



Within-day temporal patterns of smoking, withdrawal symptoms, and craving[☆]

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ABSTRACT

We examined the temporal relationships between smoking frequency and craving and withdrawal. 351 heavy smokers (≥ 15 cigarettes per day) used ecological momentary assessment and electronic diaries to track smoking, craving, negative affect, arousal, restlessness, and attention disturbance in real time over 16 days. The waking day was divided into 8 2-h “bins” during which cigarette counts and mean levels of craving and withdrawal were computed. Cross-sectional analyses showed no association between restlessness and smoking, and arousal and smoking, but craving ($b = 0.65, p < 0.01$) was positively associated, and negative affect ($b = -0.20, p < 0.01$), and attention disturbance ($b = -0.24, p < 0.01$) were inversely associated with smoking. In prospective lagged analyses, higher craving predicted more subsequent smoking and higher smoking predicted lower craving (p 's < 0.01). Higher restlessness also predicted more subsequent smoking and higher smoking predicted lower restlessness (p 's < 0.01). Higher negative affect did not predict later smoking, but more smoking preceded lower negative affect ($p < 0.01$). Neither attention disturbance nor arousal predicted, or were predicted by variations in smoking. In short, smoking exhibits time-lagged, reciprocal relationships with craving and restlessness, and a one-way predictive relationship with negative affect. Temporal patterns of craving and restlessness may aid in the design of smoking cessation interventions.

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1. Introduction

Previous studies have demonstrated systematic, temporal variations in cigarette consumption during the waking day. In addition to evidence from a series of early laboratory studies (Ray et al., 1982; Nellis et al., 1982), we (Chandra et al., 2007) recently demonstrated circadian variations in smoking behavior with Ecological Momentary Assessments (EMA) – smoking data collected in real-time and in real-world settings (Stone and Shiffman, 1994; Shiffman et al., 2008). Our work identified several distinct temporal patterns of smoking related to stable, participant characteristics (e.g., demographics, history of depression) and that also prospectively predicted relapse risk. Several dynamic factors have been hypothesized to maintain systematic patterns in daily smoking (e.g., pharmacokinetics and pharmacodynamics, environmental smoking restrictions, exposure to smoking cues; Gries et al., 1996;

Emurian et al., 1982; Chandra et al., 2007). Few of these potential influences however, have been systematically studied. One should expect patterns of smoking to relate dynamically to complementary patterns of craving and withdrawal symptoms. That is, periods of the day when craving is high should be followed by periods of increased smoking. Conversely, periods of increased smoking should be followed by periods of decreased craving, with similar patterns for nicotine withdrawal symptoms. In this study, we explored whether patterns of smoking behavior are related to circadian patterns of nicotine craving and nicotine withdrawal symptoms including negative affect, restlessness, arousal and attention disturbance. Specifically, we examined these lead and lag relationships between smoking and patterns of craving and withdrawal symptoms.

Studies have identified systematic daily patterns in craving that might influence or maintain patterns of daily smoking. During ad lib smoking, craving is typically highest in the morning, lowest mid-day, and in some studies, elevated again in the evening hours (e.g., Perkins et al., 2009; Dunbar et al., 2010). Craving has also been shown to be reliably generated by smoking deprivation (Gomeni et al., 2001; Jarvik et al., 2000; Schuh and Stitzer, 1995; Teneggi et al., 2002), and smoking reliably relieves craving in the laboratory (e.g., Donny et al., 2007). Despite these craving-smoking links (Shiffman et al., 2002), particularly in the context of relapse (e.g., Shiffman et al., 1996a; Zhou et al., 2009), some researchers have

[☆] Figures illustrating data for one subject at three stages of the adjustment process can be found as supplementary material by accessing the online version of this paper at <http://dx.doi.org>.

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questioned the importance of craving for understanding smoking patterns, for example, because the reciprocal relationship (i.e., craving predicting or leading to smoking) is unreliable (Tiffany, 1990). Indeed, smoking can occur in the absence of craving (Shiffman et al., 2002; Dunbar et al., 2010). Conflicting findings about the importance of craving in maintaining smoking behavior make it important to understand how craving and smoking relate to each other during ad lib smoking.

A potential, related influence on smoking patterns is symptoms of nicotine withdrawal. Nicotine withdrawal is marked primarily by negative affect (or NA; APA, 2000), including tension or anxiety, irritability, and depressed affect. Like craving, previous studies have also demonstrated systematic, daily patterns in withdrawal symptoms that might influence or maintain patterns in daily smoking (e.g., Shiffman, 1979; Shiffman et al., 1996a; Teneggi et al., 2002; Perkins et al., 2009). Studies of negative affect have generally shown daily cycles, with the most negative affect in the morning and improvement in mood throughout the day (although other patterns have been reported; Rusting and Larsen, 1998). Some studies of negative affect in smokers have even shown that smokers report a pattern of repetitive fluctuations in affect related to smoking, such that negative affect increases in periods between cigarettes (O'Neill and Parrott, 1992; Parrott, 1995) suggesting systematic, lagged covariation between smoking and negative affect, consistent with the nicotine regulation model of smoking.

