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Brief Report

The Reliability of Puff Topography and Subjective Responses During Ad lib Smoking of a Single Cigarette

Kenneth A. Perkins, Ph.D., Joshua L. Karelitz, M.A., Grace E. Giedgowd, B.S., & Cynthia A. Conklin, Ph.D.

Department of Psychiatry, University of Pittsburgh, Pittsburgh, PA

Corresponding Author: Kenneth A. Perkins, Ph.D., *Western Psychiatric Institute & Clinic, University of Pittsburgh School of Medicine, 3811 O'Hara Street, Pittsburgh, PA 15213, USA. Telephone: 412-246-5395; Fax: 412-246-5390; E-mail: perkinska@upmc.edu*

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Abstract

Introduction: Acute smoking behavior (i.e., puff topography) and subjective responses during the ad lib smoking of a single cigarette in the laboratory may provide useful measures of smoking reinforcement and reward, respectively. However, the reliability of such measures is not clear, leaving uncertain the utility of a single assessment of smoking behavior as an individual difference measure.

Methods: Dependent smokers ($N = 94$) smoked normally prior to each of 4 laboratory sessions during which they were instructed to smoke 1 cigarette of their preferred brand in ad libitum and unblinded fashion and then rate it for subjective effects. Puff topography (puff number, total volume, and maximum volume) was assessed via portable Clinical Research Support System device. Subjective reward and perception were assessed by visual analog scales of "liking" and "how strong," respectively. The reliability of puff topography and subjective measures was determined across days by intra-class correlations (ICCs). Differences due to sex and nicotine dependence (high and low Fagerström Test for Nicotine Dependence score) were also examined.

Results: Reliability was highly significant for each measure. ICCs were .70 for total puff volume, .60 for maximum puff volume, .73 for puff number, .64 for liking, and .78 for how strong. Reliability generally did not differ by sex or dependence, but absolute values for total volume and maximum puff volume were greater in men and in high dependent smokers. Liking was also greater in high dependent smokers.

Conclusions: Puff topography and subjective measures during the ad lib smoking of a single cigarette are highly reliable. Smoking responses during a single ad lib smoking session may be useful in identifying stable individual differences in smoking reinforcement and reward.

Introduction

Laboratory assessment of acute smoking behavior and subjective responses may be useful for identifying individual differences and acute situational influences on smoking reinforcement and reward. For example, we recently found that smokers with a history of depression smoked a cigarette more intensely (greater total puff volume), regardless of mood induction condition, than those without a history of depression (Perkins, Karelitz, Giedgowd, Conklin, & Sayette, 2010). We also found greater intensity of smoking after overnight abstinence, but not other conditions, among those low in distress tolerance (Perkins, Karelitz, Giedgowd, et al., 2010). These results suggest that depression history and distress tolerance may be associated with greater acute smoking reinforcement, at least under some conditions. Differences in acute smoking topography could have clinical implications as the mean puff volume during the smoking of a single cigarette has been shown to predict poorer outcome of an attempt to quit smoking (Strasser, Pickworth, Patterson, & Lerman, 2004). We have also observed genetic associations with acute smoking behavior (puff number) and reward (i.e., self-reported liking) during negative mood induction (Perkins et al., 2008). However, the validity of any individual differences in smoking topography and subjective responses requires that these measures be highly reliable, so that greater responses on these measures are not due merely to chance but reflect meaningful and predictable patterns of responding.

Several studies have examined the reliability of puff topography measures of smoking behavior, showing high reliability of topography measures across multiple cigarettes within a single session (e.g., Battig, Buzzi, & Nil, 1982; Blank, Disharoon, & Eissenberg, 2009). Of more interest here, however, is the reliability of smoking topography of a single cigarette across different sessions to determine whether a brief assessment of ad libitum smoking of one cigarette constitutes a reliable measure of characteristic smoking behavior. Shahab et al. (2008) assessed the reliability of both self-reported puffing behavior and objective smoking topography measures on two occasions just 24 hr apart in 118 smokers of the most popular light and regular brands in four different countries. Reliability was high for most measures (intra-class correlations [ICCs] above .6). However, the association between the objective and self-report measures was low, especially for puffing intensity and total exposure, suggesting that self-report measures of smoking behavior may have limited

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validity. Lee, Malson, Waters, Moolchan, and Pickworth (2003) examined the reliability of objective smoking topography measures during the ad lib smoking of a single cigarette of one's own brand on four different occasions, finding high reliability for puff volume, duration, and velocity. Although these results suggest that topography measures from a single cigarette are reliable across several occasions, this study examined only seven highly dependent smokers, all but one of whom were Black. Little research has examined the reliability of subjective responses to smoking a cigarette, although other research has shown high reliability of subjective responses to fixed doses of nicotine nasal spray across days (Perkins, Jetton, Stolinski, Fonte, & Conklin, 2003).

