Brief Report

Puffing behavior during the smoking of a single cigarette in tobacco-dependent adolescents

Charles C. Collins, David H. Epstein, Craig S. Parzynski, Debra Zimmerman, Eric T. Moolchan, & Stephen J. Heishman

Abstract

Introduction: Adult and adolescent smokers regulate their nicotine and smoke intake by smoking low-yield cigarettes more intensely than high-yield cigarettes. One likely mechanism of nicotine regulation is altered puffing topography, which has been demonstrated in adult smokers. The purpose of this study was to examine the pattern of puffing behavior during the smoking of a single cigarette in adolescents.

Methods: Tobacco-dependent adolescents (n = 89) were enrolled in a treatment trial testing the efficacy of nicotine replacement therapy. About 1 week before their quit date, participants smoked *ad libitum* one of their usual brand of cigarettes during a laboratory session. Smoking topography measures included puff volume, puff duration, puff velocity, and interpuff interval.

Results: Controlling for sex, race, and number of puffs, puff volume and puff duration decreased 12.8% and 24.5%, respectively, from the first 3 to the last 3 puffs. Puff velocity and interpuff interval increased 14.8% and 13.5%, respectively. Puff volume was positively correlated with puff duration and puff velocity, whereas puff duration and puff velocity were negatively correlated. However, none of the topography measures were correlated with smoking history variables.

Discussion: These results suggest that adolescent smokers, like adults, are able to regulate smoke and nicotine intake on a puff-by-puff basis, therefore indicating that this aspect of smoking control is acquired early in the tobacco-dependence process.

Introduction

The initiation of tobacco use and the development of tobacco dependence typically occur during adolescence (U.S. Department of Health and Human Services, 1994). Every day in the United States, about 4,000 adolescents aged 12–17 years smoke their first cigarette, and 1,200 become daily smokers (Fiore et al., 2008). Smoking rates among youth declined from 1997 to 2003 but have since remained stable (Centers for Disease Control and Prevention, 2008).

The analysis of puffing and inhalation behaviors, known as smoking topography, has provided important information about the control of nicotine and tobacco constituent intake. For example, adult smokers regulate their nicotine and smoke intake over time by smoking low-yield cigarettes more intensely than high-yield cigarettes (Hammond, Fong, Cummings, & Hyland, 2005; Strasser, Lerman, Sanborn, Pickworth, & Feldman, 2007; Woodward & Tunstall-Pedoe, 1993). One likely mechanism of nicotine regulation is altered puffing behavior (Scherer, 1999). Such behavioral regulation is evident even during the smoking of a single cigarette; puff volume and duration decrease, and interpuff interval increases (Gust, Pickens, & Pechacek, 1983; Guyatt, Kirkham, Baldry, Dixon, & Cumming, 1989; Kolonen, Tuomisto, Puustinen, & Airaksinen, 1992).

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Although much is known about adult smoking regulation, fewer studies have evaluated adolescent smoking topography. Kassel et al. (2007) reported evidence for nicotine regulation by adolescents, who took more puffs from a low-yield than a high-yield nicotine cigarette. Franken, Pickworth, Epstein, and Moolchan (2006) found that smaller baseline puff volume predicted tobacco abstinence at the end of treatment and at 3-month follow-up. Several investigators have reported topography values averaged over the smoking of a single cigarette in adolescents. In general, puffing behavior (puff number, volume, and duration; interpuff interval) of adolescents (Corrigall, Zack, Eissenberg, Belsito, & Scher 2001; Franken et al.; Kassel et al.; Wood, Wewers, Groner, & Ahijevych, 2004; Zack, Belsito, Scher, Eissenberg, & Corrigall, 2001) is similar to that of adults (Brauer, Hatsukami, Hanson, & Shiffman, 1996; Eissenberg, Adams, Riggins, & Likness, 1999; Lee, Malson, Waters, Moolchan, & Pickworth, 2003).

We do not know whether the puffing behavior of adolescent smokers changes during the smoking of a single cigarette. If so, this would suggest that adolescents are able to regulate smoke and nicotine intake on a puff-by-puff basis. Based on data from adult smokers, we hypothesized that over a single cigarette, puff volume and duration would decrease and interpuff interval would increase.

Methods

Participants

We recruited adolescent cigarette smokers (n = 89) to participate in a placebo-controlled trial testing the safety and efficacy of nicotine replacement therapy combined with cognitive behavioral therapy (Moolchan et al., 2005). The Food and Drug Administration and the National Institute on Drug Abuse Institutional Review Board approved the protocol for adolescents smoking at least 10 cigarettes/day for 6 months and scoring ≥5 on the Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerström, 1991). Before the study, participants were given medical and psychiatric examinations and were interviewed about drug use and smoking history. Exclusion criteria were pregnancy, use of nicotine replacement in the last month, untreated psychiatric disorder, and drug (excluding nicotine) or alcohol dependence. Adolescents provided written informed assent, and parents or guardians provided written consent.

