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Delay discounting and e-cigarette use: An investigation in current, former, and never cigarette smokers

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Abstract

Background: Cigarette smokers show greater delay discounting (devaluation of delayed consequences) than non-smokers, suggesting that rapid devaluation of the future contributes to tobacco use through a mechanism in which tobacco-related health consequences are too delayed to discourage smoking. However, little work has quantified delay discounting in relation to electronic cigarette (EC) use, a tobacco product that many users believe to pose fewer negative health consequences than cigarettes.

Methods: We assessed discounting of delayed monetary rewards in a web-based sample of 976 participants, stratified by both EC use (current and never) and cigarette use (current, former, and never).

Results: Controlling for demographic variance, current EC users generally showed greater discounting than never EC users ($p = .019$). Current cigarette smokers also showed greater discounting than former and never smokers ($p < .001$). However, the between-group difference for EC use was much smaller ($\eta_p^2 = .006$) than for cigarette use ($\eta_p^2 = .026$). Moreover, differences in discounting in relation to EC use were not statistically apparent in most pairwise comparisons. Most notably, the difference between former smokers who achieved smoking cessation by

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Contributors

JSS designed the experiment. JSS and ESP conducted the experiment. JSS performed data analyses and drafted the manuscript, with feedback from BWH, DAP, ESP, GTF, KMC, and WKB. All authors read and approved the final manuscript.

Conflicts of interest

WKB is a principal of HealthSim, LLC and Notifius, LLC; a scientific advisory board member of Sober Grid, Inc. and DxRx, Inc.; and a consultant for ProPhase, LLC and Teva Branded Pharmaceutical Products R & D, Inc. KMC has received grant funding from Pfizer Inc. to study the impact of a hospital-based tobacco cessation intervention and has received funding as an expert witness in litigation filed against the tobacco industry. None of the other authors has any real or potential conflict(s) of interest.

Appendix A. Supplementary data

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transitioning to ECs (i.e., exclusive EC users) and those who have never used ECs or cigarettes was nonsignificant and small ($\eta_p^2 = .010$).

Conclusions: The smaller effect size for the association between delay discounting and current EC use, relative to current cigarette use, suggests that public perception of ECs as a safer alternative to cigarettes attenuates the role of delay discounting in decisions to use ECs.

Keywords

Delay discounting; Tobacco; Cigarettes; Electronic cigarettes; e-cigarettes

1. Introduction

Delay discounting, or the devaluation of delayed outcomes (for overview, see Madden and Johnson, 2010), serves as a reliable behavioral marker of cigarette use and dependence (Bickel et al., 2014). In between-group comparisons, a large body of evidence demonstrates that cigarette smokers show greater discounting of delayed rewards than non-smokers (e.g., Bickel et al., 1999; MacKillop et al., 2011). Within groups, discounting correlates positively with smoking frequency and dependence (e.g., Ohmura et al., 2005; Amlung et al., 2017), negatively with intention to quit smoking (Athamneh et al., 2017), and prospectively predicts both smoking initiation and relapse (Audrain-McGovern et al., 2009; Sheffer et al., 2014; Yoon et al., 2007). Moreover, experimental reductions in discounting produce concomitant reductions in both cigarette smoking (Chiou and Wu, 2017; Stein et al., 2016) and cigarette valuation (Stein et al., 2017). Collectively, these findings suggest that delay discounting plays an etiological role in cigarette smoking through a mechanism in which rapidly devaluing the future reduces one's sensitivity to the delayed, otherwise aversive, consequences of smoking-related illness.

Little work, however, has examined possible associations between delay discounting and electronic cigarette (EC) use. Although EC use poses unique health risks which have yet to be fully understood (Abrams et al., 2018; NASEM, 2018), widespread public perception of ECs as a safer alternative to cigarettes (e.g., Huerta et al., 2017; Farsalinos et al., 2014; Wagner et al., 2017) may produce a weaker association between discounting and EC use than that observed for cigarettes. That is, because one facet of ECs' appeal is their perceived relative safety, many smokers who initiate or transition to EC use may be those who value their future health incrementally more than smokers who do not use EC. In turn, this may produce less extreme estimates of discounting in EC users compared to cigarette smokers. To date, only three studies to our knowledge have examined delay discounting in relation to EC use. In one study, Weidberg et al. (2017) reported that discounting in EC users was greater than in former smokers, but was statistically undifferentiated from both current smokers and control participants who have never smoked cigarettes or used ECs regularly. This latter finding is consistent with a weaker role of discounting in EC use. However, in a second study, Bialaszek et al. (2017) reported that discounting in EC users was greater than in never smokers and undifferentiated from current smokers. Thus, whether discounting differs between EC users and those who use neither ECs nor cigarettes remains to be determined, as findings relevant to this question differed between the two studies. Here, we note that neither study clarified the proportion of EC users who were former smokers. This

