Addictive Behaviors 48 (2015) 1–4

Contents lists available at ScienceDirect

Addictive Behaviors

Short Communication

Changes in puffing behavior among smokers who switched from tobacco to electronic cigarettes

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HIGHLIGHTS

- Nicotine intake from e-cigarette has been shown to increase with experience.
- We assessed puffing behavior after switching from tobacco to electronic cigarettes.
- E-cigarette puffing behavior differed significantly between participants.
- Smokers modified their puffing behaviors after switching to e-cigarettes.
- Smokers took longer puffs and puffed slower after one week of e-cigarette use.

ARTICLE INFO

Available online 16 April 2015

Keywords:
Electronic cigarettes
E-cigarettes
Puffing topography
Nicotine
Compensation
Vapor

ABSTRACT

Introduction: Nicotine intake from electronic cigarette (e-cigarettes) increases with user's experience. This suggests that smokers who switched from tobacco to electronic cigarettes compensate for nicotine over time to get as much nicotine as they need. One of the mechanisms by which smokers may compensate for nicotine is by modifying their puffing behavior. The aim of the study was to assess the changes in puffing behavior after switching from conventional to electronic cigarettes among regular smokers.
Materials and methods: Twenty smokers (11 female, aged 31 ± 10, CPD 16 ± 8, FTND 4 ± 3, and exhaled CO 16 ± 17 (mean ± SD)) who were naïve to e-cigarettes participated in this study. They were asked to substitute their regular tobacco cigarettes with first generation e-cigarettes (labeled 18 mg nicotine) for two weeks. Puffing topography (number of puffs, puff volume, intervals between puffs, and average puff flow rate) was measured at the initial use (baseline), as well as after one and two weeks of product use. We tested changes in puffing topography outcomes using repeated measures ANOVA.
Results: We found that after one week of using e-cigarettes, participants significantly increased the average time they puffed on e-cigarettes from 2.2 ± 0.1 (mean ± SEM) to 3.1 ± 0.3 s ($p < 0.05$). The average puff flow rate decreased from 30.6 ± 2.3 to 25.1 ± 1.8 ml/s after one week of e-cigarette use ($p < 0.05$).
Conclusions: Our data show that smokers modify their puffing behavior after switching from tobacco to electronic cigarettes by taking longer and slower puffs. The potential reason for changing puffing behavior is to compensate for less efficient nicotine delivery from e-cigarettes.

1. Introduction

Electronic cigarettes (e-cigarettes) are promoted as an alternative product to conventional tobacco cigarettes (Hajek, Etter, Benowitz, Eissenberg, & McRobbie, 2014a). The use of e-cigarettes has been increasing rapidly around the world, especially among tobacco cigarette smokers and young people (Carroll Chapman & Wu, 2014). E-cigarettes are battery-driven devices which vaporize nicotine solutions in a form of inhalable aerosol. These products contain tobacco-derived nicotine and flavorants such as tobacco, menthol, fruit, and coffee. Nicotine, flavorants and other additives are dissolved in propylene glycol, glycerin or a mixture of both substances. There is a consensus among researchers and public health advocates that e-cigarettes are less harmful to individual users and bystanders than tobacco cigarettes since e-cigarettes contain fewer hazardous chemicals than conventional cigarettes (Cahn & Siegel, 2011; Goniewicz et al., 2014; Grana, Benowitz, & Glantz, 2014; Gualano et al., 2014).

Nicotine is the primary pharmacologically active substances in e-cigarettes. It is responsible for addictiveness of tobacco products and

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http://dx.doi.org/10.1016/j.addbeh.2015.04.003
0306-4603/

administration of nicotine from other sources than tobacco cigarettes has been shown to alleviate withdrawal symptoms among abstinent smokers (Benowitz, 2010). Studies have shown that vapor generated from e-cigarettes contain variable yields of nicotine (Goniewicz, Hajek, & McRobbie, 2014; Goniewicz, Kuma, Gawron, Knysak, & Kosmider, 2013). It has been shown that e-cigarettes can deliver nicotine effectively to blood while reducing exposure to combustion toxicants and carcinogens among their users (Farsalinos et al., 2014; Goniewicz, Hajek, & McRobbie, 2014; Goniewicz, Knysak, et al., 2014; Vansickel & Eissenberg, 2013).

The nicotine delivery from e-cigarettes is likely to play a major role in the patterns of product use among smokers who are interested in substituting their regular cigarettes with safer alternatives. Some pharmacokinetic studies on e-cigarettes revealed that nicotine intake from the devices on initial use is lower compared to tobacco cigarettes (Eissenberg, 2010; Hajek et al., 2014b). However, studies on long-term e-cigarette users found that those users who have significant experience with these devices actually can achieve plasma nicotine levels similar to levels observed among smokers (Farsalinos et al., 2014; Vansickel & Eissenberg, 2013). Our group has also shown that nicotine uptake from e-cigarettes increases with practice (Hajek et al., 2014b). Using pharmacokinetic data from six smokers, we found that 4 weeks of practice generated a 24% increase in the peak plasma concentrations and a 79% increase in overall nicotine intake when compared to initial e-cigarette use. The studies cited above suggest that although e-cigarettes may deliver less nicotine than conventional cigarettes but that intake may improve with practice. At this time, it remains unclear how smokers increase nicotine intake over time. It has been suggested that there is a 'learning period' during which naïve users learn how to puff on e-cigarettes to get desired doses of nicotine (Hajek, Goniewicz, et al., 2014b; Norton, June, & O'Connor 2014). The aim of the study was to assess the changes in puffing behavior among adult smokers who were naïve to e-cigarettes and who switched from conventional to electronic cigarettes for two weeks.