Following up results of Shahab et al. and Lee et al., we examined the reliability of puff topography measures during the ad lib smoking of one cigarette of one's own brand on four different occasions. We expanded the assessment of reliability to subjective reward (liking) and perception (how strong) of the cigarette. We assessed a sample of nearly 100 smokers to increase confidence in the reliability results and to allow some examination of characteristics that might relate to differences in reliability of responses. For example, puff topography may be more reliable among highly dependent smokers, whose smoking behavior may be more invariant and automatic (e.g., Shiffman & Paty, 2006). Secondarily, we also examined individual differences in the absolute magnitude of responses based on sex and dependence level.

Methods

Participants

Participants ($n = 94$; 55 male and 39 female) were adult smokers (≥10 cigarettes/day) recruited via ads posted in the surrounding community for a study examining the relationship between negative mood induction and smoking responses (see Perkins, Karelitz, Conklin, Sayette, & Giedgowd, 2010). Ethnic representation was 83% Caucasian, 16% Black, and 1% Hispanic. Mean ± *SE* sample characteristics were age of 26.8 ± 1.0 years, nicotine yield of preferred brand of 1.04 ± 0.02 mg, daily smoking rate of 19.5 ± 0.6 cigarettes/day for 10.6 ± 0.9 years, and Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991) score of 4.7 ± 0.2, indicating moderate dependence. Men and women did not differ on any of these characteristics.

Procedure

The larger study involved five sessions, but one session did not involve ad lib smoking upon arrival, and so, only smoking topography data from the other four sessions are examined here. A mean of 2.8 ± 0.1 days separated sessions, and sessions were scheduled for the same time of day (±1 hr) within subjects. Participants were instructed to smoke ad libitum prior to arriving for each session. Upon arrival, they were given one cigarette of their preferred brand to smoke ad libitum without any blinding to brand. We wanted to maximize generalizability of results to smoking in the natural environment, where smokers are not blind to brand. This smoking was done via the Clinical Research Support System (CReSS; Borgwaldt KC, Inc., Richmond VA; www.plowshare.com), which assesses puff number, total puff volume (total intake across all puffs from a single cigarette), and maximum puff volume (amount of intake during largest single puff). (Eleven other participants in the larger study were not included because they did not smoke on at least one of the four sessions.) After finishing the cigarette, subjects rated subjective reward and perception with variations on two items from the Cigarette Evaluation Scale (Westman, Behm, & Rose, 1996), "How much do you like the puffs you just took?" and "How strong was that cigarette?", respectively. Each was rated on a 0 (*not at all*) to 100 (*very much*) Visual Analog Scale. Because the postsmoking subjective measure was not included in the protocol for the first 23 participants, only 71 subjects were included in the analyses of subjective responses to smoking.

Reliability for each measure was determined by ICC (McGraw & Wong, 1996). We reported both Type C ICC values, which estimate consistency of responses and ignore any systematic differences due to day (i.e., provides a relative ranking of responses), and the typically lower Type A ICC values, which estimate agreement of responses while taking into consideration the systematic changes across days (i.e., determines similarity of absolute responses; McGraw & Wong, 1996). Differences in reliability due to sex and nicotine dependence level were determined by examining the 95% *CI*s to determine overlap. High and low nicotine dependence was determined by median split of FTND scores, with 5 or higher indicating high dependence and below 5 low dependence. We also used analyses of variance to examine the influence of time (i.e., study day), as well as sex and dependence level, on smoking topography and subjective responses.

Results

Reliability

Smoking Topography

Means for total puff volume, maximum puff volume, and number of puffs by day are shown in Figure 1. The effect of time (i.e., days) was significant for just two measures, total volume and maximum volume, $F(3, 270)$'s of 3.46 and 3.25, respectively, both $p < .05$, as these values decreased after Day 1. Puff number was not influenced by time, $F(3, 270) = 1.32$, not significant. The reliability of each measure of smoking behavior was highly significant for agreement as Type A ICC values (and 95% *CI*) for total volume, maximum volume, and puff number were 0.70 (0.62–0.77), 0.60 (0.50–0.69), and 0.73 (0.66–0.80), respectively, all $p < .001$. Respective Type C ICC values were uniformly higher at 0.90 (0.87–0.93), 0.86 (0.80–0.90), and 0.92 (0.89–0.94), $p < .001$, showing high consistency of responses.

