HHS Public Access

Author manuscript

Exp Clin Psychopharmacol. Author manuscript; available in PMC 2024 June 01.

Published in final edited form as:

Exp Clin Psychopharmacol. 2023 June ; 31(3): 724–732. doi:10.1037/pha0000612.

Effects of short-term nicotine deprivation on delay discounting among young, experienced, exclusive ENDS users: An initial study

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Abstract

Delay discounting describes how rapidly delayed rewards lose value as a function of delay and serves as one measure of impulsive decision-making. Nicotine deprivation among combustible cigarette smokers can increase delay discounting. We aimed to explore changes in discounting following nicotine deprivation among electronic nicotine delivery systems (ENDS) users. Thirty young adults (aged 18–24 years) that exclusively used ENDS participated in two laboratory sessions: one with vaping as usual and another after 16 hours of nicotine deprivation (biochemically assessed). At each session, participants completed a craving measure and three hypothetical delay discounting tasks presenting choices between small, immediate rewards and large, delayed ones (money-money; e-liquid-e-liquid; e-liquid-money).

Craving for ENDS significantly increased during short-term nicotine deprivation relative to normal vaping. Delay discounting rates in the e-liquid now vs. money later task increased (indicating a shift in preference for smaller, immediate rewards) following short-term nicotine deprivation relative to vaping as usual, but no changes were observed in the other two discounting tasks.

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Short-term nicotine deprivation increased the preference for smaller amounts of e-liquid delivered immediately over larger, monetary awards available after a delay in this first study of its kind. As similar preference shifts for drug now vs. money later have been shown to be indicative of increased desire to use drug as well as relapse risk, the findings support the utility of the current model as a platform to explore interventions that can mitigate these preference shifts.

Keywords

ENDS; Young Adults; Deprivation; Delay Discounting

Introduction

Electronic nicotine delivery systems (ENDS) are relatively new types of tobacco products that deliver nicotine via an inhalable aerosol. ENDS use among youth and young adults is a serious public health concern given the rapid increase in popularity and ENDS use in this vulnerable sub-population (Huang et al., 2019) In 2019, 8% of young adults (aged 18–24) had used ENDS in the past 30-days(Prakash et al., 2021), nearly twice the rate of adults (4.7%). Well-known short-term health concerns of ENDS use include abnormality in respiratory function, lung oedema, and e-cigarette or vaping product use-associated lung injury (EVALI) (Marques et al., 2021; Münzel et al., 2020).

Impulsivity is consistently recognized as both a determinant and consequence of drug use (de Wit, 2009), including tobacco (Audrain-McGovern et al., 2009). One operational definition of impulsivity is preference for a relatively smaller, immediate reward (e.g., drug consumption) over a larger, delayed one (e.g., greater health, financial stability, etc.). Delay discounting characterizes how rewards are devalued as a function of length of delay to its delivery (Audrain-McGovern et al., 2009; Madden & Bickel, 2010). Steep delay discounting is characterized by a preference for smaller, immediate over larger, delayed rewards and is associated with various maladaptive behaviors, including substance use (Amlung et al., 2017; Green & Myerson, 2004; Madden & Bickel, 2010).

Extensive research has characterized delay discounting in relation to multiple clinically relevant aspects of tobacco use, mostly in cigarette smokers. Greater discounting is associated with being a current smoker compared to both a non-smoker and former smoker (Bickel et al., 1999; Friedel et al., 2014; MacKillop et al., 2011), an increased risk of smoking initiation among youth (Audrain-McGovern et al., 2009), greater nicotine dependence (Amlung & MacKillop, 2014; Amlung et al., 2017) and smoking severity (Ohmura et al., 2005), a lower likelihood of quitting smoking (Yoon et al., 2007), and a higher likelihood of smoking relapse (Dallery & Raiff, 2007; García-Pérez et al., 2022; González-Roz et al., 2019; Yoon et al., 2009; Yoon et al., 2007). In general, delay discounting has been observed to be a relatively stable, trait-like characteristic, but there is evidence that delay discounting among smokers may change depending on many environmental and individual factors (Bickel et al., 2015). For example, earlier studies have shown that short-term nicotine deprivation (12–24 hours) increases discounting for monetary rewards (Ashare & Hawk, 2012; Field et al., 2006; Heckman et al., 2017; Yi & Landes,

2012) and cigarettes (Field et al., 2006; Mitchell, 2004) among current smokers. There is also evidence indicating that the level of discounting varies as a function of nicotine dependence and the number of substances used (Barlow et al., 2016; García-Rodríguez et al., 2013; Johnson et al., 2007), with higher delay discounting rates among those who smoke more cigarettes per day or smokers who use illicit substances. Conversely, prior studies have shown that delay discounting can be reduced by applying interventions such as episodic future thinking or contingency management (García-Pérez et al., 2022; Yi et al., 2008). Finally, although a considerable amount of work has demonstrated that delay discounting is a negative prognostic factor of smoking cessation (Coughlin et al., 2020; Halpern et al., 2016), prior research reveals that individuals who quit smoking exhibit significant decreases in delay discounting (Secades-Villa et al., 2014).

A few discounting studies performed with ENDS users have compared discounting for monetary rewards between ENDS users and users of other tobacco products, predominantly cigarette smokers (Białaszek et al., 2017; Chivers et al., 2016; DeHart et al., 2020; Huynh et al., 2021; Stein et al., 2018). These studies showed that ENDS users exhibit similar delay discounting for monetary rewards compared to other tobacco users (Białaszek et al., 2017; Chivers et al., 2016; DeHart et al., 2020; Weidberg et al., 2017). These earlier studies also demonstrated greater monetary discounting among ENDS users compared to non-tobacco users (Białaszek et al., 2017; DeHart et al., 2020; Huynh et al., 2021; Stein et al., 2018; Weidberg et al., 2017), which is consistent with existing delay discounting studies conducted among smokers. Moreover, recent research has shown that greater delay discounting among ENDS users is associated with more unsuccessful quit attempts (Pericot-Valverde et al., 2020). Whether nicotine deprivation changes delay discounting among exclusive ENDS users remains unexplored. This is an important gap unaddressed in the literature since delay discounting during a short-term nicotine deprivation can provide important information to help develop interventions aimed at reducing ENDS use. More specifically, if research shows that delay discounting changes after acute abstinence, it would confirm the malleability of this behavioral index and perhaps its utility as a treatment target for reducing ENDS use.

Those limited number of studies exploring delay discounting among ENDS users have predominantly used the same reward available now or later (i.e., money), which is often referred to as single-commodity discounting (Białaszek et al., 2017; Chivers et al., 2016). Nevertheless, most real-world choices are more tangled and involve choosing between alternative commodities (e.g., vape now vs health later). Cross-commodity discounting tasks (Moody et al., 2017), in which individuals are asked to make choices between different amounts of commodities (e.g., money, tobacco, food) now and in the future provide a more complex, closer approximation to real-word decision making.(Bickel et al., 2011; Moody et al., 2017; Pritschmann et al., 2021). In addition, cross-commodity tasks have shown to be more sensitive to the effects of smoking abstinence. In this regard, Yoon et al (2009) showed changes in a cross-commodity delay discounting task between money and cigarettes, but not in a single-commodity task involving only money after 14 days of smoking abstinence. To our knowledge, only our prior study has explored cross-commodity delayed discounting among exclusive ENDS users (Pericot-Valverde et al., 2020) and no study has explored cross-commodity discounting under short-term deprivation among ENDS users. This is

another important limitation in prior literature given that cross-commodity discounting tasks may provide a more natural insight into how ENDS users make choices, and perhaps have greater clinical relevance as has been shown among cigarette smokers.