Procedure

About 1 week before their quit date, participants completed baseline assessments, including a smoking topography session. At the start of the session, participants gave a presmoking breath carbon monoxide (CO) sample. Average time from the last cigarette was 166.3 min (SD = 126.5). The computer-based topography system (Clinical Research Support System; Plowshare Technologies, Baltimore, MD) was located in a ventilated room. Participants smoked *ad libitum* one cigarette of their usual brand by placing it in a mouthpiece that was connected via tubing to a differential pressure transducer. For each puff, the topography system calculated puff number, puff volume, puff duration, interpuff interval, and mean puff velocity. Within 1–2 min after the end of smoking, participants gave a postsmoking CO sample.

Data analysis

Each dependent variable (puff duration, puff volume, puff velocity, and interpuff interval) was entered into a regression model in SAS Proc Mixed with the continuous predictor variables Puff Number (with which puff the value was associated) and Total Number of Puffs (how many puffs the participant took during the session to control for individual differences). Preliminary bivariate analyses showed that the dependent variables were affected by sex and race, so each model also included control terms for sex, race (White or non-White), and their interaction. Each participant had data for up to 28 puffs (median = 14, mean = 15.2, range = 8–28). An autoregressive error structure was used. Proc Mixed provides analysis of variance–like output (such as F values and least-squares means) for categorical predictors; we report these where appropriate. To determine magnitude of change, percent change for each variable was calculated using the mean of the first three and last three puffs. In all analyses, the initial lighting puff was excluded. Pearson product moment correlations were used to examine relationships among puffing variables and between puffing variables and smoking history. Effects were considered significant at $p < .05$, two-tailed.

Results

Participant characteristics

The sample comprised 13 Black males (14%), 12 Black females (13%), 17 White males (19%), 44 White females (48%), 2 mixed-race males, and 1 American Indian female. Mean age was 15.3 years (SD = 1.3). Participants reported smoking a mean of 18.6 cigarettes/day (SD = 9.2) for 3.3 years (SD = 1.2) and had a mean FTND score of 7.3 (SD = 1.3).

Smoking topography

Mean breath CO at baseline was 11.0 ppm (SD = 6.5) and after smoking was 21.2 ppm (SD = 7.2), yielding a significant ($p <$ .0001) CO boost of 10.2 ppm (SD = 3.9). Controlling for sex, race, and number of puffs, puff volume showed a significant linear decrease over puffs, $B = -0.415$, $SEM = 0.12$, $t(1261) = -3.33$, $p < .001$. Puff duration also showed a significant linear decrease over puffs, $B = -0.030$, $SEM = 0.004$, $t(1261) = -7.81$, $p < .0001$. Percent decrease in puff volume and puff duration (from first three to last three puffs) was 12.8% and 24.5%, respectively. In contrast, puff velocity showed a significant linear increase over puffs, $B = 0.723$, $SEM = 0.19$, $t(1261) = 3.79$, $p <$ .001. Interpuff interval showed a trend toward a linear increase over puffs, $B = 0.136$, $SEM = 0.08$, $t(1172) = 1.77$, $p = .08$. Percent increase in puff velocity and interpuff interval was 14.8% and 13.5%, respectively.

Adjusted means for each dependent variable by sex and race are shown in Table 1. The regression models showed that puff volume was greater in Whites than non-Whites, $F(1, 84) = 6.29$, $p < .05$; puff duration was greater in males than females, $F(1, 84) =$ 13.93, $p < .001$; interpuff interval was shorter in males than females, $F(1, 84) = 4.70$, $p < .05$; and puff velocity was slowest in non-White males (sex by race interaction), $F(1, 84) = 5.31$, $p <$ .05. There was a trend ($p = .07$) for shorter interpuff intervals in non-Whites than in Whites.

In bivariate analyses, number of cigarettes smoked per day was positively correlated with number of years smoking, $r = .30$,

Table 1. Mean (*SEM*) across puffs of each smoking topography variable for the total sample and by sex and race

	Total sample[a] ($n = 89$)	Females[b] ($n = 57$)	Males[b] ($n = 32$)	Non-Whites[b] ($n = 28$)	Whites[b] ($n = 61$)
Measure					
Puff volume (ml)	41.5 (1.2)	38.7 (1.1)	41.4 (1.2)	37.9 (1.3)	42.2 (1.0)[c]
Puff duration(s)	1.3 (0.04)	1.2 (0.03)	1.4 (0.04)[d]	1.2 (0.04)	1.3 (0.03)
Interpuff interval(s)	14.5 (0.7)	14.3 (0.5)	12.5 (0.6)[e]	12.6 (0.7)	14.2 (0.5)
Puff velocity (ml/s)	53.9 (2.0)	56.3 (2.1)	49.2 (2.3)	51.2 (2.5)	54.3 (2.0)

Note. [a]Means from raw data.