Individual differences in reliability of topography measures were generally not observed as 95% *CI*s overlapped between men and women and between high and low nicotine dependence (FTND score). However, the reliability of maximum puff volume was poorer for high ($n = 28$) versus low ($n = 27$) dependent men as 95% *CI*s for maximum volume did not overlap. Type A ICCs for high versus low dependent men were 0.29 (0.11–0.52) versus 0.70 (0.55–0.83), respectively, and Type C ICCs were 0.62 (0.32–0.81) versus 0.90 (0.83–0.95), respectively, as both Type A and Type C reliability differed for high versus low dependent men.

Subjective Responses

Means for liking and how strong are also shown by day in Figure 1. The main effect of time was not significant. The reliability of each

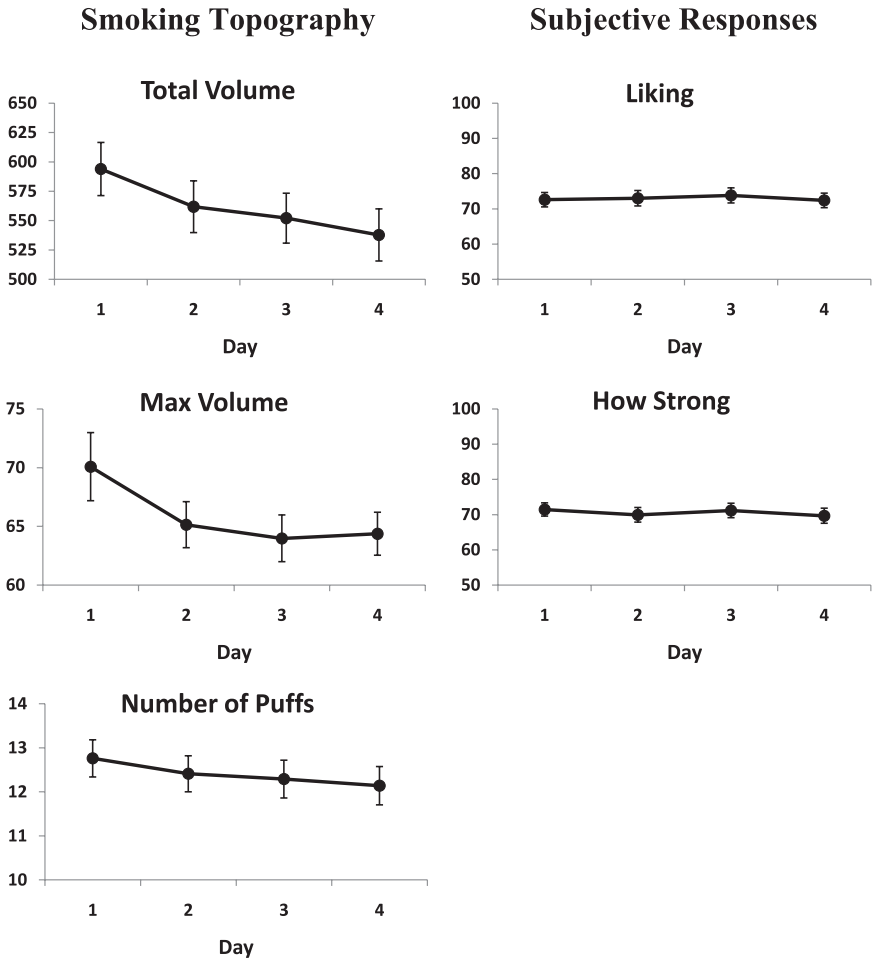

Figure 1. Mean (*SE*) smoking topography (volume in milliliters) and subjective ratings across the four study days.

subjective measure was highly significant as Type A ICC values (and 95% *CI*) for liking and how strong were 0.64 (0.54–0.74) and 0.78 (0.70–0.84), respectively, $p < .001$. Respective Type C ICC values were 0.88 (0.82–0.92) and 0.93 (0.90–0.96). There were no individual differences in the reliability of the subjective responses to cigarette smoking.