The current study is an extension of prior work exploring delay discounting among ENDS users and the first study of its kind to examine whether short-term nicotine deprivation increases delay discounting rates for hypothetical e-liquid and monetary rewards among young, experienced ENDS users.

Materials and Methods

Participants

Participants were young adult exclusive e-cigarette users recruited from the greater Burlington VT area via ads posted on social media platforms (i.e., Facebook and Reddit). Inclusion criteria included being between the ages of 18 and 24, using ≥1 mL of e-liquid per day with a nicotine concentration of ≥3mg/ml, and having used an e-cigarette ≥3 months. Participants were excluded if they smoked conventional cigarettes, had a physical or psychiatric condition based on the Mini-International Psychiatric Interview, or used prescription medication other than birth control. Exclusive ENDS use was biochemically verified through a combination of recent nicotine exposure (≥3 in NicAlert) and lack of recent combusted use (carbon monoxide (CO)≤6 parts per million (ppm)) in (Smokelyzer, Covita, Santa Barbara, CA, USA). The protocol was approved by the institutional review board at the University of Vermont. All participants provided written informed consent prior to participating in the parent study.

Parent Trial Design

Participants were enrolled in a 3-session cross-over pilot study examining the effects of acute stress on the reinforcing value of e-cigarettes (Pericot-Valverde et al., 2021). Participants completed an introductory session to confirm eligibility, provided consent, completed baseline assessments, and were trained with the tasks and protocols. Participants who completed these steps and met eligibility criteria then participated in the first non-deprivation delay discounting task. After this, they were scheduled for two 2.5 hour laboratory sessions at least 48 hours apart. Participants were asked to abstain from vaping at least 16 hours prior to the two laboratory sessions. During these two laboratory sessions, participants were exposed to a stress or a non-stress task on the two separate days (counterbalanced), and then engaged in an e-cigarette self-administration task in which participants could choose to vape or earn money. The second, short-term deprivation delay discounting session occurred at the beginning of the first 2.5 hour laboratory session.

Measures

All participants completed a questionnaire which included basic demographic information (e.g., gender, age) and vaping-related measures (e.g., months of regular use, mL/day).

The 10-item Penn State E-Cigarette Dependence Index (PSECD) was used to measure e-cigarette specific nicotine dependence (Foulds et al., 2015). The PSECDI scores range

from 0 to 20 with scores ≤3, 4–8, 9–12, and ≥13 indicating no dependence, low dependence, medium dependence, and high dependence, respectively. The 10-item Questionnaire of Vaping Craving (QVC) was utilized to measure craving for vaping nicotine, including the domains of desire, intention, and positive outcome (Dowd et al., 2019). QVC items are rated on a 7-point scale and scores range from 7 to 70. Exhaled CO levels were measured to determine recent exposure to combusted tobacco products using the Micro+™ Smokelyzer (Bedfont Scientific, Kent, England). Cotinine levels in urine were measured to determine e-cigarette abstinence using NicAlert test strips (Nymox Pharmaceutical Corporation).

Delay discounting was assessed using a hypothetical, computer-based task utilized in prior research studies and followed similar procedures (González-Roz et al., 2019; Pericot-Valverde et al., 2020; Weidberg et al., 2015). Participants were presented with repeated choices between a smaller, immediate and a larger, delayed reward. Three delay discounting tasks were administered presenting choices between 1) money now vs. money later (money-money); 2) e-liquid now vs. e-liquid later (e-liquid-e-liquid); and 3) e-liquid now vs. money later (e-liquid-money). Hypothetical monetary values and e-liquid equivalents ranged from $5 to $955 in value available immediately versus $1,000 in value after a fixed delay. When presenting the e-liquid option for the two tasks involving e-liquid, the monetary value was also explicitly presented (i.e., 25ml of e-liquid (worth $75). The value of e-liquid was determined on an individual basis by asking participants the cost of their preferred e-liquid. The reported cost for each ml was then used for the purchase task. Participants reported that one ml of e-liquid costs on average $3.0 (SD=3.2; range 0.6–7.1). The units of e-liquid chosen were ml rather than puff given the available literature showing that ml is a more valid unit of measure for ENDS users (Cassidy et al., 2020; Pericot-Valverde et al., 2020). The value of the immediate option was varied using a computer-based algorithm until the two choices were subjectively equivalent (i.e., indifference point). Delays were 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years and presented in ascending order. These delays were the same for the three discounting tasks. Participants were informed that they would not receive real rewards but asked to make choices as they would in real life. No time limit was provided to conduct the delay discounting tasks. The three delay discounting tasks took approximately 15 minutes to complete for each participant and were presented in random order.

General Procedures

Participants completed two laboratory sessions separated by no more than one week. The first session was conducted after vaping normally and the second session after abstaining from vaping for at least 16 hours prior to the session.

During the first session (i.e., non-deprivation session), participants completed a questionnaire assessing their demographics and various features related to their ENDS use. In both sessions, participants completed the QVC questionnaire, the delay discounting tasks, and provided biological samples (expired CO and urine sample).

During the first session, eligibility as an exclusive ENDS user was confirmed with a combination of exposure to nicotine (NicAlert) and lack of exposure to combusted tobacco (CO≤6). During the second session (i.e., deprivation session), ENDS deprivation was

verified through a urine sample, and defined as a decrease of at least 1 point from baseline on the semiquantitative urine cotinine index(Leventhal et al., 2019). Participants in the deprivation session that did not meet the abstinence criteria were asked to come back another day to conduct the session. Participants were compensated up to $136 for completing all the sessions and tasks.

Data Analyses

Descriptive analyses were carried out to characterize the sample in terms of demographics and vaping-related characteristics. Paired sample t-tests were conducted to compare scores on the QVC questionnaire during the non-deprivation and deprivation sessions. Normality tests were conducted for the distribution of log$k$ values for each discounting task to test for normality of the data.

Indifference points from the three delay discounting tasks were analyzed using two different approaches. First, Mazur's hyperbolic equation, $V = A/(1 + kD)$ was used. The Equation (1) shows how the value (V) of a reward of some amount (A) decreases as a function of increasing delay (D) to receiving it. The free parameter k describes the rate of discounting, with larger values indicating greater discounting.

$$V = A/(1 + kD) \quad \text{Equation 1:}$$

Second, we used a relatively new variation of area under the curve (AUC)(Gilroy & Hantula, 2018). In this variation, delay values are initially log-transformed, which reduces the disparate influence of areas from larger delays (Yoon et al., 2017).

$$\text{AUClog} = (D_{2\log} - D_{1\log)}(Vi + V_2)/2) \quad \text{Equation 2:}$$

Equation (2) describes how the AUClog value was obtained, where $D_{1\log}$ and $D_{2\log}$ are the delays associated with successive indifference points, and Vi and V_2 are the indifference point values associated with these delays in a log scale.

Delay discounting data was assessed for systematicity using the criteria proposed by Johnson and Bickel (2008). As done in earlier delay discounting studies (DeHart et al., 2020; Friedel et al., 2014), we chose not to remove participant data from the analyses due to the within-subject design of this study. That is, if one participant had data that met the exclusion criteria for one of the delay discounting tasks, all of his/her data would have to be excluded as well, resulting in a considerable amount of loss of systematic data.

Mixed effect models using restricted maximum likelihood (REML), including time and type of measurement as fixed effects, were conducted to compare the AUClog and log$k$ values for three different delay discounting tasks (money-money, e-liquid-e-liquid, and e-liquid-money) across all participants at the non-deprivation and the deprivation sessions. Eta-squared was used to estimate the magnitude effects, with 0.01, 0.06, and 0.14 corresponding to small, medium, and large effect sizes. Then, Tukey's honest significant difference (HSD) pairwise comparisons were conducted to identify possible differences between sessions and

tasks in AUClog and log*k* values. Significance for all statistical analyses was defined as p < .05 and the statistical package used was SAS version 9.1 (SAS Institute, Cary, NC, USA).

