Brief Report

Impact of E-cigarette Sampling on Cigarette Dependence and Reinforcement Value

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Abstract

Introduction: E-cigarettes have risen in prevalence in recent years, and most public health experts agree they deliver fewer toxicants than combustible tobacco products such as cigarettes. Thus, it is important to understand how use of e-cigarettes by current smokers impacts dependence on combustible cigarettes.

Methods: The present study is a secondary analysis of a randomized pilot trial of e-cigarette sampling. Nontreatment seeking current smokers were randomized in a 2:1 ratio to either receive or not receive a weekly supply of e-cigarettes for 3 weeks. Participants completed the Brief Wisconsin Inventory of Smoking Dependence Motives (WISDM) scale and the cigarette purchase task before and after the sampling period and at monthly follow-up visits for 3 months.

Results: Individuals assigned to receive an e-cigarette had significantly lower mean WISDM scores at the end of sampling and the end of the follow-up period compared with those in the control group. Both frequency of e-cigarette use as well as nicotine concentration of the e-cigarette given to smokers were significant predictors of changes in the mean WISDM score. E-cigarette sampling significantly reduced the demand parameter O_{max} , which measures the maximum amount of money participants estimate they would spend on cigarettes in a single day.

Conclusions: These data suggest that current smokers who try using an e-cigarette may experience reductions in dependence on combustible cigarettes.

Implications: The present analysis suggests that providing an e-cigarette to current cigarette smokers is likely to reduce cigarette dependence, especially if the e-cigarette delivers sufficient nicotine and is used frequently.

Introduction

E-cigarette use has risen in prevalence in recent years,^{1–3} and most reports suggest that they deliver fewer toxicants than cigarettes.^{3,4} Most experts agree that the public health impact of e-cigarettes is likely to depend on whether they increase or decrease the prevalence of combustible cigarette use.³ Among current smokers, some research suggests that e-cigarettes, especially those that deliver nicotine effectively, can aid in smoking cessation and reduce rates of smoking

even among those who do not quit.^{5–8} However, some researchers have argued that e-cigarettes can delay quitting and reduce quitting success by diverting smokers away from using more effective stop smoking treatments.⁹

The impact of e-cigarettes on public health may also depend on whether their use reduces the reinforcement value of, and dependence on, cigarettes. If e-cigarette use decreases dependence on cigarettes, smokers may find it easier to quit smoking when motivated to do so or be more sensitive to traditional tobacco control efforts

like smoking taxation or clean indoor-air laws. Observational studies have reported that smokers who begin using e-cigarettes have reduced dependence on combustible cigarettes.¹⁰ However, no randomized controlled trials of e-cigarettes have reported on the impact of e-cigarette use on smoking dependence. Thus, the goal of the present analysis was to explore whether more frequent e-cigarette use lowers smoking dependence and the reinforcement value of cigarettes. Cigarette dependence was assessed using the Brief Wisconsin Inventory of Smoking Dependence Motives (WISDM) which *does not* include any items related to smoking rate (ie, cigarettes per day). The WISDM has previously been found to be a reliable measure that is related to other dependence measures and predictive of smoking abstinence in smoking cessation trials.^{11,12} Reinforcement value was measured using the cigarette purchase task (CPT), which asks smokers about their willingness to purchase cigarettes at different prices. Although tobacco dependence and reinforcement value are distinct constructs, dependence is likely driven, in part, by reinforcement value.^{13,14} Demand parameters derived from the CPT have been shown to be correlated with measures of tobacco dependence and treatment motivation.^{15,16}

Methods

The present analysis utilized data collected as part of a randomized trial; full methods are presented elsewhere.⁵ Briefly, nontreatment seeking adults smoking at least five cigarettes per day were assigned in a 2:1 ratio to either receive or not receive a supply of e-cigarettes over a 3-week period. Participants had minimal prior e-cigarette experience. Participants attended a baseline visit, three weekly visits during sampling, and three monthly follow-up visits.

