Published in final edited form as:
J Adolesc Health. 2011 February ; 48(2): 176–181. doi:10.1016/j.jadohealth.2010.06.015.

Predictors and Sequelae of Smoking Topography Over the Course of a Single Cigarette in Adolescent Light Smokers

Jennifer C. Veilleux, M.A.[a], **Jon D. Kassel, Ph.D.**[a,*], **Adrienne J. Heinz, M.A.**[a], **Ashley Braun, M.A.**[a], **Margaret C. Wardle, Ph.D.**[b], **Justin Greenstein, Ph.D.**[c], **Daniel P. Evatt, Ph.D.**[d], and **Megan Conrad, B.S.**[a]

[a]Department of Psychology, University of Illinois at Chicago, Chicago, Illinois [b]Department of Psychiatry, University of Chicago, Chicago, Illinois [c]Psychology Department, Edward J. Hines VA Medical Center, Hines, Illinois [d]Department of Psychiatry, School of Medicine, Johns Hopkins University, Baltimore, Maryland

Abstract

Purpose—The objective of this study was to determine whether adolescent smokers, who varied in their smoking histories and symptoms of nicotine dependence, exhibit any decrease in puff volume and duration similar to that typically seen in dependent adolescent and adult smokers. Moreover, we examined whether puffing trajectories were moderated by individual difference factors, as well as whether puffing topography over the course of smoking a single cigarette was predictive of an escalation in dependence symptoms.

Methods—We assessed smoking topography (puff number, duration, volume, maximum flow rate [velocity], and inter-puff interval) over the course of smoking a single cigarette in a sample of 78 adolescent light smokers, using hierarchical linear modeling. We examined moderators (anxiety, depression, nicotine dependence) of the topographic trajectories, as well as whether smoking topography predicted any change in dependence over a 2-year period.

Results—Puff volume and puff duration decreased over the course of smoking the cigarette, whereas puff velocity and inter-puff interval increased. Slopes for puff volume and duration were moderated by anxiety and depressive symptoms. Moreover, individuals with a less "typical" topography pattern (exhibited stable or increasing volume and duration over the course of smoking the cigarette) demonstrated a heightened dependence escalation in the subsequent 2 years.

Conclusion—Our findings suggest that adolescent light smokers self-regulate nicotine during the course of smoking a single cigarette, similar to that reported in dependent adolescent and adult smokers. However, single cigarette self-regulation was influenced by certain affective factors. Implications of these findings and future directions for adolescent smoking research are discussed.

Keywords

Adolescence; Smoking; Dependence; Topography

Most teenagers will attempt smoking a cigarette at least once before graduating from high school. Indeed, despite recent declines in regular cigarette use among adolescents, 20% of 12th graders reported smoking in the past month [1]. Therefore, identification of adolescents

*Address correspondence to: Department of Psychology, University of Illinois at Chicago, 1007 W. Harrison St., Chicago, IL 60607. jkassel@uic.edu. .

who are at a greater risk of progression to nicotine dependence represents a critical target for public health research [2,3]. The marked relationship between smoking and comorbid mental health problems (e.g., depression, anxiety) is also of concern, particularly among adolescents dependent on nicotine [4,5].

Experts in the field have encouraged research on adolescent smoking to address questions at multiple levels of analysis, including social and demographic factors that promote smoking, as well as situational influences [2,3]. The following questions should therefore be framed to address the issue: (1) *who* is most likely to initiate smoking?; (2) *what* contexts (both intrapersonal and interpersonal) are associated with smoking?; (3) *when* are adolescents motivated to smoke?; and (4) what are some of the etiological factors associated with *why* adolescents make the decision to smoke? Far less research, however, has been conducted on *how* adolescents smoke, an important question that can be perhaps best addressed through the assessment of smoking topography.

Although smoking topography (puffing behaviors) has been examined frequently in studies of adult smokers, it has been assessed in adolescents only in the past several years [6–9]. Knowledge of smoking topography is important because puffing behavior is one mechanism by which smokers self-regulate nicotine intake. To date, published data suggest that adolescent smoking topography (e.g., puff number, volume, velocity, duration, and inter-puff-interval) is roughly equivalent to adult puffing behavior [6]. For example, adolescent [8] and adult [10] smokers appear to regulate their nicotine intake such that they end up taking more puffs from a low-yield nicotine cigarette compared with a high-yield one.