Results

Participants

The sample baseline characteristics are depicted in Table 1 (N=30). The majority of participants were White, non-Hispanic (100%), heterosexual (90.6%), college-educated males with an annual household income above $100,000. Participants were on average 19.1 years old, vaping regularly for a year (2.3 ml/day), and were moderately nicotine dependent (M=9.3). Most participants (70%) were never smokers and 30% were former smokers.

Subjective Measures

Nicotine craving scores were significantly higher during the deprivation (M= 39.7, SD= 12.8) vs. non-deprivation session (M=29.8, SD = 12.7) as measured by the QVC ($t(28) = -3.40$, p=.002, $\eta_p^2 = 0.29$).

Delay Discounting

Supplemental Material depicts histograms of log*k* data for the three tasks (money-money, - liquid-e-liquid, e-liquid-money). Values were normally distributed, and none failed the Shapiro-Wilk normality tests.

Mixed effects models testing the effect of short-term nicotine deprivation on delay discounting (log*k*) showed a significant effect of task type ($F(2, 145) = 29.57$, $p < .001$ $\eta_p^2 = 0.12$) and task-by-session interaction ($F(2, 145) = 8.88$, $p < .001$ $\eta_p^2 = 0.04$), but no effect of session alone ($F(1, 145) = 1.00$, $p = .318$ $\eta_p^2 = 0.00$), indicating that mean log*k* values were different across the three different delay discounting tasks and that the log*k* values changed differently between non-deprivation and deprivation session across the three tasks (see Figure 1). Post hoc analyses showed that log*k* values were significantly larger in the deprivation session ($M_{\log k} = -2.85$ (SE = 0.23)) compared to the non-deprivation session ($M_{\log k} = -3.63$ ($SE = 0.23$)) for the e-liquid-money task ($p \leq .001$). No differences were found between sessions for the money-money task (non-deprivation session $M_{\log k} = -2.67$ ($SE = 0.18$); deprivation session $M_{\log k} = -2.93$ ($SE = 0.17$), $p = .18$) or e-liquid-e-liquid task (non-deprivation $M_{\log k} = -2.09$ ($SE = 0.24$); deprivation session $M_{\log k} = -2.28$ ($SE = 0.20$), $p = .35$). Figure 1a shows the mean log*k* values for the non-deprivation and the deprivation session, with larger values along the y-axis indicating greater delay discounting.

Mixed effects models testing the effects of nicotine deprivation on AUClog values also showed a significant effect of type of task ($F(2, 145) = 26.15$, $p < .001$ $\eta_p^2 = 0.13$)) and task-by-session interaction ($F(2, 145) = 4.60$, $p = .015$ $\eta_p^2 = 0.02$), but not for session ($F(1, 145) = 1.20$, $p = .274$ $\eta_p^2 = 0.0$), showing again that mean AUClog values were different across the three different delay discounting tasks and between sessions across the three delay discounting tasks. Post hoc analyses provided evidence that AUClog values for the e-liquid -money ($p = .0026$) were smaller at the deprivation session ($M_{\text{AUClog}} = 0.64$ (SE

= 0.03)) compared to the non-deprivation session (M_{AUClog} = 0.77 (SE = 0.03)). Again, no differences were found in AUClog values (p = .31) between sessions for the money-money task (non-deprivation session M_{AUClog} = 0.63 (SE = 0.04); deprivation session M_{AUClog} = 0.67 (SE = 0.03)) and e-liquid -e-liquid (non-deprivation session M_{AUClog} = 0.49 (SE = 0.04); deprivation session M_{AUClog} = 0.50 (SE = 0.05), p= 0.87). Figure 1b shows the mean AUClog values for the non-deprivation and deprivation session, with smaller values along the y-axis evidencing greater delay discounting.

At the non-deprivation session greater discounting was observed in the e-liquid-e-liquid task, than in the money-money task, and the least discounting was found in the e-liquid-money task. In contrast, the order from larger to smaller discounting in the deprivation session was e-liquid-e-liquid, e-liquid-money, and money-money (Figure 2).

Discussion

The present study is the first to conduct an initial examination of the effects of nicotine deprivation on delay discounting rates for two commodities (money and e-liquid) among young-adult, exclusive ENDS users. Three major conclusions were drawn from the results. First, young ENDS users exhibited significantly greater discounting in the e-liquid-money task following nicotine deprivation. Second, nicotine deprivation did not impact delay discounting rates for monetary rewards and e-liquid in the same commodity task. Third, short-term nicotine deprivation produced an elevation in craving levels.

Discounting significantly increased in the e-liquid vs. money task following nicotine deprivation (i.e., cross-commodity task), which resulted in greater preference for immediately available e-liquid versus waiting for a larger magnitude of money. This finding is consistent with prior research showing increased discounting in a cigarette now vs. money later task among smokers after 24 hours of nicotine deprivation (Mitchell, 2004). Our finding suggests that after a period of nicotine deprivation young-adult, experienced ENDS users become even more impulsive for the drug of choice (i.e., nicotine) relative to monetary rewards. There are several possible explanations for this result. For instance, our participants were in a state of nicotine deprivation, that is, they may have discounted e-liquid more steeply than money during the deprivation session because even a small amount of the drug of choice (in this study e-liquid) could reduce or eliminate their cravings to vape (Odum et al., 2020). Our finding is also partly in agreement with the Estle et al.'s (2007) Inconsistency of Desire Hypothesis. This hypothesis suggests that the degree to which non-monetary rewards are wanted fluctuates over time, whereas money, a generalized (fungible) conditioned reward, does not change its value because it can be exchanged for a wide variety of goods in the future. In our study, nicotine deprivation may have enhanced the salience of e-liquid, but it did not impact the need for a monetary reward. Future studies should explore other potential mechanisms associated with an increased discounting for e-liquid over money. For example, this approach could be used to investigate other factors (or combinations of these), such as stress and alcohol, on delay discounting rates. More importantly, future studies should explore alternative rewards that may be able to compete with the immediate availability of e-liquid during deprivation, which could have important implications for treatment development. This information is particularly relevant

for contingency management, which has shown to be an efficacious approach for promoting abstinence among tobacco users (Dallery et al., 2007; Higgins et al., 2022). In this sense, delay discounting studies can be helpful to determine the specific rewards able to shift reinforcement away from ENDS use towards other healthy behaviors that both compete with and can't occur at the same time as vaping. Additional delay discounting studies could explore novel ways to deliver rewards, perhaps using remote delivery methods, the specific types of rewards that may be more appealing and able to compete with ENDS use, and the timing for delivering these rewards.