may be a critical variable that accounts for discrepant findings, as both prior data (Bickel et al., 1999) and the study by Weidberg et al. (2017) demonstrate that non-EC using former smokers resemble never smokers on measures of discounting. Whether such a finding would also be apparent in former smokers who achieve cessation by transition to ECs remains to be determined and was one focus of the present study. Moreover, these studies used relatively small sample sizes per group ($n = 28-40$), did not examine potential group differences in many demographic characteristics known to correlate with delay discounting (e.g., income, education; Green et al., 1996; Wilson et al., 2015), and did not control for observed differences in gender. Each of these considerations, either alone or in combination with others, may have had an impact on results.

In a third study using larger sample sizes, Chivers et al. (2016) examined 800 current and never smokers, including 255 EC users. Overall, EC users showed only a marginally significant trend toward greater delay discounting compared to non-users ($p = .068$). Additional comparisons of EC users and non-users within current and never smokers also yielded nonsignificant differences in discounting. However, the inclusion criterion for EC use required only that participants used an EC at least some days in the past year, with very few participants (1.8%) reporting daily EC use. Because a prior meta-analysis indicates that differences in discounting between substance-using and non-using groups are smaller for subclinical, than clinical, levels of substance use (MacKillop et al., 2011), further examination of daily or almost daily EC users is warranted.

In the present study we sought to build upon, clarify, and extend prior research by comparing delay discounting in current EC users (i.e., daily/almost daily use) and never EC users (fewer than five lifetime uses) in a large, web-based sample of current, former, and never cigarette smokers ($n = 976$). As the largest study of discounting and EC use to date, we were also better positioned than prior studies to explore and control for potential demographic differences between groups.

2. Material and methods

2.1. Participants

The numbers of participants who screened for, enrolled in, and completed the study are provided in Fig. 1. Participants were recruited from Amazon Mechanical Turk, a crowdsourcing platform in which participants can complete short behavioral tasks in return for compensation. Participants were either: (1) dual EC/cigarette users (i.e., current EC users/current smokers; $n = 198$), (2) exclusive smokers (i.e., never EC users/current smokers; $n = 198$), (3) exclusive EC users (i.e., current EC users/former smokers; $n = 198$), (4) exclusive former smokers (i.e., never EC users/former smokers; $n = 198$), or (5) never users of both products (i.e., never-using controls; $n = 184$). This approximated a 2 (current and never EC users) $\times$ 3 (current, former, and never smokers) factorial design, but with those who currently used ECs but have never used cigarettes (i.e., current EC users/never smokers) omitted due to the rarity of this population (i.e., 10% or less of all EC users; Chivers et al., 2016; Sutfin et al., 2013; Vickerman et al., 2013). The total sample size was chosen to provide 80% statistical power to detect a small effect size or greater in main effects of EC and cigarette use, and their interaction, in analysis of covariance (ANCOVA).

Inclusion criteria for EC use required that participants reported daily/almost daily use (regardless of frequency of use/day; *current EC users*) or fewer than five lifetime uses (*never EC users*). Inclusion criteria for cigarette use required that participants reported daily/almost daily use (5/day for at least one month; *current smokers*), former daily/almost daily use (5/day and at least one month since cessation; *former smokers*), or fewer than five lifetime uses (*never smokers*). Additional inclusion criteria required that participants be 18 years of age or older, live in the United States, and have a Mechanical Turk user approval rating of 90% or higher.

Participants who completed the study were provided with a payment that equated approximate hourly compensation rates across groups at \$9/hour (Groups 1–4, above: \$3.00 for approximately 20 min; Group 5: \$1.50 for approximately 10 min). All study procedures were approved by Virginia Tech's Institutional Review Board.

2.2. Procedures

Participants initially completed a brief demographic questionnaire and (where applicable) tobacco use questionnaires, including: (1) questions on preferred EC device types, flavors, and nicotine strengths; (2) the Fagerström Test for Cigarette Dependence (FTCD; Fagerström, 2012; Heatherton et al., 1991); and (3) a modified Fagerström Test for EC Dependence (FTED; Etter and Eissenberg, 2015), in which references to cigarettes were replaced with ECs. Although Etter and Eissenberg (2015) defined EC uses in the modified FTED as any instance of use containing 10 puffs or more, our observations suggest that the majority of EC uses contain fewer than 10 puffs (e.g., in this sample, median = 4 puffs/use; IQR: 3, 6). Thus, for the FTED, we defined EC uses as any instance in which the participant picked up the EC, used it, and then put it back down again.