The question of how individuals smoke has also been examined by assessing whether puffing behaviors change over the course of smoking a single cigarette. Previously published research on adults has demonstrated that nicotine-dependent smokers tend to self-regulate their nicotine intake by taking longer and larger puffs at the beginning, with a decrease in volume and duration over the course of smoking a cigarette [11,12]. Likewise, a recent study [6] reported a similar smoking topography pattern in nicotine-dependent adolescent smokers. Although no definitive explanation exists as to why smokers display this pattern, Guyatt et al [11] have suggested that as the cigarette shortens, the delivery of tar and nicotine increases (per puff), such that a decrease in the volume and duration of puffing may in turn bring about a consistent delivery of nicotine throughout the cigarette.

To our knowledge, no published study has examined puffing behavior over a single cigarette in a sample of adolescents, with varying levels of nicotine dependence and smoking histories. Inclusion of light smokers in studies using smoking topography is necessary to identify whether puffing behaviors change as smokers gain more exposure to cigarettes. For example, if neophyte smokers do not differ in their puffing behaviors from more experienced, dependent smokers, then those behaviors (and the associated nicotine self-regulation) are most likely to be spontaneous or learned very early on during the development of an individual's smoking trajectory. One study suggested that this may, indeed, be the case, as daily and nondaily adolescent smokers did not differ on any of the puffing variables [7]. However, these data were averaged topographical indices and therefore did not address any dynamic self-regulation that might occur over the course of smoking a single cigarette.

Limited evidence also points to individual variability in dynamic puffing behaviors. A study by Guyatt et al [11], which was one of the few studies examining puffing behavior over the course of smoking a single cigarette, reported significant differences in puffing trajectories between the subjects, such that, although most participants exhibited a decrease in puff volume and duration, there were some who exhibited consistent topographic measures over

the course of smoking a cigarette, whereas a small percentage of them actually exhibited the exact opposite pattern (e.g., increased puff volume over the course of smoking the cigarette). The authors proposed that the "responders," those with a modal pattern of decreased volume and duration, may differ in significant ways from "nonresponders," those who showed little change over the course of smoking a cigarette, and that single cigarette puffing patterns may help identify such individuals. Extrapolating from this suggestion, it may also be the case that other, as yet unstudied, individual difference variables may influence single cigarette puffing trajectories.

As noted previously, puffing behaviors over a single cigarette might vary on the basis of smoking experience (i.e., the number of cigarettes smoked) or nicotine dependence. Moreover, based on the substantial published data available on the relationship between smoking and emotion [13], affective factors could be likely candidate variables that might influence puffing behaviors. Many smokers, including adolescents [14], have reported that they smoke so as to alleviate affective distress. Rates of anxiety and depression have been found to be higher among smokers as compared with nonsmokers [5,15]. In fact, longitudinal studies suggest a bidirectional relationship between affective distress and smoking [3,4].

In contrast, limited evidence is available on relationship between anxiety, depression, and smoking topography. One study reported higher mean puff volumes in smokers with, as opposed to without, post-traumatic stress disorder [16]. Interestingly, laboratory studies have found that when using a sad mood induction, higher levels of depression were associated with an increased puff duration [17], and induced anxiety prompted more frequent puffing as compared with induced relaxation [18].

In summation, the dynamics of puffing trajectories over the course of smoking a single cigarette suggest that self-regulation of nicotine intake occurs among smokers. Identifying when these trajectories are stabilized in the course of development of the act of smoking may provide useful information related to the development of nicotine dependence. Moreover, individual differences in smoking behavior and/or affective factors might further influence puffing trajectories. Finally, these questions may become of further importance if the method by which an adolescent smokes influences whether that individual progresses to nicotine dependence. In short, do puffing trajectories predict escalation to dependence?