[b]Least-squares means from repeated-measures analysis (SAS Proc Mixed), adjusted for number of puffs and number of data points contributed by each subject.

[c]Significantly different from non-Whites, $p < .05$.

[d]Significantly different from females, $p < .001$.

[e]Significantly different from females, $p < .05$.

$p < .01$, and with FTND score, $r = .67$, $p < .0001$. However, no smoking history variable (cigarettes per day, years smoking, FTND score) was significantly correlated with any of the puffing variables. CO boost was positively correlated with interpuff interval, $r = .23$, $p < .05$, and marginally so with puff velocity, $r = .20$, $p = .06$. Puff volume was positively correlated with puff duration, $r = .65$, $p < .0001$, and puff velocity, $r = .44$, $p < .0001$. Puff duration and puff velocity were negatively correlated, $r = -.26$, $p < .01$.

Discussion

To our knowledge, this is the first study to report discrete puff-by-puff behavior during the smoking of a single cigarette in tobacco-dependent adolescents. We found decreases in puff volume and puff duration and increases in interpuff interval and puff velocity over the course of the cigarette. Similar single-cigarette changes in puffing behavior have been reported in adult smokers (Gust et al., 1983; Guyatt et al., 1989; Kolonen et al., 1992). These results suggest that adolescent smokers, like adults, are able to regulate smoke and nicotine intake on a puff-by-puff basis.

The magnitude of change in puffing behaviors across the cigarette was relatively small compared with changes reported in adult smokers. We observed a 13% decrease in puff volume, 25% decrease in puff duration, and 14% increase in interpuff interval. Guyatt et al. (1989) reported that adult smokers showed a 33% decrease in puff volume, 39% decrease in puff duration, and 75% increase in interpuff interval. Similarly, Gust et al. (1983) observed in adults a 30% decrease in puff volume over 10 puffs. Although the adolescents in our study smoked nearly a pack a day and had been smoking for more than 3 years, these differences suggest that adult smokers are more capable of altering puffing behaviors within a single cigarette.

Several investigators have reported topography data averaged over a single cigarette in adolescents (Corrigall et al., 2001; Franken et al., 2006; Kassel et al., 2007; Wood et al., 2004; Zack et al., 2001). In general, our averaged data (Table 1) were consistent with these studies. The one exception was interpuff interval; our mean interval was 7–10 s shorter than previously reported values. Presumably, this would result in more puffs per cigarette; however, the mean number of puffs in our study (15.2) was within the range (14–17) reported by others. Shorter interpuff intervals might also be expected to result in a greater total puff volume; however, our mean total puff volume (619 ml) was identical to that reported by Wood et al. and comparable to the range (606–713 ml) of other studies (Corrigall et al.; Kassel et al.). Most adolescent topography studies have tested daily smokers with at least moderate levels of nicotine dependence. The exception is Kassel et al., whose participants smoked less than daily and averaged 3.6 cigarettes/day. The fact that their topography values were similar to those of this and other studies testing dependent daily adolescent smokers suggests that reliable puffing behavior is established early during the development of tobacco dependence.

We found that males exhibited longer puff duration and shorter interpuff interval and tended to show greater puff volume than females (Table 1). Wood et al. (2004) reported similar trends; they also found that males had greater total puff volume than females, which is consistent with our results (671.6 ± 189.4 ml for males vs. 589.4 ± 172.0 ml for females, $p < .05$). The shorter interpuff interval for males was consistent with their taking more puffs over the cigarette (16.4 ± 4.2) than females (14.5 ± 3.9, $p < .05$). Similarly, the shorter interpuff interval and smaller puff volume observed for non-White participants were consistent with non-Whites taking more puffs (17.1 ± 3.7) than Whites (14.1 ± 3.6, $p < .001$).

Some limitations of the study should be noted. White females comprised nearly half of our sample; however, there was no evidence that White females were responsible for the few demographic differences we found in topography. Indeed, our mean topography data were comparable to those of other studies investigating diverse groups of adolescents (Corrigall et al., 2001; Kassel et al., 2007; Wood et al., 2004; Zack et al., 2001). Another limitation of the study is that adolescents smoked only one cigarette in a laboratory setting after an uncontrolled time since their last cigarette. Thus, we were unable to determine the reliability of the puffing behavior and the extent to which it generalizes to real-world smoking. A study with adult smokers showed that topography data were consistent across days and that several measures of tobacco exposure were similar when cigarettes were smoked in the laboratory and in the natural environment (Lee et al., 2003).

In tobacco-dependent adolescent smokers, we found evidence of regulation of puffing behavior across the smoking of a single cigarette. This suggests that adolescent smokers, like adults, learn early in the dependence process to regulate their smoke and nicotine intake. These results are further confirmation that tobacco dependence is a pediatric disease (Fiore et al., 2008).

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Declaration of Interests

None declared.

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