We also found that nicotine deprivation did not alter delay discounting rates for monetary rewards and e-liquid among young ENDS users in the same commodity tasks. The finding that the rates of delay discounting for money did not change is consistent with results reported by some earlier studies conducted among smokers (Ashare & Kable, 2015; Czuczman et al., 2021; Miglin et al., 2017; Mitchell, 2004; Roewer et al., 2015) which showed no evidence of an effect of nicotine deprivation on discounting for monetary rewards, but contradicts other published studies (Ashare & Hawk, 2012; Field et al., 2006; Heckman et al., 2017; Searcy, 2011; Yi & Landes, 2012) that showed an increase in discounting of money following nicotine deprivation. Our result contributes to the contradictory literature on the effects of nicotine deprivation on delay discounting for monetary rewards. Although this result is puzzling, we have various potential explanations. First, it is possible that short-term nicotine deprivation only produces an increased delay discounting for the drug of choice, in this study ENDS, relative to monetary rewards and does not enhance the decision-making for other rewards. This explanation would suggest that discounting rates for different types of rewards are mostly independent (Jimura et al., 2011) or at least influenced by different factors. In addition, the overall sample was made up of affluent, young adults living in a household with an average income above the median US household income ($67,521 in 2020). Given the evidence that socioeconomic (SES) status influences delay discounting, with individual with higher SES evidencing lower discounting rates for monetary rewards (Ishii et al., 2017), it is understandable that our sample of young adults did not provide evidence of an increase on monetary rewards while deprived of nicotine. Finally, methodological differences across studies may have an important role in the divergent findings, including different types of delay discounting tasks (i.e., real vs hypothetical tasks) and participants' characteristics. Future studies should replicate and build upon prior study procedures to test whether earlier findings are reproducible.

Unexpectedly, we did not find a significant change in the delay discounting rates of e-liquid as a function of short-term nicotine deprivation. No changes in delay discounting rates for nicotine products were reported in a prior study involving cigarette smokers in short-term nicotine deprivation (24h)(Yi & Landes, 2012). One possible explanation for our finding may be related to a commodity effect (Yi & Landes, 2012). It is possible that e-liquid, (i.e., the substance of choice) is highly preferred immediately over larger, delayed amount of e-liquid, and thus, even a state of nicotine deprivation does not impact this preference. The strong preference for e-liquid is also supported by our finding in the cross-commodity tasks that showed that immediate valuation of e-liquid relative to money, which is enhanced during short-term nicotine deprivation. Alternatively, as suggested by Yi et al(Yi & Landes, 2012), it is also possible that the option of delayed e-liquid is extremely disliked as most

tobacco users, including e-cigarette users. Therefore, the availability of delayed e-liquid may seem valueless to these individuals. Finally, it is also possible that the 16-h deprivation was not sufficient to produce changes in the same commodity delay discounting task (e-liquid now vs. e-liquid later), despite producing increases in the cross-commodity task (e.g., e-liquid now vs. money later). Future studies could explore whether a longer period of nicotine deprivation is associated with increased delay discounting for e-liquid.

Finally, we found that our sample of young, experienced ENDS users reported an increase in craving levels after a 16-hr period of nicotine deprivation. We used the only questionnaire that has been specifically validated for ENDS users (i.e., QVC)(Dowd et al., 2019). Extensive prior literature has demonstrated that tobacco users experience increments in craving after a period of nicotine deprivation (Bedi et al., 2011; Drobes & Tiffany, 1997). In contrast, there are only a few studies that have explored craving from vaping only among ENDS users (Felicione et al., 2021; Hughes et al., 2020; Pericot-Valverde et al., 2021). Craving is a clinical phenomenon that plays an important role in the maintenance of drug use (Kassel et al., 2007; Niaura et al., 1988), including tobacco use. More importantly, craving has been identified as a precipitant of relapse among traditional cigarette smokers (Wray et al., 2013). Therefore, the availability of studies delineating craving for ENDS is important for treatment development. If future research determines that ENDS produces modest levels of craving, this would suggest that ENDS have less abuse liability than combustible tobacco cigarettes. Additionally, if future research demonstrates that deprivation-induced craving does not necessarily precipitate ENDS use, it would represent a step toward determining the effectiveness of ENDS as a cessation aid for combustible tobacco users. Therefore, future studies should explore craving for ENDS under other conditions, such as comparing the magnitude of craving between ENDS users and smokers or determining the effect of abstinence-induced craving on motivation to vape.

The following limitations should be taken into consideration. First, the sample size was relatively small, mostly men, White, and only ENDS users, which may reduce the generalization of the results to other ENDS users, such as older users, women, underrepresented minorities or dual users. Second, although the delay discounting tasks were presented in random order, the sessions were completed in a fixed order. While there is a potential for practice effects, the intrinsic characteristics of the delay discounting task make the likelihood to either consciously or unconsciously alter or modify the responses very unlikely (Odum, 2011). Third, participants were in a brief state of nicotine deprivation from ENDS (16hr). Future studies should explore whether delay discounting rates among ENDS users after longer periods of nicotine deprivation (e.g., 24hr). Fourth, in this study we used a delay discounting task involving hypothetical choices. It should be noted, however, that prior studies have reported similar results in estimating delay discounting for both real and hypothetical discounting tasks.(Johnson & Bickel, 2002; Lagorio & Madden, 2005; Madden et al., 2003) Whether similar findings can be found using delay discounting tasks involving real rewards (i.e., e-liquid and money) and, more importantly, whether these choices can be modified using behavioral interventions, such as episodic future thinking, are unknown. Fifth, the sample of young adults was relatively wealthy with annual household income (˃$100,000). The economic situation of our participants may have influenced the decisions where the participant had to choose monetary rewards. Finally, we would like to

acknowledge that this study took place within the context of a parent study. Therefore, there is a possibility that the findings may have been affected by the parent study's procedures.

In conclusion, the present study demonstrated that young, exclusive ENDS users demonstrate an increase in delay discounting for immediate e-liquid over delayed money when deprived. However, such users did not show change for monetary rewards or e-liquid when compared with the same commodity. The present study builds upon prior research on delay discounting while providing a step forward by conducting the first study exploring the impact of ENDS deprivation on delay discounting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by the Tobacco Centers of Regulatory Science Award P50DA036114 from the National Institute on Drug Abuse (NIDA) and Food and Drug Administration (FDA), and the Center of Biomedical Research Excellence Award P20GM103644 from the National Institute of General Medical Sciences (NIGMS).

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Irene Pericot-Valverde played lead role in conceptualization, funding acquisition, writing of original draft and writing of review and editing. Jin H. Yoon played lead role in formal analysis and software, supporting role in conceptualization and writing of original draft and equal role in writing of review and editing. Kaileigh A. Byrne played supporting role in conceptualization, methodology, writing of original draft and writing of review and editing. Moonseong Heo played lead role in formal analysis and supporting role in writing of original draft. Jiajing Niu played lead role in formal analysis. Alain H. Litwin played supporting role in conceptualization, writing of original draft and writing of review and editing. Diann E. Gaalema played supporting role in conceptualization, writing of original draft and writing of review and editing and equal role in funding acquisition.

This study was registered under ClinicalTrials.gov (NCT04522362). Data, analysis code, and materials are available from the authors upon reasonable request.