Individual Differences in Magnitude of Responses

Although reliability of responses generally did not vary by sex or dependence (see above), we examined whether the absolute magnitude of smoking topography and subjective responses may differ by these characteristics since such individual differences are typically of greater interest.

Smoking Topography

Total volume and maximum volume were significantly greater in men versus women, $F(1, 90)$'s of 8.08, $p < .01$, and 12.28, $p < .001$, respectively. Total volume and maximum volume were also significantly greater in high versus low dependent smokers, $F(1, 90)$'s of 5.12, $p < .05$, and 8.79, $p < .005$, respectively. No differences were significant for puff number, and there were no significant interactions, although the interaction of Sex × Dependence approached significance for total volume, $F(1, 90) = 3.06$, $p < .10$. Means for topography measures by sex and dependence level are shown separately in Figure 2, collapsed by day.

Subjective Responses

The only significant individual difference in subjective responses was a main effect of dependence on liking, $F(1, 67) = 3.90$, $p = .05$ as liking was higher for high versus low dependent smokers (see Figure 2).

Discussion

We found that puff topography and subjective measures from the ad libitum smoking of a single cigarette were highly reliable, indicating that such brief assessments of smoking behavior may be useful in studies of individual differences in smoking reinforcement and reward. Our results with nearly 100 subjects confirm the topography findings of Shahab et al. (2008), across just two sessions, and of Lee et al. (2003), with only seven smokers, and extend this reliability to self-reported reward (liking) and perception (how strong) ratings of smoking. Reliability may be poorer for smokers blind to brand (e.g., Perkins, Gerlach, Vender, Grobe, Meeker, & Hutchison, 2001), but our procedure of having smokers smoke their preferred brand in ad libitum and unblinded fashion is most similar to smoking in the natural environ-