Next, participants completed two iterations of the five-trial, adjusting-delay task (Koffarnus and Bickel, 2014), in which we assessed discounting of both \$100 and \$1000 (order randomized). These reward magnitudes were chosen because, although degree of delay discounting varies by magnitude (e.g., Green et al., 1997; Kirby and Marakovi, 1996), \$100 and \$1000 provide approximately equal sensitivity to detect differences in discounting between substance users and non-users (Mellis et al., 2017). Participants made repeated, hypothetical choices between a larger amount (\$100 or \$1000, depending on task iteration) available after a delay and half of this amount (\$50 or \$500) available immediately. Across trials, the delay to the larger amount titrated based on previous choices (see Supplementary Fig. 1 for an example) until reaching an indifference delay (possible range: 1 h–25 years, in approximately logarithmic intervals). At this indifference delay, the larger reward has lost half of its subjective value. Following both iterations of the task, we added an attention check question in which participants chose between larger and smaller amounts, both delivered immediately. Four participants failed the attention checks (i.e., chose the smaller amounts; see Fig. 1) and were thus excluded from all analyses.

2.3. Data analysis

All analyses were performed in SPSS version 24.0 (IBM SPSS Statistics for Windows, IBM Corp).

2.3.1. Participant characteristics—We compared demographic characteristics between groups using Fisher’s Exact tests (income, education, gender, race, and ethnicity) or two-way ANOVA (age). Because of a missing cell in the experimental design (i.e., current EC users/never smokers), Type IV sums of squares was specified for this and all subsequent uses of ANOVA (Shaw and Mitchell-Olds, 1993). Demographic variables that differed significantly across groups were included as covariates in primary analyses.

We also compared EC/cigarette use measures between groups using two-way ANOVA, *t* tests, or Mann-Whitney *U* tests, depending on number of groups in the analysis and the observed distribution of measures.

2.3.2. Delay discounting—Discount rate was derived from Mazur’s (1987) hyperbola, in which *V* is the discounted value of the delayed option, *A* is its objective amount, *D* is its delay, and *k* indexes discount rate.

$$V = \frac{A}{1 + kD}$$

Values of *k* were calculated for each participant as the inverse of the indifference delay (i.e., 1/indifference delay; Koffarnus and Bickel, 2014; Yoon and Higgins, 2008; see Supplementary Fig. 1 for an example). Because *k* values were positively skewed, data were natural log transformed ($\ln k$) prior to analysis.

We compared discount rate between groups using two-way, repeated-measures ANCOVA, including between-subjects effects of EC use (current and never) and cigarette use (current, former, and never), a within-subjects effect of reward magnitude (\$100 and \$1000), and all two- and three-way interactions between these factors.

Because we were specifically interested in differences between individual EC and cigarette use subgroups to clarify prior mixed findings (Białaszek et al., 2017; Chivers et al., 2016; Weidberg et al., 2017), we also conducted planned pairwise comparisons of covariate-adjusted discount rates between individual subgroups. Sequential Bonferroni correction was used to maintain Type I error rate at the conventional level of $\alpha = .05$. In interpretation of pairwise comparisons, we treated those who have never used either product (i.e., never EC users/never smokers) as a control group. We also quantified the magnitude of main effects and planned comparisons using partial η^2 effect size (η_p^2), in which approximate values of .010, .059, and .138 correspond to small, medium, and large effects, respectively (Cohen, 1988).

Finally, because prior studies have reported significant within-subject correlations between delay discounting and cigarette smoking frequency and dependence (Amlung et al., 2017), we examined Spearman *rho* correlations between discounting and use and dependence measures. For both the FTCD and FTED, the frequency of use item was removed prior to this analysis to avoid partial redundancy with direct measures of use frequency. Fisher’s *z* transformation was used to determine whether strengths of correlations differed by group.

3. Results

3.1. Participant characteristics

3.1.1. Demographic characteristics—Table 1 summarizes demographic characteristics. Age differed significantly in relation to both EC use ($F(1, 971) = 85.44, p < .001$) and cigarette use ($F(2, 971) = 42.59, p < .001$). Likewise, the distribution of all categorical demographic measures except for ethnicity differed significantly between groups, including income (higher in former vs. current and never smokers, $X^2(4) = 12.16, p = .016$), education (higher in never vs. current and former smokers, $X^2(4) = 30.48, p < .001$; higher in never vs. current EC users, $X^2(2) = 18.38, p < .001$), gender (males more common in current vs. never EC users, $X^2(2) = 19.23, p < .001$), and race (white race more common in current and former vs. never smokers, $X^2(4) = 20.76, p < .001$).