Participants assigned to the sampling group received a weekly supply of BluCig, a disposable e-cigarette and the most popular e-cigarette product on the market at the time of the study. Participants could choose between tobacco and menthol flavors. The nicotine concentration of the BluCig was changed during the study from 16 mg/mL (25 participants) to 24 mg/mL (21 participants). Participants were instructed that the e-cigarette product could be used “as you wish, to cut down or quit smoking, help manage smoking restrictions, or both. It is entirely up to you if and how you use this product.”

Relevant to this study, participants completed the Brief-WISDM¹⁷ at baseline, the end of the sampling, and each of the follow-up visits. The 37-items in the Brief-WISDM comprise 11 subscales, four of which are considered to be most closely related to dependence (ie, primary dependence motives: automaticity, loss of control, craving, and tolerance), and the remaining seven of which may be important, but less so (ie, secondary dependence motives: affiliative attachment, cognitive enhancement, cue exposure, social and environmental goals, taste, weight control, and affective enhancement). The CPT¹⁶ was completed at all visits and asked participants to estimate the number of cigarettes they would smoke in a typical day across price points and to assume that they had no access to any other cigarettes or nicotine products (FREE, \$0.01, \$0.05, \$0.10, \$0.15, \$0.20, \$0.25, \$0.30, \$0.35, \$0.40, \$0.45, \$0.50, \$0.60, \$0.70, \$0.80, \$0.90, \$1.00, \$2.00, \$3.00, \$4.00, \$5.00). Participants also reported their e-cigarette use at each in-person visit using the timeline followback.¹⁸

Data Analysis

Analyses examined whether e-cigarette sampling, use frequency, and nicotine concentration impacted WISDM scores and demand

parameters. Generalized Estimating Equation (GEE) analyses were used to test the impact of sampling (vs. control), time (visit), and their interaction after controlling for the relevant outcome at baseline. The sampling group was divided between those who self-reported daily e-cigarette use during the last week of sampling and those who did not. Additional models tested (1) the impact of e-cigarette frequency (daily, nondaily, control group), time (visit), and their interaction after controlling for baseline and (2) the impact of e-cigarette nicotine concentration (low, high, control), time (visit), and their interaction after controlling for baseline. QIC scores were used to assess whether the nicotine concentration or e-cigarette frequency model was a better fit, with smaller scores indicating better fit. For each model, in the case of significant group differences, we tested differences between groups at individual timepoints. Type 1 error rate was 0.05. When omnibus tests were not significant, no follow-up tests were conducted.

Breakpoint was defined as the highest price at which participants reported they would continue to smoke, O_{max} was the maximum amount of money participants reported they would spend on cigarettes in a single day across all prices, P_{max} was the price that produced O_{max} , and Intensity was the number of cigarettes participants reported they would smoke if they were free. To estimate elasticity (α), reported number of cigarettes per day across all prices more than \$0.00 was fit to an exponential equation¹⁹:

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

A small number of outlier observations were removed from individual parameters (O_{max} , >\$75.00; Intensity, >90 CPD; α , > 0.2; each ~1% of observations).

For the demand analysis, observations were excluded when their data did not conform to an exponential curve.²⁰ Specifically, observations were excluded when the number of cigarettes participants estimated they would smoke increased from one price to the next by more than 10 cigarettes and more than 100% of the previous price (three observations), the number of cigarettes a participant reported they would smoke was the same across all prices (22 observations), and a participant reported that they would smoke zero cigarettes at all prices more than \$0.00 (23 observations).

Excluding observations where participants reported they would smoke zero cigarettes at all prices may bias analyses against observing changes for the sampling group (ie, it excludes those who quit smoking). A Fisher-exact test was used to test whether the likelihood of falling into this category was significantly different between the two groups at the end of sampling. A sensitivity analysis was also conducted for each parameter in which the most extreme possible value was inserted for each of these observations (Breakpoint, O_{max} , P_{max} , and Intensity = 0; α = 0.2). Results from this analysis are reported here when different from the primary analysis. To understand whether this subset of participants drove observed differences between groups in the WISDM, a sensitivity analysis was conducted in which these observations were excluded from WISDM analyses. Results from this analysis were generally similar to the primary analysis in which all participants were included and thus are not reported here for simplicity.