2. Materials and methods

2.1. Subjects

Cigarette smokers willing to switch to potentially reduced exposure product to reduce their smoking were recruited from the Silesia metropolitan area in Poland using advertisements in campus, local media, and by word of mouth. A total of 20 adult smokers (11 female) who were naïve to e-cigarettes were recruited for the study. All participants were provided written informed consent. The average age of participants was 31 years (SD = 10, range 20–52). Participants smoked on average 16 tobacco cigarettes per day (SD = 8, range 5–35), for on average 13 years (SD = 7, range 5–35), the mean exhaled CO level was 16 ppm (SD = 17, range 3–85), and the average FTND score was 4 points (SD = 3, range 0–9).

2.2. Product

Participants were provided with the e-cigarette M201 type (Mild, Poland) with cartridges containing 11.0 ± 1.5 mg of nicotine as determined in a previous study (labeled 18 mg) (Goniewicz et al., 2013). Participants were also provided with 20 cartridges for one week of use, one spare battery, and a charger. Verbal and written instruction on how to use, recharge, and store the product were given to all participants.

2.3. Study protocol

Participants were asked to substitute their regular tobacco cigarettes with e-cigarettes for two weeks and refrain from smoking any combustible tobacco products. They were required to attend three clinic visits in the mornings on the same days of the week: during Day #1 (baseline), during Day #7 (Week 1), and during Day #14 (Week 2) of the study. Participants were asked to refrain from using e-cigarettes at least 8 h before each clinic visit. At each visit, subjects participated in an experimental puffing session during which they were asked to puff *ad lib* on e-cigarettes. They were allowed to take as many puffs as desired. Participants provided measures of puffing topography with CressMicro monitor with a connector for e-cigarettes (Borgwaldt Ltd., Germany). The topography monitor was calibrated before each puffing session using a piston-like smoking machine and a square-shaped puff profile. Measurement variables of puffing topography included number of puffs, puff volume, intervals between puffs, and puff flow rate. The study protocol was reviewed and approved by the IRB at the Medical University of Silesia, Poland.

2.4. Statistical analysis

To analyze the effect of experience with e-cigarette use on puffing behavior, we compared average puffing variables measured during initial e-cigarette use (baseline) with variables registered over two weeks (during the first and the second follow-up sessions). Statistical comparisons were performed using repeated measures ANOVA with Statistica 9.0 software (Statsoft, USA). Difference were considered significant if p-value was <0.05.

3. Theory

We hypothesized that smokers who switched from tobacco to electronic cigarettes compensate to get as much nicotine as they need. The compensation refers to adjustment of behaviors associated with product use in such a way that nicotine uptake remains the same. Compensatory behaviors have been studied among smokers who switched from cigarettes with high nicotine yields to low-nicotine (denicotinized) cigarettes (Hammond, Fong, Cummings, & Hyland, 2005; Kassel et al., 2007). These studies have shown that smokers compensate for nicotine by taking deeper puffs or puffing on cigarettes more frequently. Thus, we hypothesized that smokers who switch from tobacco cigarettes to e-cigarettes will also compensate for nicotine by modifying their puffing behavior.

4. Results

All subjects reported significant reduction in number of tobacco cigarettes smoked per day (on average from 16.2 to 0.6 CPD) and 8 subjects reported complete tobacco abstinence during the study. A substantial variability in puffing topography between smokers was found. Table 1 presents average puffing topography outcomes on initial use of e-cigarettes, as well as after one week and after two weeks of product use. Smokers took on average 19.3 ± 2.5 (3–40) (mean ± SEM (range)) puffs on initial e-cigarette use; 23.7 ± 2.4 (8–40; $p > 0.05$) puffs after one week; and 21.3 ± 2.4 (6–40; $p > 0.05$) puffs after two

Table 1
Puffing topography among 20 smokers who switched from tobacco to electronic cigarettes for two weeks.

	E-cigarette puffing topography (mean ± SEM, $n = 20$)		
	Initial use	After 1 week	After 2 weeks
Puff count (n)	19.3 ± 2.5	23.7 ± 2.4	21.3 ± 2.4
Interval between puffs (s)	19.2 ± 2.7	15.2 ± 2.2	22.1 ± 4.9
Puff volume (ml)	64.0 ± 4.8	66.5 ± 3.7	63.3 ± 5.2
Puff duration (s)	2.2 ± 0.1	3.1 ± 0.3*	2.9 ± 0.2*
Puff flow rate (ml/s)	30.6 ± 2.3	25.1 ± 1.8*	24.8 ± 1.9*

* Indicates significant change compared to initial use (repeated measures ANOVA; $p < 0.05$).