30 _____
5. $1.00 _____
6. $3.00 _____
7. $10.00 _____
8. $30.00 _____
9. $100.00 _____

Appendix G

Group Proportion Choices of Larger Delayed Reward by Cue Type



Note. Group proportion choices of the larger delayed reward (LDR) on the puffs and minutes MCQ, plotted by the *k* values associated with each of the 27 items, for ECIG and neutral cues.