References

Amlung M, & MacKillop J. (2014). Clarifying the relationship between impulsive delay discounting and nicotine dependence. Psychology of addictive behaviors : journal of the Society of Psychologists in Addictive Behaviors, 28(3), 761–768. 10.1037/a0036726 [PubMed: 24841186]

Amlung M, Vedelago L, Acker J, Balodis I, & MacKillop J. (2017, Jan). Steep delay discounting and addictive behavior: a meta-analysis of continuous associations. Addiction, 112(1), 51–62. 10.1111/add.13535

Ashare RL, & Hawk LW Jr. (2012). Effects of smoking abstinence on impulsive behavior among smokers high and low in ADHD-like symptoms. Psychopharmacology, 219(2), 537–547. 10.1007/s00213-011-2324-2 [PubMed: 21559802]

Ashare RL, & Kable JW (2015). Sex differences in time perception during smoking abstinence. Nicotine and Tobacco Research, 17(4), 449–454. 10.1093/ntr/ntu260 [PubMed: 25762755]

Audrain-McGovern J, Rodriguez D, Epstein LH, Cuevas J, Rodgers K, & Wileyto EP (2009). Does delay discounting play an etiological role in smoking or is it a consequence of smoking? Drug and Alcohol Dependence, 103(3), 99–106. 10.1016/j.drugalcdep.2008.12.019 [PubMed: 19443136]

Barlow P, McKee M, Reeves A, Galea G, & Stuckler D. (2016). Time-discounting and tobacco smoking: a systematic review and network analysis. International Journal of Epidemiology, 46(3), 860–869. 10.1093/ije/dyw233

Bedi G, Preston KL, Epstein DH, Heishman SJ, Marrone GF, Shaham Y, & de Wit H. (2011). Incubation of Cue-Induced Cigarette Craving During Abstinence in Human Smokers. Biological Psychiatry, 69(7), 708–711. 10.1016/j.biopsych.2010.07.014 [PubMed: 20817135]

Białaszek W, Marcowski P, & Cox DJ (2017). Differences in Delay, but not Probability Discounting, in Current Smokers, E-cigarette Users, and Never Smokers. The Psychological Record, 67(2), 223–230. 10.1007/s40732-017-0244-1 [PubMed: 28546648]

Bickel WK, Landes RD, Christensen DR, Jackson L, Jones BA, Kurth-Nelson Z, & Redish AD (2011). Single- and cross-commodity discounting among cocaine addicts: the commodity and its temporal location determine discounting rate. Psychopharmacology, 217(2), 177–187. 10.1007/s00213-011-2272-x [PubMed: 21487658]

Bickel WK, MacKillop J, Madden GJ, Odum AL, & Yi R. (2015). Experimental manipulations of delay discounting & related processes: an introduction to the special issue. Journal of the Experimental Analysis of Behavior, 103(1), 1–9. 10.1002/jeab.133 [PubMed: 25641079]

Bickel WK, Odum AL, & Madden GJ (1999). Impulsivity and cigarette smoking: delay discounting in current, never, and ex-smokers. Psychopharmacology, 146(4), 447–454. 10.1007/PL00005490 [PubMed: 10550495]

Cassidy RN, Long V, Tidey JW, & Colby SM (2020). Validation of an E-cigarette Purchase Task in Advanced Generation Device Users. Nicotine & Tobacco Research, 22(10), 1851–1859. 10.1093/ntr/ntaa060 [PubMed: 32267947]

Chivers LL, Hand DJ, Priest JS, & Higgins ST (2016). E-cigarette use among women of reproductive age: Impulsivity, cigarette smoking status, and other risk factors. Preventive Medicine, 92, 126–134. 10.1016/j.ypmed.2016.07.029 [PubMed: 27492277]

Coughlin LN, Tegge AN, Sheffer CE, & Bickel WK (2020, Mar 16). A MachineLearning Approach to Predicting Smoking Cessation Treatment Outcomes. Nicotine AND Tobacco Research, 22(3), 415–422. 10.1093/ntr/nty259 [PubMed: 30508122]

Czuczman C, Thompson M, Wileyto EP, Schnoll R, Metzger D, Leone F, Mounzer K, Gross R, & Ashare RL (2021, 2021/02/01). No differences in delay discounting between smokers with and without HIV. Psychopharmacology, 238(2), 529–537. 10.1007/s00213-020-05701-x [PubMed: 33180174]

Dallery J, Glenn IM, & Raiff BR (2007, Jan 12). An Internet-based abstinence reinforcement treatment for cigarette smoking. Drug and Alcohol Dependence, 86(2–3), 230–238. 10.1016/j.drugalcdep.2006.06.013 [PubMed: 16930854]

Dallery J, & Raiff BR (2007, Mar). Delay discounting predicts cigarette smoking in a laboratory model of abstinence reinforcement. Psychopharmacology, 190(4), 485–496. 10.1007/s00213-006-0627-5 [PubMed: 17205320]

de Wit H. (2009). Impulsivity as a determinant and consequence of drug use: a review of underlying processes. Addiction Biology, 14(1), 22–31. 10.1111/j.1369-1600.2008.00129.x [PubMed: 18855805]

DeHart WB, Friedel JE, Berry M, Frye CCJ, Galizio A, & Odum AL (2020). Comparison of delay discounting of different outcomes in cigarette smokers, smokeless tobacco users, e-cigarette users, and non-tobacco users. J Exp Anal Behav, 114(2), 203215. 10.1002/jeab.623

Dowd AN, Motschman CA, & Tiffany ST (2019). Development and Validation of the Questionnaire of Vaping Craving. Nicotine and Tobacco Research, 21(1), 63–70. 10.1093/ntr/nty046 [PubMed: 29546379]

Drobes DJ, & Tiffany ST (1997, Feb). Induction of smoking urge through imaginal and in vivo procedures: physiological and self-report manifestations. J Abnormal Psychology, 106(1), 15–25. 10.1037//0021-843x.106.1.15

Estle SJ, Green L, Myerson J, & Holt DD (2007). Discounting of Monetary and Directly Consumable Rewards. Psychological Science, 18(1), 58–63. 10.1111/j.1467-9280.2007.01849.x [PubMed: 17362379]

Felicione NJ, Douglas AE, McClernon FJ, & Blank MD (2021). Preliminary Evaluation of Short-Term Abstinence Effects Among Never-Smoking Experienced Users of Modern Electronic Cigarettes. Nicotine & Tobacco Research, 24(7), 1125–1129. 10.1093/ntr/ntab252

Field M, Santarcangelo M, Sumnall H, Goudie A, & Cole J. (2006, Jun). Delay discounting and the behavioural economics of cigarette purchases in smokers: the effects of nicotine deprivation. Psychopharmacology, 186(2), 255–263. 10.1007/s00213-0060385-4 [PubMed: 16609902]

Foulds J, Veldheer S, Yingst J, Hrabovsky S, Wilson SJ, Nichols TT, & Eissenberg T. (2015, Feb). Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking E-cigarette users. Nicotine and Tobacco Research, 17(2), 186–192. 10.1093/ntr/ntu204 [PubMed: 25332459]

Friedel JE, DeHart WB, Madden GJ, & Odum AL (2014, 2014/12/01). Impulsivity and cigarette smoking: discounting of monetary and consumable outcomes in current and non-smokers. Psychopharmacology, 231(23), 4517–4526. 10.1007/s00213014-3597-z [PubMed: 24819731]

García-Pérez Á, Aonso-Diego G, Weidberg S, González-Roz A, & Secades-Villa R. (2022, Aug). Reinforcer pathology predicts relapse in smokers. Psychology of addictive behaviors, 36(5), 565–571. 10.1037/adb0000773 [PubMed: 34323527]

García-Pérez Á, Aonso-Diego G, Weidberg S, & Secades-Villa R. (2022, Feb). Effects of episodic future thinking on reinforcement pathology during smoking cessation treatment among individuals with substance use disorders. Psychopharmacology, 239(2), 631–642. 10.1007/s00213-021-06057-6 [PubMed: 35020047]

García-Rodríguez O, Secades-Villa R, Weidberg S, & Yoon JH (2013, Oct). A systematic assessment of delay discounting in relation to cocaine and nicotine dependence. Behavioral Processes, 99, 100–105. 10.1016/j.beproc.2013.07.007

Gilroy SP, & Hantula DA (2018, Mar). Discounting model selection with area-based measures: A case for numerical integration. Journal of Experimental Analysis of Behavior, 109(2), 433–449. 10.1002/jeab.318

González-Roz A, Secades-Villa R, Pericot-Valverde I, Weidberg S, & Alonso-Pérez F. (2019). Effects of Delay Discounting and Other Predictors on Smoking Relapse. The Spanish Journal of Psychology, 22, E9, Article E9. 10.1017/sjp.2019.11 [PubMed: 30885283]