The objective of the current study was to examine smoking topography over the course of smoking a single cigarette in a sample of adolescents who varied in their smoking histories and nicotine dependence. More specifically, we were interested in determining whether the relatively neophyte adolescent smokers exhibited a decreased puff volume and duration, and an increased inter-puff interval and puff velocity, over the course of smoking a cigarette–a pattern of topographical indices that is typically observed in nicotine dependent, adult smokers. In the laboratory, we also examined the role of smoking frequency, nicotine dependence, and affective symptoms as potential moderators of puffing trajectories during the smoking of a cigarette. Finally, we were interested in addressing the issue of whether individual differences in puffing trajectories predict increases in nicotine dependence over time.

Methods

Participants

This study was approved by the Institutional Review Board at the University of Illinois at Chicago. Because all the participants included in the study were adolescents, laboratory sessions were conducted after obtaining a signed parental consent, in addition to a signed

assent from each of the participants. Because of the sensitive nature of the study (i.e., administration of cigarettes to minors), caution was taken to ensure that the participants and their guardians understood the aims and expectations of the study. Of note, no participant was authorized to smoke during the session. A participant was provided the opportunity to smoke a cigarette in the laboratory only if he or she was qualified to do so, that is, he or she should have smoked at least one puff of a cigarette in the 2 weeks before the study and had no intention of quitting smoking. All participants who were allowed to smoke in the laboratory were instructed to smoke "as much or as little of the cigarette as you wish."

Data related to smoking were obtained from 78 adolescent smokers across two experimental sessions that investigated the relationship between smoking and emotional response (Kassel JD, unpublished data). The study was conducted under the umbrella of a program project entitled The Social and Emotional Contexts of Adolescent Smoking, which longitudinally followed up 1,263 high-risk (the study oversampled adolescent smokers) high-school freshman and sophomores for 24 months [19].

The current analyses focused on participants who smoked in one of the two experimental sessions separated by 6–8 weeks. At the start of the laboratory session, participants completed self-report questionnaires on smoking behaviors. Participants were randomized to smoke during either session 1 (n = 40) or session 2 (n = 38).

Measures

Smoking topography—Smoking topography was assessed using the handheld, portable version of the clinical research support system (CReSS; Plowshare Technologies, Baltimore, MD). Measures that were assessed included the number of puffs taken, puff duration, puff volume, inter-puff interval, and maximum flow rate (velocity) per puff. Previous research supports the use of smoking topography as a valid index of smoking behavior in adult [11,12] as well as adolescent smokers [6,8].

Carbon monoxide assessment—Participants provided expired air breath samples for the measurement of alveolar carbon monoxide (CO, ppm) on arrival at the laboratory and immediately after smoking the cigarette (Vitalograph EC 50 Carbon Monoxide Monitor; Lexington, KY). The CO reading provides an objective index of both recency of smoking and the CO boost from pre- to post-smoking.

Smoking behavior—At the onset of each laboratory session, participants provided information regarding their smoking status, number of cigarettes smoked per day, and lifetime history of smoking.

Nicotine dependence—Nicotine dependence was assessed using a modified version of the Fagerstrom tolerance questionnaire (mFTQ), which was developed specifically for adolescent smokers [20]. Previous research has demonstrated that this measure is valid and applicable to adolescent smokers [14,20]. The mFTQ was assessed longitudinally such that the adolescents completed the measure at baseline, 6 months, 15 months, and 24 months.

Affective symptomatology—Depressive symptoms were measured during the laboratory visit using the Beck Depression Inventory II [21], a 21-item questionnaire that measured depression symptomatology in the past 2 weeks. Anxiety symptoms were assessed using the Beck Anxiety Inventory [22], a 21-item measure that also focused on symptoms experienced in the past 2 weeks. Both scales demonstrate excellent reliability and validity and are widely used in both adult and adolescent populations [23].