3.1.2. EC use characteristics—Table 2 presents EC use characteristics. Current cigarette smokers used ECs less frequently per day than former smokers ($U = 12484, p < .001$), but took more EC puffs/use ($U = 15704, p < .001$). To control for these opposing differences, we calculated EC puffs/day (uses/day $\times$ puffs/use), finding that current smokers took fewer EC puffs/day than former smokers ($U = 15388, p < .001$). Similarly, we observed lower EC dependence in current compared to former smokers ($t(392) = 2.57, p = .011$). In contrast, current cigarette smokers preferred stronger EC nicotine strengths than former cigarette smokers ($U = 13039, p < .001$); however, 22 of 396 EC users (5.56%) did not know their usual strength and were excluded from this analysis. Only 3 of 396 EC users (0.76%) reported 0 mg/mL as their usual nicotine strength.

Current and former smokers did not differ significantly in their duration of EC use ($U = 17574, p = .104$). Finally, a larger proportion of current than former smokers ($p = .024$) reported that they normally used a first-generation EC device (i.e., less powerful “cig-a-like” products that resemble conventional cigarettes; for overview, see Orellana-Barrios et al., 2015) instead of second- and third-generation devices (i.e., more powerful, tank-based products that may be refilled with a liquid nicotine solution).

3.1.3. Cigarette use characteristics—Table 2 also presents cigarette use characteristics. We observed a main effect of cigarette use on cigarettes/day ($F(1, 786) = 14.72, p < .001$), with current cigarette smokers reporting fewer cigarettes/day than former smokers (prior to quitting). Neither the main effect of EC use ($F(1, 786) = 0.21, p = .647$), nor the EC $\times$ cigarette use interaction ($F(1, 786) = 0.08, p = .777$), was significant. We also observed a main effect of EC use on FTCD scores ($F(1, 786) = 24.16, p < .001$), with higher cigarette dependence in current EC compared to never EC users. Neither the main effect of cigarette use ($F(1, 786) = 3.52, p = .061$), nor the EC $\times$ cigarette use interaction ($F(1, 786) = 0.34, p = .561$), was significant. Finally, within former smokers, current EC users had been abstinent from cigarettes for a shorter duration than never EC users ($U = 9172, p < .001$).

3.2. Delay discounting

Table 3 provides results of ANCOVA examining group differences in delay discounting. All covariates except for race were significant, with lower discounting associated with higher age, income, and education, as well as being male (in all cases $p < .05$).

Fig. 2 depicts main effects of EC use, cigarette use, and reward magnitude on covariate-adjusted discount rates (also see Table 3). We observed significant main effects of both EC use (greater discounting in current EC users; $p = .018$; $\eta_p^2 = .006$), cigarette use (greater discounting in current smokers; $p < .001$; $\eta_p^2 = .026$), and reward magnitude (greater discounting of \$100 vs. \$1000; $p < .001$; $\eta_p^2 = .010$), but no significant two- or three-way interactions between EC use, cigarette use, and magnitude (in all cases, $p > .637$, $\eta_p^2 = .000$).

Fig. 3 depicts planned pairwise comparisons between individual EC and cigarette user subgroups (also see Supplementary Table 1). Dual EC/cigarette users (i.e., current EC users/current smokers) showed greater discounting than exclusive EC users (i.e., current EC users/former smokers; $p = .002$, $\eta_p^2 = .027$), exclusive former smokers (i.e., never EC users/former smokers; $p < .001$, $\eta_p^2 = .056$), and never-using controls (i.e., never EC users/never smokers; $p < .001$, $\eta_p^2 = .068$). Moreover, exclusive smokers (i.e., never EC users/current smokers) showed greater discounting than both exclusive former smokers (i.e., never EC users/former smokers; $p = .008$, $\eta_p^2 = .022$) and never-using controls (i.e., never EC users/never smokers; $p < .001$, $\eta_p^2 = .031$). No other group differences were significant (in all cases, $p > .160$), including the difference between exclusive EC users (i.e., current EC users/former smokers) and never-using controls (i.e., never EC users/never smokers; $p = .160$, $\eta_p^2 = .010$). This latter comparison is particularly informative because it provides a direct test of whether those who exclusively use ECs differ from those who use neither EC nor cigarettes, which is most similar to prior comparisons of exclusive cigarette smokers and never smokers (e.g., Bickel et al., 1999).