Yet, analyses of real-time data have generally not shown smoking occasions to be associated with negative affect states at the time of smoking (Carter et al., 2008; Shiffman et al., 2002, 2004b; see also Kassel et al., 2003 for a review). This may be because such instantaneous measures, right at the time of smoking are muddied by smokers' affective reactions in anticipation of enjoying a cigarette. Indeed, nicotine withdrawal symptoms and craving are usually assessed during abstinence, and contemporary models of smoking suggest that more subtle withdrawal reactions occur during the natural ebb and flow of ad lib smoking, and that they help maintain smoking, especially in an era of smoking restrictions. Research that addresses the relationship between negative affect and smoking in participants' natural environments (that include time spent in environments where smoking is both restricted and permitted) is needed to resolve these conflicting findings. Restlessness is also a nicotine withdrawal symptom (APA, 2000), but seems to represent a distinct phenomenon (Shiffman et al., 1996b, 2002) that is uniquely related to ad lib smoking, even when NA has been accounted for (Shiffman et al., 2002). Accordingly, we analyzed both NA and restlessness as separate symptoms of nicotine withdrawal.

The overall aim of this study was to characterize the dynamic relationship between craving, symptoms of nicotine withdrawal, and smoking, in temporal patterns seen during ad lib smoking. To do this, we analyzed EMA data on craving, nicotine withdrawal symptoms (negative affect, restlessness, arousal and attention disturbance), and smoking, taken in real-time and in participants' natural environments, with a novel analytic model in which we examined both contemporaneous and prospective relationships among these variables over successive 2-h time-blocks during smokers' waking day. We conceptualized 2-h time blocks as a "middle-ground" between other common units of analysis, such as entire days, which may blur temporal dynamics, and momentary assessments, which may focus too narrowly on the moment the smoker lights up. In addition to approximating the elimination half-life of nicotine (Le Houezac, 2003), 2-h intervals represented an even division of a typical, 16-h waking day that were able to reveal meaningful temporal variations in cigarette consumption (Chandra et al., 2007). We first analyzed data cross-sectionally (i.e., assessing how smoking, craving and nicotine withdrawal symptoms correlate within each time block), but recognize that such cross-sectional analyses do not establish temporal priority and thus can confound

Table 1
Participant characteristics^a.

Baseline characteristics	
N	351
Demographics	
Age	39.5 (9.5)
Female (%)	51.3
Ethnicity (% Caucasian)	84.9
Education (% with some college)	64.4
Income (% households > \$30,000)	57.2
Smoking characteristics	
Cigarettes per day	24.1 (9.2)
Years smoked	22.0 (9.7)
Breath CO (ppm)	37.69 (15.12)
Salivary cotinine (ng/mL)	314.36 (157.09) ^b
FTND	5.9 (2.0) ^c
FTND range	[1,10]
NDSS total	−0.01 (0.9)
NDSS range	[−2.01,2.52]

^a Means, with standard deviations in parentheses, unless otherwise indicated.

^b $n = 314$.

^c $n = 304$.

cause and effect. Accordingly, we also analyzed the data prospectively, adopting the approach of Granger's Analysis of Precedence (Granger, 1969), which examines, for example how craving at time 1 predicts smoking at time 2, while controlling for smoking at time 1. While the results of such analyses are not regarded as firm proof of causality, Granger analyses are regarded as strong indicators of potentially causal relationships (Hacker and Hatemi-J, 2006). We hypothesized reciprocal relationships between craving, nicotine withdrawal symptoms and smoking such that increased craving and withdrawal symptoms would drive later increased smoking, and increased smoking would drive later decreased craving and withdrawal symptoms.

2. Methods

2.1. Participants

Participants in the study were 412 adult men and women between the ages of 21 and 65 (mean age 39.3 ± 9) recruited through local media advertisements for a research-based smoking cessation program (Table 1). Inclusion criteria were: smoking rate ≥ 15 cigarettes per day for ≥ 5 years; self-reported good health; and high motivation and confidence to quit smoking (defined as a total of ≥ 150 on the sum of two 100 point scales). Exclusion criteria were: regular use of non-cigarette forms of tobacco; weight < 110 lbs or 50 kg; specific medical counter-indications to nicotine patch use (e.g., uncontrolled hypertension; allergy to adhesives); serious medical illness; history of recent alcohol/drug abuse or mental illness; current participation in a smoking cessation clinic or study; recent (in the last 30 days) participation in a clinical trial for smoking cessation; or use of bupropion hydrochloride within the past 2 months. Women who were pregnant, planning to become pregnant, or breastfeeding were also excluded. Eligible smokers who also passed a medical screening, and who signed an informed consent form were enrolled. Overall, study participants smoked an average of 24 ± 9 cigarettes per day and had smoked on average for 22 ± 10 years. Data were collected between 1995 and 2000 in Pittsburgh, Pennsylvania. During this time, state law prohibited smoking in government and private work sites, restaurants, and other work sites (Shelton et al., 1995). The study was approved by the University of Pittsburgh Institutional Review Board. Clinical outcomes and other findings from the cessation phase of this study have been reported elsewhere (Shiffman et al., 2006; Ferguson et al., 2009; Chandra et al., 2007). After data cleaning and processing, described in Section 2.6, data for 351 subjects were used in the analysis.

2.2. Procedure

Upon entering the study, participants completed a battery of questionnaires (described below) and were instructed in how to use the Electronic Diary (ED). Participants were instructed to continue smoking ad libitum, without changing their smoking frequency or pattern. The EMA protocol followed the methods described for a prior study (Shiffman et al., 2002). Participants were directed to use the ED for 16 days to record each cigarette smoked before smoking it. Both debriefing and quantitative analysis indicated that recording each cigarette before smoking it did not affect the number of cigarettes smoked (Shiffman et al., 2002). Also, the num-

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