Procedure

After obtaining parental consent and participant assent, participants were asked to complete baseline self-report questionnaires related to smoking behavior, depression, and anxiety, and were asked to provide an initial CO reading. At the first visit, participants who qualified as smokers were randomized to either the smoking or the nonsmoking condition. At the second visit, participants who had been randomized to the nonsmoking condition at the first visit were checked for continued qualification and were invited to smoke at that time. Participants were given the opportunity to smoke one of eight popular brands (that varied in tar and nicotine content, as well as the menthol content). Any participant in the nonsmoking condition or anyone who did not wish to smoke was asked to sit quietly for 10 minutes and was given access to neutrally valenced magazines.

After agreeing to smoke, participants were asked to complete a CO reading before smoking, and were then instructed to smoke in an ad libitum manner. Participants were guided to light the cigarette and place the filter-end in the CReSS unit, and to smoke the cigarette through the mouthpiece of the CReSS device. After smoking, participants were asked to complete a final CO reading. At the end of the study, participants were debriefed, financially compensated, and provided referrals to aid in smoking cessation.

Data analysis

Data analysis was conducted in three stages. First, average smoking topography values were calculated and evaluated along with descriptive statistics for nicotine dependence, anxiety, depression, and demographic variables. Second, hierarchical linear modeling (HLM) 6 [24] was used to model separate puffing trajectories for each of the four dependent variables (puff volume, puff duration, inter-puff interval, and velocity). HLM is considered to be appropriate because the analysis can easily incorporate varying number of data points for each person (i.e., when all the participants do not take the same number of puffs per cigarette) and allows for individual heterogeneity in puffing trajectories. Specifically, the initial level (intercepts) and the rate of change (slope) for each of the dependent variables were examined at Level 1, and individual differences (nicotine dependence, smoking frequency, depression, and anxiety) were included at Level 2 as potential moderators of the Level 1 trajectories. Because of the skewness and kurtosis of the puff volume and interpuff interval data, logarithmic transformations were conducted on these variables before HLM analyses. Also, similar to other studies of smoking topography [11], the first and last puffs were excluded from the analyses. Finally, empirical Bayes estimates capturing the best fitting model for each dependent variable were saved [25]. These estimates represent individual intercepts and slopes predicted by the HLM models, and therefore are empirical representations of the puffing trajectories for each person. These values were then used as Level 2 predictors in a new HLM model that examined the change in nicotine dependence over the course of 2 years (Level 1).

Results

Sample characteristics

The sample comprised 78 adolescent smokers (75.6% white, 47.4% women), with a mean age of 15.71 years (*SD*=.61). Participants exhibited a mean mFTQ score of 2.69 (*SD* = 1.39), and reported smoking 23.06 (*SD* = 20.04) cigarettes in the week before the experimental session (Table 1). The majority (75.6%) of the participants reported smoking almost every day, where 38.5% smoked two or less cigarettes per day, 37.2% smoked 3–5 cigarettes per day, and 24.3% smoked six or more cigarettes per day. In total, 72% of the participants reported smoking on the day of the session, and although 51.3% of the participants reported

having smoked at least 500 cigarettes in their lifetime, the remaining participants had yet to smoke 500 cigarettes.

Expired air CO, at baseline averaged 6.14 ppm ($SD = 5.80$). Before smoking, CO was 5.91 ($SD = 5.44$), which increased to 15.01 ppm (SD=9.85) after smoking the cigarette, $t(67) = -9.51$, $p<.001$. Participants took an average of 16.54 puffs per cigarette (SD=6.11), ranging from 4 to 39. Zero-order correlation analyses (Table 1) revealed a significant relationship between anxiety and depression scores. Of note, anxiety and depression were not associated with average smoking topography indices. Nicotine dependence as measured by baseline mFTQ was associated with the number of cigarettes smoked in the past 7 days, but not with any of the topography variables. Higher number of cigarettes smoked in the past week evidenced a marginal positive association with puff duration, and was significantly (positively) associated with increased puff volume and velocity.

Puffing trajectories

The central analyses investigated puffing behavior over the course of smoking a single cigarette. Initial Level-1 models all revealed a significant change in topography over the course of smoking the cigarette. Although puff volume ($\beta = -.004$, $SE = .001$, $p < .05$) and puff duration ($\beta = -.02$, $SE = .004$, $p < .05$) decreased over the course of smoking the cigarette, inter-puff interval ($\beta = .01$, $SE = .002$, $p < .05$) and puff velocity ($\beta = .30$, $SE = .10$, $p < .05$) displayed a linear increase.