Finally, discount rate was significantly positively correlated with FTCD scores at both the \$1000 reward magnitude ($\rho = .12$, $p = .001$) and the \$100 magnitude ($\rho = .07$, $p = .04$). No other EC or cigarette use or dependence measure correlated significantly with discounting, including cigarettes/day, FTED scores, EC puffs/use, or EC puffs/day (in all cases, $p > .116$; see Supplementary Table 2). Additional analysis separately by group revealed that the strength of these correlations did not differ significantly by group (in all cases, $p > .144$), except for the correlation between \$100 and \$1000 discount rates. These were more strongly correlated in former smokers ($\rho = .85$) compared to both current smokers ($\rho = .74$; $z = 3.96$, $p < .001$) and never smokers ($\rho = .78$; $z = 2.28$, $p = .023$).

4. Discussion

In the present study, current EC users generally showed greater delay discounting than never EC users, regardless of cigarette use status and reward magnitude, however, this effect was very small ($\eta_p^2 = .006$; i.e., below effect size conventions for a small effect). In contrast, the effect of cigarette use (greater discounting in current smokers) was larger than for EC use and in the small to medium effect size range ($\eta_p^2 = .026$). Finally, in planned comparisons,

only dual EC/cigarette users (i.e., current EC users/current smokers)) and exclusive smokers (i.e., never EC users/current smokers) showed significantly greater discounting compared to other groups, including never-using controls (i.e., never EC users/never smokers). In contrast, discounting in both former smoker subgroups (current and never EC users) were statistically undifferentiated from never-using controls and the effect sizes for these comparisons were either small or very small ($\eta_p^2 = .010$ and $.001$).

4.1. Synthesis of present and prior findings

The present findings may aid in interpretation of prior reports on discounting in EC users and non-users. The smaller effect size for EC compared to cigarette use was significant in the present study's multi-factorial, large N design, which included daily/almost daily EC users, but may not be consistently evident in studies examining smaller sample sizes, infrequent and likely subclinical EC users, or only select subgroups of EC users (e.g., former smokers). Specifically, in the present study, only dual users (i.e., current EC users/current smokers) and exclusive smokers (i.e., never EC users/current smokers) showed significantly greater discounting than the never-using control group. In contrast, exclusive EC users (i.e., former smokers who had transitioned to exclusive EC use) did not differ significantly from either exclusive smokers or never-using controls. This finding is very similar to the data reported by Weidberg et al. (2017), in which discounting in EC users (some or all of whom were former smokers) was intermediate between discounting in current and never smokers, and not significantly different than either. This intermediate status suggests that EC use may facilitate smoking cessation in individuals who are concerned about their future health enough to quit smoking cigarettes, but are either unable or unwilling to stop using nicotine entirely.

However, somewhat contrary to these data, Bialaszek et al. (2017) reported that EC users and cigarette smokers both differed significantly from, and approximately equally by visual comparison, a never-using control group. Here, we note that smokers in Bialaszek et al.'s study showed minimal dependence (mean FTCD score: 2, or "very low" dependence; Fagerstrom et al., 1992). Due to the moderating role of dependence in delay discounting described previously (see Amlung et al., 2017; MacKillop et al., 2011), recruitment of minimally dependent cigarette smokers in the study by Bialaszek et al. may have attenuated differences in discounting compared to both never smokers and EC users. Alternatively, Bialaszek et al.'s findings may be the result of differing regulatory environments or other factors in Poland, where the study was conducted, compared to Spain (Weidberg et al., 2017) or the United States (present study, Chivers et al., 2016). This may highlight the need to compare findings from multiple countries simultaneously, including prevailing health risk perceptions, in examinations of EC use. Among extant data, however, Bialaszek et al.'s findings remain the outlier on this topic and perhaps the result of unexamined and/or uncontrolled demographic or other variance.

4.2. Delay discounting, EC use, and perceived health risks

Convergent cross-sectional (e.g., Bickel et al., 1999), longitudinal (Audrain-McGovern et al., 2009; Sheffer et al., 2014; Yoon et al., 2007), and experimental (Chiou and Wu, 2017; Stein et al., 2017, 2016) evidence demonstrate a robust association between delay

discounting and cigarette smoking. These data are mirrored by complementary findings in which a present-oriented time perspective, or a tendency to act in one's immediate self-interest, were associated with greater cigarette smoking, weaker intentions to quit smoking, fewer quit attempts, and reduced success in quitting (Hall et al., 2012, 2014; Sansone et al., 2013). Collectively, these data support the hypothesis that those who discount the future rapidly are more likely to use tobacco because they fail to integrate their present behavior with the delayed, otherwise aversive, health consequences of tobacco use. To some extent, the present study extends this hypothesis to include EC use, although differences in discounting related to EC use were again smaller than for cigarettes.