Green L, & Myerson J. (2004, Sep). A discounting framework for choice with delayed and probabilistic rewards. Psychological Bulletin, 130(5), 769–792. 10.1037/0033-2909.130.5.769 [PubMed: 15367080]

Halpern SD, French B, Small DS, Saulsgiver K, Harhay MO, Audrain-McGovern J, Loewenstein G, Asch DA, & Volpp KG (2016, Oct 15). Heterogeneity in the Effects of Reward- and Deposit-based Financial Incentives on Smoking Cessation. American Journal Respiratory Critical Care Medicine, 194(8), 981–988. 10.1164/rccm.201601-0108OC

Heckman BW, MacQueen DA, Marquinez NS, MacKillop J, Bickel WK, & Brandon TH (2017). Self-control depletion and nicotine deprivation as precipitants of smoking cessation failure: A human laboratory model. Journal of Consulting and Clinical psychology, 85(4), 381–396. 10.1037/ccp0000197 [PubMed: 28333537]

Higgins ST, Nighbor TD, Kurti AN, Heil SH, Slade EP, Shepard DS, Solomon LJ, Lynch ME, Johnson HK, Markesich C, Rippberger PL, Skelly JM, DeSarno M, Bunn J, Hammond JB, Roemhildt ML, Williams RK, O'Reilly DM, & Bernstein IM (2022, 2022/03/03/). Randomized Controlled Trial Examining the Efficacy of Adding Financial Incentives to Best practices for Smoking Cessation Among pregnant and Newly postpartum Women. Preventive Medicine, 107012. 10.1016/j.ypmed.2022.107012

Huang J, Duan Z, Kwok J, Binns S, Vera LE, Kim Y, Szczypka G, & Emery SL (2019). Vaping versus JUULing: how the extraordinary growth and marketing of JUUL transformed the US retail e-cigarette market. Tobacco Control, 28(2), 146–151. 10.1136/tobaccocontrol-2018-054382 [PubMed: 29853561]

Hughes JR, Peters EN, Callas PW, Peasley-Miklus C, Oga E, Etter J-F, & Morley N. (2020). Withdrawal Symptoms From E-Cigarette Abstinence Among Adult Never-Smokers: A Pilot Experimental Study. Nicotine & Tobacco Research, 22(5), 740–746. 10.1093/ntr/ntz169 [PubMed: 31504882]

Huynh T, Alstatt K, Abram SV, & Schmitzer-Torbert N. (2021). Vicarious Trial-and-Error Is Enhanced During Deliberation in Human Virtual Navigation in a Translational Foraging Task. Frontiers in Behavioral Neuroscience, 15, 586159–586159. 10.3389/fnbeh.2021.586159

Ishii K, Eisen C, & Hitokoto H. (2017). The Effects of Social Status and Culture on Delay Discounting. Japanese Psychological Research, 59(3), 230–237. 10.1111/jpr.12154

Jimura K, Myerson J, Hilgard J, Keighley J, Braver TS, & Green L. (2011). Domain independence and stability in young and older adults' discounting of delayed rewards. Behavioural Processes, 87(3), 253–259. 10.1016/j.beproc.2011.04.006 [PubMed: 21550384]

Johnson MW, & Bickel WK (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. Journal of Experimental Analysis of Behavior, 77(2), 129–146. 10.1901/jeab.2002.77-129

Johnson MW, & Bickel WK (2008). An algorithm for identifying nonsystematic delay-discounting data. Experimental and Clinical Psychopharmacology, 16(3), 264–274. 10.1037/1064-1297.16.3.264 [PubMed: 18540786]

Johnson MW, Bickel WK, & Baker F. (2007). Moderate drug use and delay discounting: a comparison of heavy, light, and never smokers. Experimental and Clinical Psychopharmacology, 15(2), 187–194. 10.1037/1064-1297.15.2.187 [PubMed: 17469942]

Kassel JD, Evatt DP, Greenstein JE, Wardle MC, Yates MC, & Veilleux JC (2007). The acute effects of nicotine on positive and negative affect in adolescent smokers. Journal of Abnormal Psychology, 116(3), 543–553. 10.1037/0021-843x.116.3.543 [PubMed: 17696710]

Lagorio CH, & Madden GJ (2005). Delay discounting of real and hypothetical rewards III: steady-state assessments, forced-choice trials, and all real rewards. Behavioral Processes, 69(2), 173–187. 10.1016/j.beproc.2005.02.003

Leventhal AM, Goldenson NI, Aguirre CG, Huh J, & Kirkpatrick MG (2019). Initial application of a human laboratory model for estimating the motivational substitutability of e-cigarettes for combustible cigarettes. Exp Clin Psychopharmacol, 27(2), 125–135. 10.1037/pha0000237 [PubMed: 30688503]

MacKillop J, Amlung MT, Few LR, Ray LA, Sweet LH, & Munafò MR (2011,). Delayed reward discounting and addictive behavior: a meta-analysis. Psychopharmacology, 216(3), 305–321. 10.1007/s00213-011-2229-0 [PubMed: 21373791]

Madden GJ, Begotka AM, Raiff BR, & Kastern LL (2003). Delay discounting of real and hypothetical rewards. Exp Clin Psychopharmacol, 11(2), 139–145. 10.1037/1064-1297.11.2.139 [PubMed: 12755458]

Madden GJ, & Bickel WK (2010). Impulsivity: The behavioral and neurological science of discounting. American Psychological Association.

Marques P, Piqueras L, & Sanz M-J (2021). An updated overview of e-cigarette impact on human health. Respiratory Research, 22(1), 151. 10.1186/s12931-02101737-5 [PubMed: 34006276]

Miglin R, Kable JW, Bowers ME, & Ashare RL (2017). Withdrawal-Related Changes in Delay Discounting Predict Short-Term Smoking Abstinence. Nicotine & Tobacco Research, 19(6), 694–702. 10.1093/ntr/ntw246 [PubMed: 28486708]

Mitchell SH (2004). Effects of short-term nicotine deprivation on decision-making: Delay, uncertainty and effort discounting. Nicotine & Tobacco Research, 6(5), 819–828. 10.1080/14622200412331296002 [PubMed: 15700917]

Moody LN, Tegge AN, & Bickel WK (2017). Cross-commodity delay discounting of alcohol and money in alcohol users. Psychol Rec, 67(2), 285–292. 10.1007/s40732-017-0245-0 [PubMed: 29056767]

Münzel T, Hahad O, Kuntic M, Keaney JF, Deanfield JE, & Daiber A. (2020). Effects of tobacco cigarettes, e-cigarettes, and waterpipe smoking on endothelial function and clinical outcomes. Eur Heart J, 41(41), 4057–4070. 10.1093/eurheartj/ehaa460 [PubMed: 32585699]

Niaura RS, Rohsenow DJ, Binkoff JA, Monti PM, Pedraza M, & Abrams DB (1988). Relevance of cue reactivity to understanding alcohol and smoking relapse. J Abnorm Psychol, 97(2), 133–152. 10.1037//0021-843x.97.2.133 [PubMed: 3290304]

Odum AL (2011). Delay discounting: I'm a k, you're a k. Journal of the Experimental Analysis of Behavior, 96(3), 427–439. 10.1901/jeab.2011.96-423 [PubMed: 22084499]

Odum AL, Becker RJ, Haynes JM, Galizio A, Frye CCJ, Downey H, Friedel JE, & Perez DM (2020). Delay discounting of different outcomes: Review and theory. Journal of the Experimental Analysis of Behavior, 113(3), 657–679. 10.1002/jeab.589 [PubMed: 32147840]