We investigated the role of individual differences in puffing behavior by including variables associated with smoking behavior (mFTQ scores, number of cigarettes smoked in the past 7 days) and affective distress (anxiety and depression) at Level 2 (gender, race, and visit [whether the participant smoked at the first or second session] were investigated as moderators and none of them were found to influence any of the puffing behaviors in the present study). Results indicated that the number of cigarettes smoked in the past 7 days was associated with a higher initial (intercept) puff velocity and puff volume, whereas mFTQ scores were not significantly associated with any of the puffing variable intercepts or slopes (Table 2). Anxiety and depression predicted both puff volume and puff duration over the course of smoking the cigarette (slope), but in opposite directions. Higher anxiety scores were associated with greater puff volume and puff duration throughout the course of smoking the cigarette, whereas depressive symptoms were inversely associated with puff volume and duration (see Figure 1).

Predicting dependence escalation

Slopes and intercepts (empirical Bayes estimates) for all the participants were calculated from the best fitting model for each dependent variable. We then evaluated whether any of these slopes or intercepts predicted escalation of dependence over time. Nicotine dependence, as measured by the mFTQ, increased from baseline to 24 months ($\beta = .22$, SE=.07, p<.01). Therefore, not surprisingly, the observed sample manifested increases in nicotine dependence over time. Notably, this increase was moderated by the cigarette puff volume trajectory, ($\beta = 8.57$, $SE = 4.20$, p<.05), such that, as compared with individuals who had a more typical puffing trajectory (i.e., declines in puff volume over the course of smoking a single cigarette), individuals who exhibited steady or increasing puff volume over the course of smoking the single cigarette manifested a more rapid dependence progression over time (Figure 2).

Discussion

To our knowledge, the current study was the first to investigate puffing behavior over the course of smoking a single cigarette in a sample of adolescent smokers who varied in their smoking histories and degree of nicotine dependence. Our data were consistent with those of Collins et al [6] who also found decreases in puff volume and duration, increases in puff velocity, and a trend toward a linear increase in inter-puff interval, over the course of smoking a single cigarette. Notably, when averaging topography data over the course of smoking a single cigarette, our results also mirror those observed in other studies on smoking topography in adolescents smokers [7–9], even though our sample included generally younger and lighter smokers.

One of the central objectives of the current study was to examine the potential roles of nicotine dependence and smoking history in determining how an adolescent smokes a cigarette. Our data suggest that nicotine dependence did not, in fact, moderate puffing trajectories, nor was it associated with an increased initial puff volume or duration (as was determined through calculation of the respective variable intercepts). Although perhaps counterintuitive, our results suggest that puffing behaviors appear to be relatively consistent across adolescents of varying dependence levels. However, greater frequency of recent smoking, measured by the number of cigarettes smoked in the past week, was predictive of an increased initial puff volume and initial puff velocity.

Affective distress was also associated with several of the puffing indices. Interestingly, anxiety and depression had opposite effects on puffing behavior, such that, although anxiety was associated with an increased volume and duration over the course of smoking the cigarette, depression was found to be associated with a decreased volume and duration. Considering the frequent overlap between anxiety and depressive symptoms, especially in children and adolescents [26], the individual and divergent influences on puffing trajectories in this study are intriguing. Depression is associated with higher declines in volume and duration, most likely resulting in less overall nicotine intake. Our results, in line with the tripartite model of depression–which suggests that depression is associated with low positive affect [27]–complement findings from a recent study demonstrating that higher positive affect predicted greater nicotine boost from smoking [28]. Notably, we also found that anxiety was associated with a “nonresponsive” (nondecreasing) puffing trajectory [11]. Therefore, these anxious adolescents increased their nicotine intake throughout the course of smoking the cigarette, most likely consuming greater amounts of nicotine. In short, these adolescents appear to be upregulating their nicotine exposure over the course of smoking the cigarette, and this pattern is associated with a greater dependence trajectory escalation over the subsequent 2 years.