Results

Sixty-five participants were randomized and completed at least one additional visit (44 sampling, 21 control). Of those that received the low concentration e-cigarette and completed the timeline followback for the last week of sampling, 11 reported nondaily e-cigarette use,

and 12 reported daily e-cigarette use. Of those that received the high concentration e-cigarette and completed the timeline followback for the last week of sampling, five reported nondaily e-cigarette use, and 15 reported daily e-cigarette use. Changes in e-cigarette use, cigarette use, independent e-cigarette purchasing, and quitting are reported in the primary paper for this trial.⁵

Impact of E-cigarette Sampling on Cigarette Smoking Dependence Motives

There was a significant effect of sampling and a significant interaction between sampling and time on total WISDM. Follow-up tests revealed that the sampling group had significantly lower WISDM scores than the control group at the end of sampling, the 2-month follow-up, and the 3-month follow-up. There was a similar pattern present for many of the WISDM subscales, with significant effects of group for the primary dependence motives, secondary dependence motives, affiliative attachment, loss of control, cognitive enhancement, craving, social and environmental goads, and tolerance subscales. As shown in Figure 1A, the impact on total WISDM was largest among those who used the e-cigarette daily. There was a significant effect of frequency, time, and a significant frequency $\times$ time interaction. Follow-up tests revealed that the daily group had significantly lower scores than the control group at the 2-month follow-up, and the daily group had lower scores than the control group at the end of sampling, 2-month follow-up, and the 3-month follow-up. WISDM scores were significantly lower for the daily group than the nondaily group at the 3-month follow-up. As shown in Figure 1B, the differences in WISDM were also larger among the participants who received the e-cigarette with a higher nicotine concentration. There was a significant effect of concentration, time, and a significant concentration $\times$ time interaction. Follow-up tests revealed that the low concentration group had significantly reduced WISDM scores compared with the control group at the 2-month follow-up, but the high concentration group had significantly reduced WISDM scores compared with the control group at the end of sampling, 2-month follow-up, and the 3-month follow-up. The high and low concentration groups were not significantly different from each other at any timepoints. The model that included e-cigarette frequency provided a better fit than the model that included nicotine concentration.

Impact of E-cigarette Sampling on the Reinforcement Value of Cigarettes

At baseline, all participants reported they would purchase and smoke cigarettes for at least one price more than \$0.00. At all other timepoints, a subset of participants reported they would not purchase or smoke cigarettes at prices more than \$0.00. The proportion of participants falling into this subset was not significantly different between groups at the end of sampling: 6 (of 43) in the sampling group, 0 (of 19) in the control group ($p = .16$).

The impact of e-cigarette sampling on demand parameters was less robust than the impact on WISDM score. There was no effect of sampling, time, or interaction on breakpoint or P_{max} , nor was there any impact of e-cigarette frequency or nicotine concentration. For Intensity, there was a significant sampling $\times$ visit interaction, but group differences failed to reach significance on follow-up tests at any timepoint. There was also a significant e-cigarette frequency $\times$ visit interaction, but again there were no significant differences between groups on follow-up tests at any of the timepoints. The model that included nicotine concentration showed a significant

effect of visit but no effect of nicotine concentration or interaction. For α , there was a significant sampling $\times$ visit interaction, but the groups were not significantly different at any timepoint. There was not a significant effect of e-cigarette frequency, visit, or interaction on α . There was a significant nicotine concentration $\times$ visit interaction, but the groups were not significantly different at any timepoint. When individuals who reported they would smoke 0 cigarettes at all prices more than \$0.00 were included in the analysis using an α value of 0.2, there was a significant e-cigarette frequency $\times$ visit interaction, and follow-up tests revealed that the daily group had significantly higher α scores than both the nondaily group and the control group at the week 2 visit and the end of sampling. For O_{max} , there was a significant effect of sampling but no effect of visit or interaction. Follow-up tests revealed that the sampling group had lower O_{max} scores than the control group at the week 2 visit, 1-month follow-up, 2-month follow-up, and 3-month follow-up. There was a significant effect of frequency group, but no effect of visit or interaction effect. Follow-up tests revealed that the daily group had significantly lower O_{max} scores than the control group at the week 2 visit, 1-month follow-up, 2-month follow-up, and the 3-month follow-up, but the nondaily group only had significantly lower O_{max} scores than the control group at the week 2 visit, and the daily and nondaily groups were not significantly different at any timepoint. There was also a significant effect of nicotine concentration but no effect of visit or interaction effect. Follow-up tests revealed that the high concentration group was significantly different than the control group at the week 2 visit, 1-month follow-up, 2-month follow-up, and the 3-month follow-up, but the low concentration group was only significantly different than the control group at the week 2 visit and the 2-month follow-up. The high and low concentration groups were not significantly different at any timepoints.