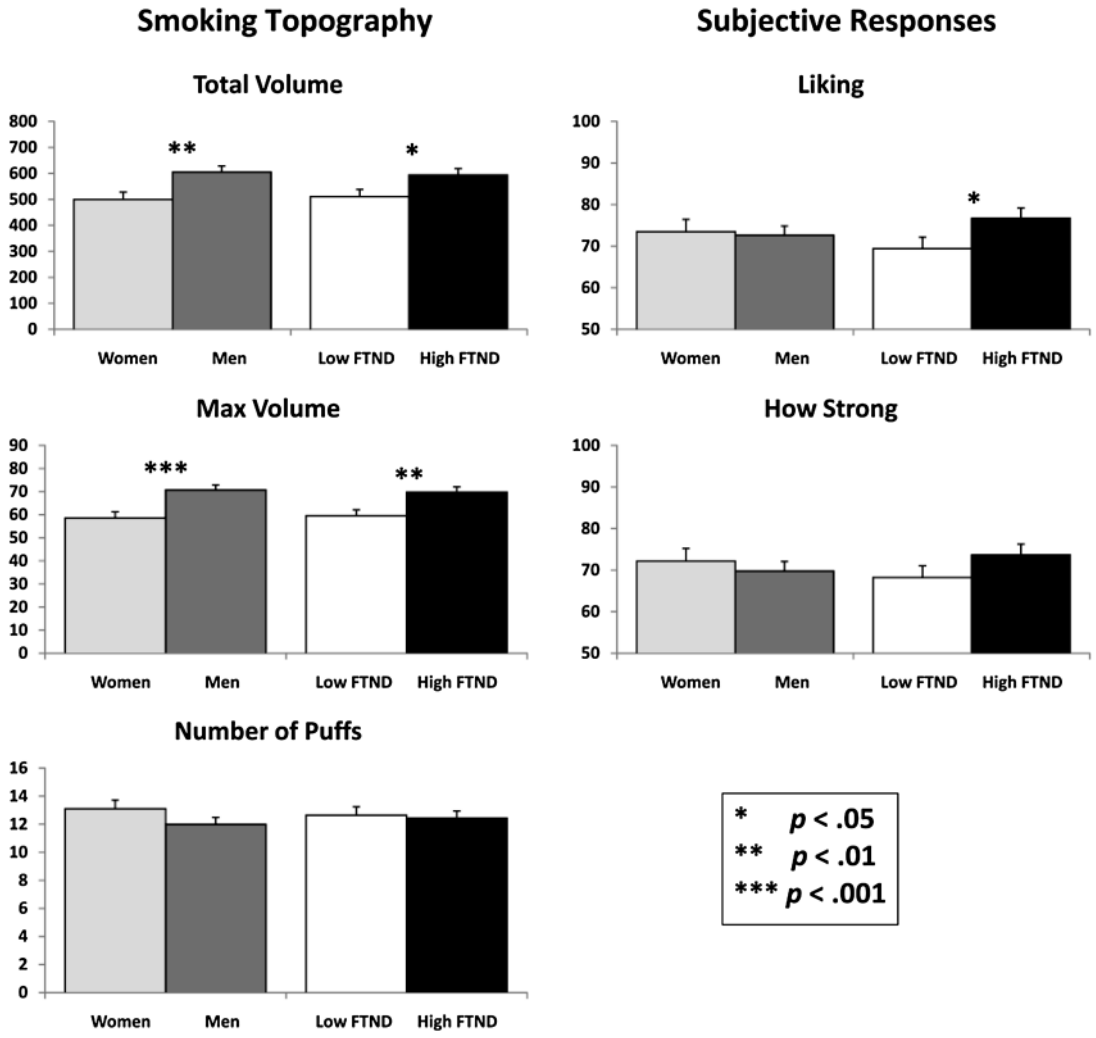

Figure 2. Mean smoking topography and subjective ratings, collapsed across days, separately by sex and by dependence level (high vs. low Fagerström Test for Nicotine Dependence [FTND]). As shown, main effects of sex and of FTND but no Sex × FTND interaction were significant for total volume and maximum puff volume. The main effect of FTND was also significant for liking.

ment, suggesting that such smoking is highly reliable. Reliability may also be different for smokers smoking conventionally, without any instrumentation (i.e., the CReSS device), although other research shows close similarity of topography between cigarettes smoked conventionally versus with the CReSS (Blank et al., 2009).

We generally did not see differences in the reliability of responses due to sex or dependence, indicating that reliability is comparable across different types of smokers. The only exception was poorer reliability of maximum puff volume (largest puff taken) in high versus low dependent men. This finding suggests that high dependent men may vary substantially across individual cigarettes in their maximum depth of puffing, perhaps inconsistent with the idea that their smoking behavior is more invariant (Shiffman & Paty, 2006). Further research is needed to confirm this individual difference. Future research should also explore other potential influences on the reliability of acute smoking responses, such as time of day (e.g., Grainge, Shahab, Hammond, O'Connor, & McNeil, 2009) and age (i.e., experimenting teens vs. dependent adults; Kassel et al., 2007).

Contrary to a lack of individual differences in reliability of responses, our main focus, we did observe individual differences in the magnitude of responses to smoking. Specifically, total volume and maximum puff volume, as well as liking, were greater in high versus low dependent smokers (see Figure 2). These differences suggest that acute reinforcement (puff volume) and reward (liking) from smoking a cigarette may typically be greater in more dependent smokers. Such a result could have clinical implications as mean puff volume during a single cigarette has been shown to predict cessation outcome (Strasser et al. 2004). Total volume and maximum puff volume were also greater in men versus women, perhaps helping to explain sex differences in cotinine levels (e.g., Gan, Cohen, Man, & Sin, 2008). Total volume and maximum puff volume dropped from Day 1 to subsequent days (Figure 1), suggesting that smokers may tend to smoke less from a single cigarette after the novelty of smoking upon arrival to a study session lessens. However, the high reliability of these measures indicates that any such decline across days is very comparable between individuals.

In conclusion, puff topography and subjective ratings while smoking a single cigarette under nondeprived unblind conditions are very reliable. These results suggest that inclusion of brief assessment of acute smoking behavior in research may provide simple and reliable measures of individual differences in smoking reinforcement and reward, demonstrating clear relevance for research attempting to understand individual variability in smoking behavior.

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Declaration of Interests

Dr. KAP has consulted with Cypress Bioscience on the development of smoking cessation medications. No other authors have any disclosures.