Several limitations of the study need to be acknowledged. First and foremost, the single measurement of smoking topography in an unfamiliar laboratory may not be an accurate representation of an individual’s typical smoking pattern. Indeed, previous research has demonstrated that individuals may smoke differently in laboratory versus naturalistic settings [29]. Therefore, for example, the relatively large boosts in CO observed in our study may be attributable, at least in part, to the artificiality of the laboratory environment, or perhaps to the unintentionally induced stress, or even boredom among the participants. However, because these adolescents visited the laboratory twice, half of the participants were at least somewhat familiar with the laboratory setting before smoking, and when we included visit number as a predictor in the analyses, it did not significantly relate to any of the puffing trajectories. Recent research has also suggested that smokers report fewer differences in smoking behavior when using a portable, handheld topography device such as the one used in this study [30]. Moreover, similar rates of nicotine delivery and number of

puffs were reported when comparing conventional smoking with smoking through a topography measurement device [31]. Finally, it is important to note that, although smoking topography is suggestive of nicotine self-regulation, smoking topography does not actually measure inhalation. As such, future studies may want to use novel technologies such as plethysmographic measurements of inhalation [32].

In summary, we found that the typical pattern of puffing behavior over the course of smoking a single cigarette–decreased puff volume and duration, coupled with an increased puff velocity and inter-puff interval–holds for even light, young adolescent smokers. These findings indicate, as has been previously suggested [6], that puffing behaviors are learned early in the act of smoking. However, we also found that puffing trajectories vary on the basis of affective factors, suggesting that symptoms of affective distress alter how adolescents smoke a cigarette. Finally, and most importantly, how a single cigarette was smoked–specifically, puff volume–predicted escalation in symptoms of nicotine dependence over a 2-year period, representing a potentially critical phenotypic marker of susceptibility to dependent smoking in this vulnerable population of smokers.

Acknowledgments

This research was supported by a grant (1PO1CA98262) from the National Cancer Institute. Certain sections of this paper were presented at the Annual Meeting of the Society for Research on Nicotine and Tobacco, Baltimore, Maryland, in February, 2010.

References

[1]. Johnston, LD.; O'Malley, PM.; Bachman, JG., et al. Monitoring the Future National Results on Adolescent Drug Use: Overview of Key Findings, 2008. National Institute on Drug Abuse; Bethesda, MD: 2008. NIH Publication No. 08-6418

[2]. Jamner LD, Whalen CK, Loughlin SE, et al. Tobacco use across the formative years: A road map to developmental vulnerabilities. Nicotine Tob Res 2003;5:S71–87. [PubMed: 14668088]

[3]. Turner L, Mermelstein R, Flay B. Individual and contextual influences on adolescent smoking. Ann NY Acad Sci 2004;1021:175–269. [PubMed: 15251888]

[4]. Munafó MR, Hitsman B, Rende R, et al. Effects of progression to cigarette smoking on depressed mood in adolescents: Evidence from the National Longitudinal Study of Adolescent Health. Addiction 2007;103:162–71. [PubMed: 18031565]

[5]. Pederson W, von Soset T. Smoking, nicotine dependence and mental health among young adults: A 13-year population-based longitudinal study. Addiction 2009;104:129–37. [PubMed: 19133898]

[6]. Collins CC, Epstein DH, Parzynski CS, et al. Puffing behavior during the smoking of a single cigarette in tobacco-dependent adolescents. Nicotine Tob Res 2009;12:164–7. [PubMed: 19969556]

[7]. Corrigall WA, Zack M, Eissenberg T, et al. Acute subjective and physiological responses to smoking in adolescents. Addiction 2001;96:1409–17. [PubMed: 11571060]

[8]. Kassel JD, Greenstein JE, Evatt DP, et al. Smoking topography in response to denicotinized and high-yield nicotine cigarettes in adolescent smokers. J Adolesc Health 2007;40:54–60. [PubMed: 17185206]

[9]. Wood T, Wewers ME, Groner J, et al. Smoke constituent exposure and smoking topography of adolescent daily smokers. Nicotine Tob Res 2004;6:853–6. [PubMed: 15700921]