Ohmura Y, Takahashi T, & Kitamura N. (2005). Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. Psychopharmacology (Berl), 182(4), 508–515. 10.1007/s00213-005-0110-8 [PubMed: 16167142]

Pericot-Valverde I, Heo M, Litwin AH, Niu J, & Gaalema DE (2021). Modeling the effect of stress on vaping behavior among young adults: A randomized cross-over pilot study. Drug and Alcohol Dependence, 225, 108798. 10.1016/j.drugalcdep.2021.108798

Pericot-Valverde I, Priest JS, Wagener TL, & Gaalema DE (2020). Examination of a mouthpiece-based topography device for assessing relative reinforcing effects of e-cigarettes: A preliminary study. Exp Clin Psychopharmacol, 28(1), 13–18. 10.1037/pha0000288 [PubMed: 31305091]

Pericot-Valverde I, Yoon JH, & Gaalema DE (2020). Single- and cross-commodity delay discounting of money and e-cigarette liquid in experienced e-cigarette users. Drug and Alcohol Dependence, 206, 107740. 10.1016/j.drugalcdep.2019.107740

Prakash S, Hatcher C, & Shiffman S. (2021). Prevalence of ENDS and JUUL Use, by Smoking Status, in National Samples of Young Adults and Older Adults in the U.S. Am J Health Behav, 45(3), 402–418. 10.5993/ajhb.45.3.2 [PubMed: 33894792]

Pritschmann RK, Yurasek AM, & Yi R. (2021). A review of cross-commodity delay discounting research with relevance to addiction. Behavioural Processes, 186, 104339. 10.1016/j.beproc.2021.104339

Roewer I, Wiehler A, & Peters J. (2015). Nicotine deprivation, temporal discounting and choice consistency in heavy smokers. Journal of the Experimental Analysis of Behavior, 103(1), 62–76. 10.1002/jeab.134 [PubMed: 25641080]

Searcy GD (2011). Short-term nicotine abstinence and decision making (Publication Number 3496366) [Ph.D., Western Michigan University]. ProQuest Dissertations & Theses Global. Ann Arbor. http://libproxy.clemson.edu/login?url=https://www.proquest.com/dissertations-theses/short-term-nicotine-abstinence-decision-making/docview/920881078/se-2?accountid=6167

Secades-Villa R, Weidberg S, García-Rodríguez O, Fernández-Hermida JR, & Yoon JH (2014. Decreased delay discounting in former cigarette smokers at one year after treatment. Addictive Behaviors, 39(6), 1087–1093. 10.1016/j.addbeh.2014.03.015 [PubMed: 24661901]

Stein JS, Heckman BW, Pope DA, Perry ES, Fong GT, Cummings KM, & Bickel WK (2018). Delay discounting and e-cigarette use: An investigation in current, former, and never cigarette smokers. Drug and Alcohol Dependence, 191, 165–173. 10.1016/j.drugalcdep.2018.06.034 [PubMed: 30121475]

Weidberg S, González-Roz A, & Secades-Villa R. (2017). Delay discounting in e-cigarette users, current and former smokers. International Journal Clinical and Health Psychology, 17(1), 20–27. 10.1016/j.ijchp.2016.07.004

Weidberg S, Landes RD, López-Núñez C, Pericot-Valverde I, González-Roz A, Yoon JH, & Secades-Villa R. (2015). Contingency management effects on delay discounting among patients receiving smoking cessation treatment. Psicothema, 27(4), 309–316. 10.7334/psicothema2015.184

Wray JM, Gass JC, & Tiffany ST (2013). A systematic review of the relationships between craving and smoking cessation. Nicotine and Tobacco Resesearch, 15(7), 1167–1182. 10.1093/ntr/nts268

Yi R, Johnson MW, Giordano LA, Landes RD, Badger GJ, & Bickel WK (2008). The Effects of Reduced Cigarette Smoking on Discounting Future Rewards: An Initial Evaluation. The Psychological Record, 58(2), 163–174. 10.1007/BF03395609 [PubMed: 23825867]

Yi R, & Landes RD (2012). Temporal and Probability Discounting by Cigarette Smokers Following Acute Smoking Abstinence. Nicotine & Tobacco Research, 14(5), 547–558. 10.1093/ntr/ntr252 [PubMed: 22311959]

Yoon JH, De La Garza R 2nd, Newton TF, Suchting R, Weaver MT, Brown GS, Omar Y, & Haliwa I. (2017). A comparison of Mazur's k and area under the curve for describing steep discounters. Psycholigal Record, 67(3), 355–363. 10.1007/s40732-017-0220-9

Yoon JH, Higgins ST, Bradstreet MP, Badger GJ, & Thomas CS (2009). Changes in the relative reinforcing effects of cigarette smoking as a function of initial abstinence. Psychopharmacology, 205(2), 305. 10.1007/s00213-009-1541-4 [PubMed: 19390842]

Yoon JH, Higgins ST, Heil SH, Sugarbaker RJ, Thomas CS, & Badger GJ (2007). Delay discounting predicts postpartum relapse to cigarette smoking among pregnant women. Experimental and Clinical Psychopharmacology, 15(2), 176–186. 10.1037/1064-1297.15.2.186 [PubMed: 17469941]