These smaller effect sizes may be due to widespread public perception of ECs as a safer alternative to cigarettes (e.g., Huerta et al., 2017; Wagner et al., 2017). That is, because many consumers believe ECs pose fewer health risks than cigarettes, the decision to use ECs (compared to cigarettes) is less clearly an intertemporal choice between immediate gratification and delayed, negative health consequences. As a result, rapid devaluation of the future may be less influential in promoting EC compared to cigarette use.

In contrast, relatively greater valuation of future health among existing smokers appears to some extent to promote transition to these putatively safer products (Berg, 2016; Brown et al., 2014; Hong et al., 2017), which would likely serve to minimize group differences in discounting between those who do and do not use ECs. Indeed, discounting in former smokers in the present study, regardless of whether they were current or never EC users, was statistically undifferentiated from discounting in a never-using control group (i.e., never EC users/never smokers). Although we observed ordinal differences in discounting between these groups, such differences were small ($\eta_p^2 = .001-.010$) and likely of minimal clinical relevance. This, combined with additional prior findings of undifferentiated discounting in non-EC using former and never smokers (Bickel et al., 1999; Weidberg et al., 2017), suggests that cigarette smokers who value the future more than their cohorts are more likely to quit smoking, either by total nicotine cessation or transition to ECs, and thus become former smokers. This interpretation of the data is further supported by studies in which greater delay discounting in groups of current smokers were cross-sectionally associated with weaker desire to quit smoking (Athamneh et al., 2017) and prospectively associated with greater relapse in smoking cessation treatment (Sheffer et al., 2014; Yoon et al., 2007), indicating that the relationship between discounting and smoking cessation predates nicotine abstinence. Future investigations may wish to extend the findings reported in the present study by examining whether intention to quit smoking cigarettes or using ECs interacts with current cigarette or EC use status to influence measures of delay discounting. For example, among dual EC/cigarette users, those with greater intention to quit smoking cigarettes may show lower levels of delay discounting.

4.3. Discounting as cause or consequence of tobacco use

Although we have focused on the hypothesis that discounting plays an etiological role in tobacco use, other hypotheses may also account for the present study's findings. For example, human and nonhuman data suggest that nicotine exposure increases delay discounting (Dallery and Locey, 2005; Perry and Carroll, 2008; Secades-Villa et al., 2014;

Yi et al., 2008). Thus, chronic nicotine consumption itself may be responsible for elevated discounting in current EC users compared to never EC users, as well as in current smokers compared to former and never smokers (Bickel et al., 1999; Weidberg et al., 2017). As a result, we note that the association between delay discounting and cigarette smoking or EC use does not confirm, but only suggests, that discounting plays an etiological role in tobacco use.

We emphasize, however, that these two hypotheses are not mutually exclusive and that elevated delay discounting may at once be a cause and consequence of tobacco use (for review, see Perry and Carroll, 2008). Specifically, discounting and tobacco use may participate in a feedback circuit in which elevated discounting predisposes individuals to initiate use (Audrain-McGovern et al., 2009) and, in turn, drug toxicity or other factors related to nicotine consumption exacerbate pre-existing dysfunction (e.g., Secades-Villa et al., 2014). Moreover, additional input into the system may further worsen clinical outcomes. For example, acute nicotine deprivation has been shown to increase delay discounting (Field et al., 2006; Heckman et al., 2017). Thus, state-dependent increases in discounting during quit attempts may further devalue the long-term benefits of smoking cessation and therefore hasten relapse (Sheffer et al., 2014; Yoon et al., 2007). Further work should strive to disambiguate these various accounts.

4.4. Dual product use and delay discounting

Although effect sizes for differences in discounting related to EC use were generally small, the difference in discounting between dual users (i.e., current EC users/current smokers) and never-using controls (i.e., never EC users/never smokers) was much larger ($\eta_p^2 = .068$; a medium effect). Indeed, this effect size was more than double that observed for the difference between exclusive smokers (i.e., never EC users/current smokers) and never-using controls ($\eta_p^2 = .031$; a small-medium effect). Thus, although discounting in dual EC/cigarette users and exclusive smokers did not differ significantly from each other, the difference in effect sizes compared to never-using controls suggests that discounting is more strongly associated with dual EC/cigarette use than exclusive smoking.