[10]. Scherer G. Smoking behavior and compensation: A review of the literature. Psychopharmacology 1999;145:1–20. [PubMed: 10445368]

[11]. Guyatt AR, Kirkjam AJ, Baldry AG, et al. How does puffing behavior alter during the smoking of a single cigarette? Pharmacol Biochem Behav 1989;33:189–95. [PubMed: 2780776]

[12]. Kolonen S, Tuomisto J, Puustinen P, et al. Puffing behavior during the smoking of a single cigarette in a naturalistic environment. Pharmacol Biochem Behav 1992;41:701–6. [PubMed: 1594637]

[13]. Kassel JD, Stroud LR, Paronis CA. Smoking, stress and negative affect: Correlation, causation and context across stages of smoking. Psychol Bull 2003;129:270–304. [PubMed: 12696841]

[14]. Kassel JD, Evatt DP, Greenstein JE, et al. The acute effects of nicotine on positive and negative affect in adolescent smokers. J Abnorm Psychol 2007;116:543–53. [PubMed: 17696710]

[15]. Mykletun A, Overland S, Aaro LE, et al. Smoking in relation to anxiety and depression: Evidence from a large population survey: The HUNT study. Eur Psychiatry 2007;23:77–84. [PubMed: 18082377]

[16]. McClernon FJ, Beckham JC, Mozley SL, et al. The effects of trauma recall on smoking topography in posttraumatic stress disorder and non-posttraumatic stress disorder trauma survivors. Addict Behav 2005;30:247–57. [PubMed: 15621396]

[17]. Fucito LM, Juliano LM. Depression moderates smoking behavior in response to a sad mood induction. Psychol Addict Behav 2009;23:546–51. [PubMed: 19769439]

[18]. Rose JE, Ananda S, Jarvik ME. Cigarette smoking during anxiety-provoking and monotonous tasks. Addict Behav 1983;8:353–9. [PubMed: 6677075]

[19]. Dierker L, Mermelstein R. Early emerging nicotine-dependence symptoms: A signal of propensity for chronic smoking behavior in adolescents. J Pediatr 2010;156:818–22. [PubMed: 20097354]

[20]. Prokhorov AV, De Moor C, Pallonen UE, et al. Validation of the modified Fagerstrom tolerance questionnaire with salivary cotinine among adolescents. Addict Behav 2000;25:429–33. [PubMed: 10890296]

[21]. Beck, AT.; Steer, RA.; Brown, GK. Manual for Beck Depression Inventory. 2nd ed. The Psychological Corporation; San Antonio, TX: 1996.

[22]. Beck, AT.; Steer, RA. Manual for the Beck Anxiety Inventory. The Psychological Corporation; San Antonio, TX: 1993.

[23]. Steer RA, Clark DA, Kumar G. Common and specific dimensions of self-reported anxiety and depression in adolescent outpatients. J Psychopathol Behav 2008;30:163–70.

[24]. Raudenbusch, SW.; Bryk, AS.; Congdon, R. Hierarchical Linear Modeling for Windows. Scientific Software International Inc; Lincolnwood, IL: 2004.

[25]. Singer, JD.; Willett, JB. Applied Longitudinal Data Analysis. Oxford University Press; New York, NY: 2003.

[26]. Brady E, Kendall PC. Comorbidity of anxiety and depression in children and adolescents. Psychol Bull 1992;111:244–55. [PubMed: 1557475]

[27]. Clark LA, Watson D. Tripartite model of anxiety and depression: Psychometric evidence and taxonomic implications. J Abnorm Psychol 1991;100:313–36.

[28]. Patterson F, Benowitz N, Shields P, et al. Individual differences in nicotine intake per cigarette. Cancer Epidemiol Biomarkers 2003;12:468–71.

[29]. Ossip-Klein DJ, Martin JE, Lomax BD, et al. Assessment of smoking topography generalization across laboratory, clinical and naturalistic settings. Addict Behav 1983;8:11–17. [PubMed: 6880921]

[30]. Hammond D, Fong GT, Cummings KM, et al. Smoking topography, brand switching, and nicotine delivery: Results from an in vivo study. Cancer Epidemiol Biomarkers 2005;14:1370–5.