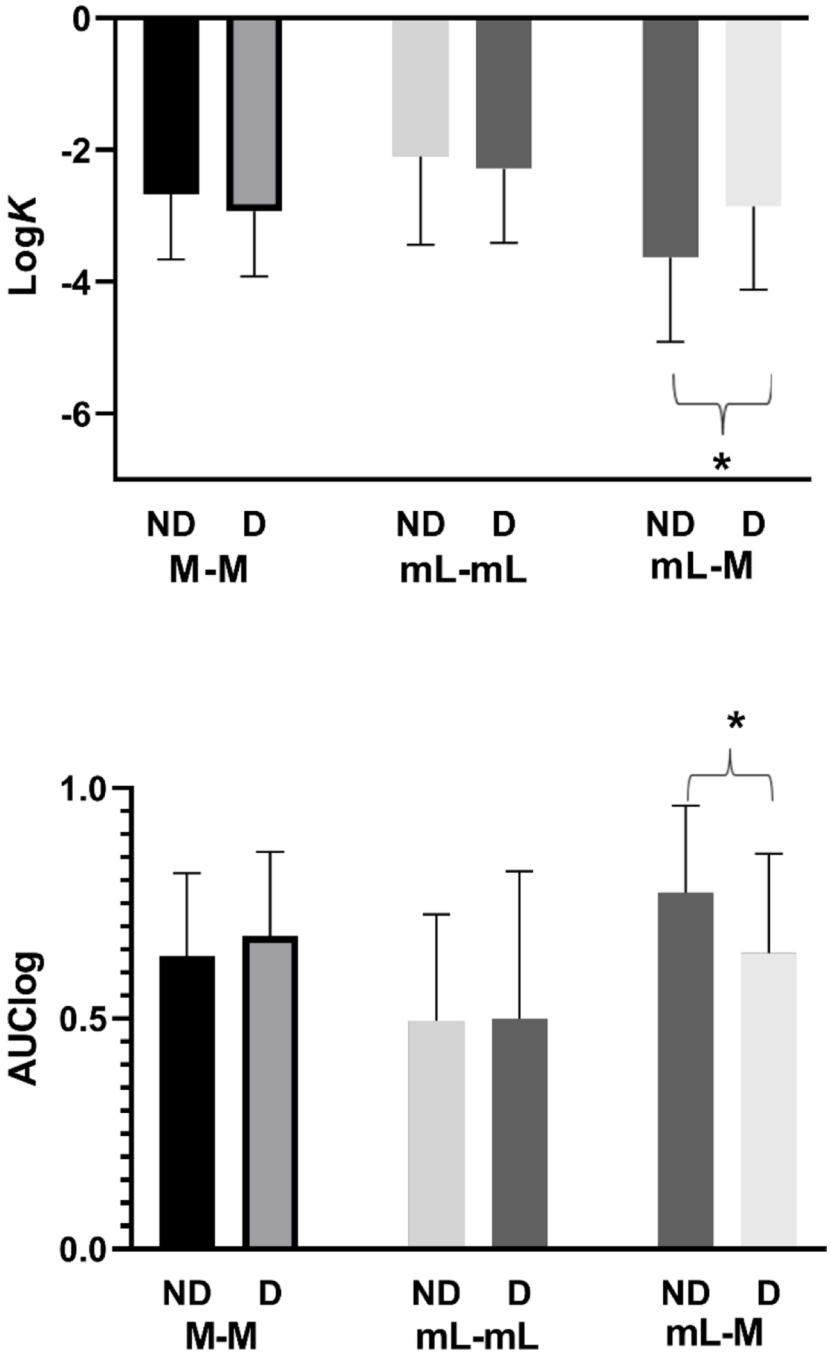

Figure 1.

Depicts mean log*k* and AUClog values for the three delay discounting tasks at the non-deprivation (ND) and deprivation (D) sessions: money now-money later (M-M), mL now-mL later (ml-ml), and mL now-money later (mL-M). Error bars represent standard error of the mean. The asterisk (*) represent $p<0.05$. Larger log*k* and lower AUClog values indicating greater discounting

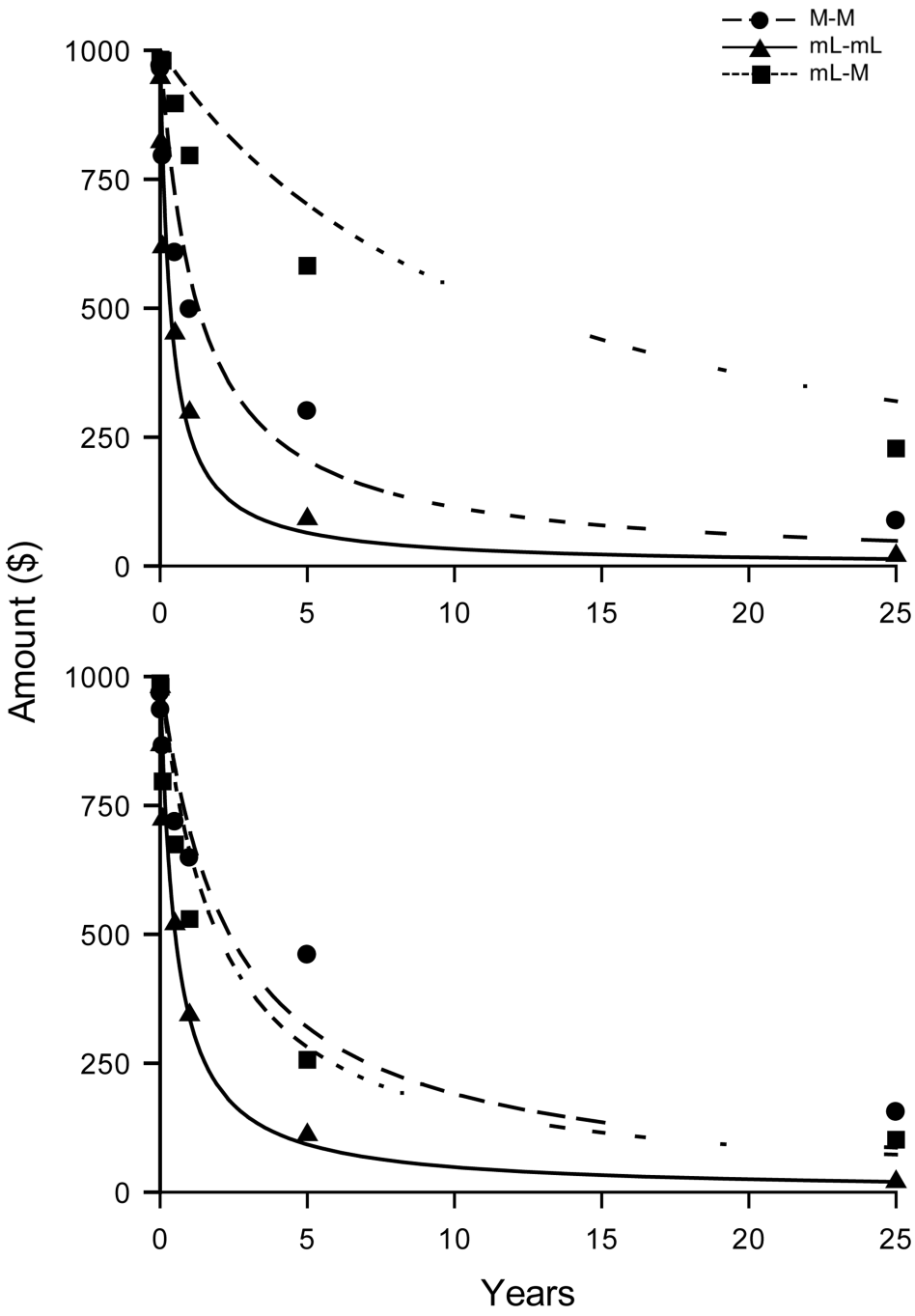

Figure 2.

shows the delay discounting curves in the non-deprivation (upper panel) and at the deprivation session (lower panel) for the three delay discounting tasks. The symbols indicate the mean indifference points for a given delay for: money now-money later (M-M) (circle), mL now-mL later (ml-ml) (triangle), and mL now-money later (mL-M) (square). These curves represent the best fitting hyperbolic function based on k values derived from Equation 1, with steeper curves denoting greater delay discounting.

Table 1.

Participant characteristics (N=30)

Characteristic	M ± SD/%
Age (years)	19.1 ± 1.1
Gender (male)	76.7
Race/ethnicity (White, non-Hispanic)	100
Sexual orientation	
Heterosexual	90.0
Bisexual	10.0
Educational attainment	
≤ High school graduate	13.3
≥ Some college	86.7
Annual household income	
≤$99,999	33.3
$100,000–$149,999	23.3
≥$150,000	43.3
Age at first ENDS use	16.2 ± 1.9
Age at regular ENDS use	18.1 ± 1.2
Months of regular ENDS use	11.5 ± 7.4
Days using ENDS in the past 30 days	27.9 ± 3.0
Puffs per day	72.3 ± 57.6
Daily use of e-liquid (mL)	2.3 ± 2.2
PSECDI	9.5 ± 3.8
CO (ppm)	2.2 ± 1.2
NicAlert score	5.4 ± 1.0
Smoking history	
Former smoker	30%
Never smoker	70%

Note: mL: milliliters. PSECDI: Penn State Electronic Cigarette Dependence Index; PSECDI scoring 0–3= not dependent; 4–8= low dependence; 9–12= medium dependence; 13+= high dependence; CO = carbon monoxide; ppm = parts per million; NicAlert levels and corresponding levels of urine cotinine 0=0–10ng/mL, 1=10–330 ng/mL, 2=30–100 ng/mL, 4=200–500 ng/mL, 5=500–1000 ng/mL, 6=˃1,000 ng/mL; Former smoker = reported having smoked >100 cigarettes lifetime. Never smoker = reported having smoked <100 cigarettes lifetime.