References

Battig, K., Buzzi, R., & Nil, R. (1982). Smoke yield of cigarettes and puffing behavior in men and women. *Psychopharmacology*, *76*, 139–148. doi: 10.1007/BF00435268

Blank, M. D., Disharoon, S., & Eissenberg, T. (2009). Comparison of methods for measurement of smoking behavior: Mouthpiece-based computerized devices versus direct observation. *Nicotine & Tobacco Research*, *11*, 896–903. doi: 10.1093/ntr/ntp083

Gan, W. Q., Cohen, SB-Z, Man, S. F. P., & Sin, D. D. (2008). Sex-related differences in serum cotinine concentrations in daily cigarette smokers. *Nicotine & Tobacco Research*, *10*, 1293–1300. doi: 10.1080/14622200802239132

Grainge, M. J., Shahab, L., Hammond, D., O'Connor, R. J., & McNeill, A. (2009). First cigarette on waking and time of day as predictors of puffing behaviour in UK adult smokers. *Drug and Alcohol Dependence*, *101*, 191–195. doi: 10.1016/j.drugalcdep.2009.01.013

Heatherton, T. F., Kozlowski, L. T., Frecker, R. C., & Fagerstrom K- O. (1991). The Fagerstrom Test for Nicotine Dependence: A revision of the Fagerstrom Tolerance Questionnaire. *British Journal of Addiction*, *86*, 1119–1127. Retrieved from http://web.ebscohost.com/ehost/pdfviewer/

Kassel, J. D., Greenstein, J. E., Evatt, D. P., Wardle, M. C., Yates, M. C., Veilleux, J. C., et al. (2007). Smoking topography in response to denicotinized and high-yield nicotine cigarettes in adolescent smokers. *Journal of Adolescent Health*, *40*, 54–60. doi: 10.1016/j.jadohealth.2006.08.006

Lee, E. M., Malson, J. L., Waters, A. J., Moolchan, E. T., & Pickworth, W. B. (2003). Smoking topography: Reliability and validity in dependent smokers. *Nicotine & Tobacco Research*, *5*, 673–679. doi: 10.1080/1462220031000158645

McGraw, K. O., & Wong, S. P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, *1*, 30–46. Retrieved from http://ft.csa.com/ids70

Perkins, K. A., Gerlach, D., Vender, J., Grobe, J. E., Meeker, J., & Hutchison, S. (2001). Sex differences in the subjective and reinforcing effects of visual and olfactory cigarette smoke stimuli. *Nicotine & Tobacco Research*, *3*, 141–150. doi: 10.1080/14622200110043059

Perkins, K. A., Jetton, C., Stolinski, A., Fonte, C., & Conklin, C. A. (2003). The consistency of acute responses to nicotine in humans. *Nicotine & Tobacco Research*, *5*, 877–884. doi: 10.1080/14622220310001614638

Perkins, K. A., Karelitz, J. L., Conklin, C. A., Sayette, M. A., & Giedgowd, G. E. (2010). Acute negative affect relief from smoking depends on the affect measure and situation, but not on nicotine. *Biological Psychiatry*, *67*, 707–714. doi: 10.1016/j.biopsych.2009.12.017

Perkins, K. A., Karelitz, J. L., Giedgowd, G. E., Conklin, C. A., & Sayette, M. A. (2010). Differences in negative mood-induced smoking reinforcement due to distress tolerance, anxiety sensitivity, and depression history. *Psychopharmacology*, *210*, 25–34. doi: 10.1007/s00213-010-1811-1

Perkins, K. A., Lerman, C., Grottenthaler, A., Ciccocioppo, M., Milanak, M., Conklin, C. A., et al. (2008). Dopamine and opioid gene variants are associated with increased smoking reward and reinforcement due to negative mood. *Behavioural Pharmacology*, *19*, 641–649. doi: 10.1097/FBP.0b013e32830c367c

Shahab, L., Hammond, D., O'Connor, R. J., Cummings, K. M., Borland, R., King, B., et al. (2008). The reliability and validity of self-reported puffing behavior: Evidence from a cross-national study. *Nicotine & Tobacco Research*, *10*, 867–874. doi: 10.1080/14622200802027156

Shiffman, S., & Paty, J. (2006). Smoking patterns and dependence: Contrasting chippers and heavy smokers. *Journal of Abnormal Psychology*, *115*, 509–523. doi: 10.1037/0021-843X.115.3.509

Strasser, A. A., Pickworth, W. B., Patterson, F., & Lerman, C. (2004). Smoking topography predicts abstinence following treatment with nicotine replacement therapy. *Cancer Epidemiology, Biomarkers, & Prevention*, *13*, 1800–1804. Retrieved from http://cebp.aacrjournals.org/content/13/11/1800.full.pdf+html

Westman, E. C., Behm, F. M., & Rose, J. E. (1996). Dissociating the nicotine and airway sensory effects of smoking. *Pharmacology, Biochemistry, & Behavior*, *53*, 309–315. doi:10.1016/0091-3057(95)02027-6