[31]. Lee EM, Malson JL, Waters AJ, et al. Smoking topography: Reliability and validity in dependent smokers. Nicotine Tob Res 2003;5:673–9. [PubMed: 14577984]

[32]. Rhoda, D.; Canlas, L.; Richter, P., et al. Technical approaches & challenges to identification of puff associated inhalations in laboratory and ad lib smoking. Proceedings of the Society for Research on Nicotine and Tobacco; Baltimore, MD. February 2010;

NIH-PA Author Manuscript
NIH-PA Author Manuscript

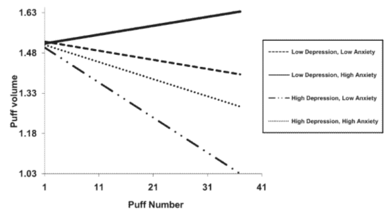

Figure 1.

Puff volume over the course of smoking a single cigarette moderated by depression and anxiety. “Low” values correspond to scores less than or equal to the 25th percentile. “High” values correspond to scores greater than or equal to the 75th percentile.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

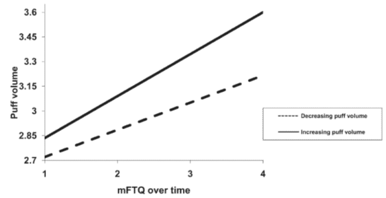

Figure 2.

Nicotine dependence over time moderated by trajectory of puffing volume. The X-axis reflects the four measurement waves in the longitudinal portion of the study: 1 = baseline; 2 = 6 months; 3 = 15 months; and 4 = 24 months. mFTQ = modified Fagerstrom tolerance questionnaire.

Table 1

Descriptives and correlations

	Variable	Mean (SD)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	BDI	9.92 (6.79)	–							
(2)	BAI	9.68 (7.98)	.71***	–						
(3)	Cigarettes smoked in the past week	23.06 (20.04)	−.17	.04	–					
(4)	mFTQ	2.69 (1.39)	−.02	.10	.59***	–				
(5)	CO boost	9.11 (7.89)	−.17	−.11	.34***	.21**	–			
(6)	Puff volume[a] (mL)	35.23 (16.19)	−.13	.01	.33***	.15	.38***	–		
(7)	Puff duration[a] (sec)	1.10 (.41)	−.08	−.07	.22**	.10	.25*	.78***	–	
(8)	Inter-puff interval[a] (sec)	19.18 (8.89)	−.09	−.06	−.17	−.04	.33***	−.10	−.04	–
(9)	Puff velocity[a] (mL/sec)	43.58 (15.57)	−.07	−.10	.29***	.06	−.07	.60***	−.07	−.19**

BDI = Beck Depression Inventory; BAI = Beck Anxiety Inventory; mFTQ = modified Fagerstrom tolerance questionnaire; CO = expired air carbon monoxide.

* $p < .10$;

** $p < .05$;

*** $p < .01$.

[a] Averages calculated for each participant.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Puffing trajectories and individual difference variables

	Parameter	Puff volume[a]	Puff duration	Inter-puff interval[a]	Puff velocity
Intercept	β_{0j}	1.511 (.023)***	1.234 (.056)***	4.14 (.027)***	41.109 (1.694)***
Cigarettes smoked in the past week	γ_{01}	.004 (.001)**	.005 (.003)	−.001 (.001)	.254 (.094)**
Slope	β_{1ij}	−.005 (.001)**	−.018 (.003)***	.006 (.002)*	.298 (.100)**
BAI	γ_{11}	.001 (.0003)*	.001 (.001)*	.000 (.0004)	.027 (.020)
BDI	γ_{12}	−.001 (.0004)*	−.002 (.001)**	−.000 (.0005)	−.026 (.025)

Numbers are presented as betas and standard errors; significant values were only included in the final models for each dependent variable.

* $p < .05$;

** $p < .01$;

*** $p < .001$.

[a] Variables were logarithmically transformed before analysis.