This greater effect size in dual users in the present study is likely a reflection of the moderating role of degree of tobacco product dependence (see Amlung et al., 2017; MacKillop et al., 2011). That is, dual EC/cigarette users showed greater tobacco product dependence than exclusive smokers (i.e., never EC users/current smokers), as dependence measures in dual users may be described additively (i.e., EC dependence plus cigarette dependence; see Table 2). In contrast, tobacco product dependence in exclusive smokers was restricted to cigarettes. Thus, larger effect sizes in comparisons of dual EC/cigarette users to never-using controls may simply reflect greater tobacco product dependence in dual users. On this topic, any group of dual EC/cigarette users is likely to comprise those who are using ECs for smoking cessation as well as others who are likely more dependent and are using ECs for other reasons (e.g., to circumvent smoking bans). Thus, following a group of dual users longitudinally to determine whether delay discounting at baseline predicts who transitions to exclusive EC use may be informative.

4.5. Limitations

A few potential limitations of the present study deserve note. First, we did not examine EC users who had never smoked cigarettes, thus, we were unable to quantify delay discounting in relation to EC use independent of current or former cigarette use. Inclusion of this group in future work may reveal findings that were not apparent here (e.g., interactions between EC and cigarette use). However, at present, EC users such as these appear rare (Chivers et al., 2016; Sutfin et al., 2013; Vickerman et al., 2013) and thus the clinical relevance of such an investigation may be limited, at least among adults. Among adolescents, such users may be more common (Wills, 2017) and future work should specifically examine discounting in this population.

Second, we were unable to use biochemical verification of EC/cigarette use (e.g., cotinine) due to the use of online data collection. Use of laboratory-based data collection may have corroborated and increased the accuracy of self-report. Nonetheless, we replicated findings from prior studies that used biochemical verification, which partially mitigates this concern (Bickel et al., 1999; Weidberg et al., 2017). Moreover, use of Amazon Mechanical Turk, a crowdsourcing platform shown previously to yield high quality data that replicate a broad range of laboratory-based phenomena (for review, see Paolacci and Chandler, 2014), allowed use of larger sample sizes of cigarette and EC users than those in most prior studies, which may increase the strength of our findings. This advantage notwithstanding, Mechanical Turk samples tend to be younger, more highly educated, and less employed than the general population (Paolacci and Chandler, 2014). Thus, future studies may wish to employ more representative samples to examine the generality of the findings reported here and in prior studies (Białaszek et al., 2017; Chivers et al., 2016; Weidberg et al., 2017).

Finally, we did not measure possible comorbid substance use and were therefore unable to quantify possible covariance between co-morbid substance use, EC or cigarette use, and delay discounting. Perhaps cigarette users or EC users were more likely to also use other substances than never users, which may have been responsible for related group differences. Future studies should examine this possibility more thoroughly. However, we note that this possible effect of co-morbid substance use is unlikely, given previous reports of significantly elevated discounting in current smokers compared to non-smokers in studies that either controlled for comorbid substance statistically (e.g., Reimers et al., 2009) or by matching smoking and non-smoking samples on levels of substance use (e.g., Reynolds et al., 2009).

4.6. Conclusions

Current EC users discount the future more than those who have never used ECs. However, effect sizes for EC use were smaller than those observed for cigarette use and not statistically apparent in all pairwise comparisons between groups. For example, those who achieve smoking cessation by transitioning to ECs were undifferentiated from never-using controls.

In general, the smaller effect size observed for EC compared to cigarette use suggests that widespread public perception of ECs as a safer alternative to cigarettes attenuates the role of delay discounting, relative to cigarettes, in decisions to use ECs. However, recent data

suggest that perceptions of ECs' relative safety are on the decline (Huerta et al., 2017; Majeed et al., 2017). If such a trend continues, then future investigations may reveal that the effect size for differences in discounting related to EC use will begin to resemble that observed for cigarette smoking.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Fig. 1.
Flowchart describing study screening, enrollment, completion, and data analysis.

Fig. 2. Significant main effects of EC use (left panel; $p < .05$), cigarette use (middle panel; $p < .001$), and reward magnitude (right panel; $p < .001$) on covariate-adjusted discount rate ($\ln \kappa$; $\pm 95\%$ CI).

Fig. 3.

Covariate-adjusted discount rate ($\ln k$, $\pm$ 95% CI), by EC and cigarette use. Superscripts represent significant difference in planned comparisons: ^adifferent than former smokers within the same EC use group ($p < .01$); ^bdifferent than former smokers in the opposite EC use group ($p < .001$); ^cdifferent than never EC users/never smokers ($p < .001$).