At baseline, total WISDM score was significantly correlated with α ($r = -0.33$, $p < .01$), but this relationship failed to reach significance at the end of sampling ($r = -0.19$, $p = .17$). Intensity was not significantly correlated with total WISDM score at baseline ($r = 0.16$, $p = .23$), but the two measures were significantly correlated at the end of sampling ($r = 0.39$, $p < .01$). Breakpoint, P_{max} , O_{max} , were not significantly correlated with total WISDM at either baseline or the end of sampling.

Discussion

Sampling of an e-cigarette reduced dependence on cigarettes as measured by the Brief WISDM, and this effect was significant at more timepoints for individuals provided with a higher nicotine concentration e-cigarette and for participants who used the e-cigarette daily. These data are encouraging in that they suggest that current smokers who try e-cigarettes may experience a reduction in dependence on combustible cigarettes. Not surprisingly, using the e-cigarette more often is likely to result in greater reductions in nicotine dependence. Choosing an e-cigarette that delivers sufficient nicotine may be important in determining whether that product effectively substitutes for cigarettes. The changes in cigarette dependence observed here were sustained past the sampling period. As reported in the primary paper, 57% of sampling participants who received the high concentration e-cigarette and 28% of sampling participants who received the low concentration e-cigarette made an independent purchase of the e-cigarette,⁵ so use of these products after the sampling period ended may have contributed to the changes in WISDM observed during the follow-up period.

Figure 1. The impact of e-cigarette use frequency (A) and nicotine concentration (B) on changes in WISDM score. Significant differences between groups at individual timepoints are indicated on the figure.

The impact of e-cigarette sampling on demand parameters was less robust than the impact on WISDM scores. Demand parameters were likely less sensitive to the impact of e-cigarette sampling because the CPT instructions asked participants to imagine that they did not have access to any other nicotine products. Thus, while e-cigarette sampling may reduce dependence on cigarettes, the CPT results suggest that the reinforcement value of and dependence on nicotine may be largely unchanged. If e-cigarettes were suddenly unavailable, individuals who have switched from cigarettes to e-cigarettes may switch back because cigarettes still hold high reinforcement value in this context. These data are consistent with other dependence interventions. In a recent clinical trial, participants provided with very low nicotine content cigarettes for 6 weeks reported reduced FTND and WISDM scores at the end of the trial, but the reinforcement value of usual brand cigarettes remained unchanged if participants were told to imagine that usual brand cigarettes were the only product available.²⁰

This trial has several limitations. First, participants in the sampling group were provided with an e-cigarette product free of charge, which may have inflated use. Second, all e-cigarettes used here contained nicotine, which eliminates the ability to fully disentangle the pharmacological and sensory impact of e-cigarette use on changes in cigarette dependence.

Third, the product used in this trial was a first-generation e-cigarette product. Later generation products more effectively deliver nicotine and suppress craving to smoke.^{21,22} Given that frequent e-cigarette use appears to be important for producing changes in cigarette dependence, it is likely that enjoyment and satisfaction with the product may be a critical determinant of whether someone uses the e-cigarette frequently and experiences reductions in dependence on and use of cigarettes. Thus, future studies should investigate other individual- or product-level characteristics that are predictive of e-cigarette enjoyment and satisfaction.

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Declaration of Interests

K. M. C. reports receiving a commercial research grant from and is a consultant/advisory board member for Pfizer Inc and has provided expert witness testimony for various plaintiffs in lawsuits involving cigarette manufacturers. No other conflicts of interest were disclosed by the other authors.

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