Table 1

Demographic characteristics.

Cigarette use	Current		Former		Never	<i>P</i>
EC use	Current	Never	Current	Never	Never	
<i>n</i>	197	198	197	198	182	
Mean age (± SD)	33.72 (10.12)	39.41 (11.28)	35.83 (10.18)	44.90 (12.64)	34.20 (11.74)	< .001
Household income ^a						
% Low income	45.18	47.98	37.06	33.33	43.96	.016
% Middle income	47.71	43.94	54.31	52.53	46.70	
% High income	7.11	8.08	8.63	14.14	9.34	
Education						
% High school/GED or lower	18.78	21.21	20.31	15.66	8.24	< .001
% Some college	45.18	44.95	52.79	38.38	35.17	
% College degree or higher	36.04	33.84	26.90	45.96	56.59	
Gender						
% Female	51.27	66.16	50.76	66.66	58.79	< .001
% Male	48.22	33.84	48.73	33.33	41.21	
% Transgender	0.51	0.00	0.51	0.00	0.00	
Race						
% White	81.73	83.33	88.83	90.40	75.27	< .001
% Black/African American	10.66	7.58	4.57	5.05	11.54	
% Other	7.61	9.09	6.60	4.55	13.19	
Ethnicity						
% Hispanic	8.63	5.56	5.58	5.05	7.69	.438
% Non-Hispanic	91.37	94.44	94.42	94.95	92.31	

EC e-cigarette; *GED* general equivalency diploma.

^aHousehold income strata were based on similar criteria defined previously (Pew Research Center, 2016; Semega et al., 2017), in which low, middle, and high income refers to ranges of < \$40,000, \$40,000-\$125,000, and > \$125,000, respectively.

Table 2

EC/cigarette use characteristics.

Cigarette use		Current		Former		Never		<i>P</i>
EC use		Current		Current		Never	Never	
<i>n</i>		197	198	197	198	198	182	
EC use								
Median uses/day (± IQR)		15 (8, 25)	-	30 (15, 50)	-	-	-	< .001
Median puffs/use (± IQR)		5 (3, 7)	-	4 (2, 6)	-	-	-	< .001
Median puffs/day (± IQR)		60 (31, 136)	-	96 (50, 198)	-	-	-	< .001
Mean FTED score (± SD)		4.95 (2.47)	-	5.56 (2.24)	-	-	-	.011
Median nicotine strength (mg/mL; ± IQR)		12 (6, 18)	-	6 (3, 12)	-	-	-	< .001
Median months of use (± IQR)		24 (12, 38)	-	21 (10, 36)	-	-	-	.104
Usual EC device type								
% 1 st generation		21.82	-	13.20	-	-	-	.024
% new generation ^a		78.17	-	86.80	-	-	-	
Cigarette use								
Mean cigarettes/day ^b (± SD)		15.80 (9.32)	15.67 (7.05)	18.74 (10.88)	18.21 (12.13)	-	-	< .001
Mean FTCD score ^b (± SD)		5.41 (2.16)	4.56 (1.95)	5.61 (2.09)	4.94 (2.46)	-	-	< .001
Median months of use ^b (± IQR)		179 (111, 242)	249 (169, 347)	203 (135, 289)	311.50 (213, 433)	-	-	< .001
Median months abstinent (± IQR)		-	-	19 (6, 38)	60 (24, 141)	-	-	< .001

EC e-cigarette; FTCD Fagerström Test for Cigarette Dependence; FTED modified Fagerström Test for EC dependence.

^aNew-generation devices refer to second- and third-generation devices, combined.^bValues for former smokers reflect prior cigarette use/dependence.

Table 3

Results of ANCOVA examining group differences in delay discounting.

	<i>F</i> (df)	<i>P</i>	η_p^2
EC use	5.59 (1, 962)	.018	.006
Cigarette use	13.02 (2, 962)	<.001	.026
Magnitude	17.10 (1, 962)	<.001	.019
EC use $\times$ cigarette use	0.05 (1, 962)	.821	.000
EC use $\times$ magnitude	0.22 (1, 962)	.638	.000
Cigarette use $\times$ magnitude	0.06 (2, 962)	.944	.001
EC use $\times$ cigarette use $\times$ magnitude	0.13 (1, 962)	.720	.000
Age	4.72 (1, 962)	.030	.005
Income	23.18 (1, 962)	<.001	.024
Education	11.78 (1, 962)	.001	.012
Gender	7.79 (1, 962)	.005	.008
Race	0.01 (1, 962)	.907	.000

EC e-cigarette.