



Full length article

## Negative urgency and ad-libitum smoking topography

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### ABSTRACT

**Background:** Negative urgency (NU), the tendency to act rashly in response to distress, is associated with negative reinforcement smoking expectancies. The study examined whether NU was associated with behavioral smoking reinforcement in the context of self-reported distress.

**Method:** Non-treatment seeking daily smokers (n = 124) completed an ad-libitum smoking trial. Puff topography, including puff volume, duration, velocity, and inter-puff interval, was averaged across the cigarette and evaluated at the puff level.

**Results:** Multilevel models revealed a significant interaction of NU and distress as reported on the Subjective Units of Distress scale over the course of smoking in relation to puff duration and inter-puff interval. There was a significant effect of quadratic time x NU x distress on duration (b = -0.00004, p = 0.04). Smokers lower in NU reporting lower baseline distress evidenced a puff duration that decreased at a faster rate over the course of a cigarette following a quadratic function. Persistently elevated puff durations over the course of a cigarette were observed among smokers with elevated NU, regardless of basal distress. There was also a linear time x NU x distress interaction on inter-puff interval (b = -0.01, p = 0.04). Lower NU smokers, regardless of acute distress, exhibited increasing inter-puff intervals that stabilized over the course of a cigarette. Smokers with elevated NU in the context of low distress also demonstrated linearly increasing inter-puff intervals, while they demonstrated increasing intervals followed by decreasing intervals in the context of higher distress.

**Discussion:** Trait NU in the context of acute distress may contribute to differences in puff topography.

### 1. Introduction

Emotional vulnerabilities, or trait-level differences in the way individuals regulate their emotions and respond to contextual factors (e.g., acute stressors), are posited to play an integral role in the comorbidity between psychopathology and the maintenance of cigarette smoking (Leventhal and Zvolensky, 2015). Negative urgency (NU) is conceptualized as a facet of impulsive behavior that represents an individual's tendency to act rashly in response to acute changes in negative affect, stress, or physical discomfort (Cyders and Smith, 2007; Whiteside and Lynam, 2001). NU is implicated in various forms of psychopathology, including depression (Settles et al., 2012; Smith et al., 2013), alcohol dependence (Settles et al., 2012), eating disorders (Anestis et al., 2009), and obsessions (Coughe et al., 2012), as well as persistent cigarette smoking. Higher levels of NU are associated with a greater likelihood of smoking initiation (Doran et al., 2013), tobacco dependence (Pang et al., 2014; Spillane et al., 2010), relapse during a

smoking cessation attempt (Bloom et al., 2014), and more severe craving for cigarettes during a quit attempt (Billieux et al., 2007). Consistent with negative reinforcement theories of drug motivation (McCarthy et al., 2010), smokers with higher levels of NU may rely on cigarettes as a means of regulating acute negative physical or psychological distress states. Initial empirical research indicates that NU is associated with stronger beliefs (i.e., expectancies) about the negative reinforcing properties of cigarettes, which in turn contribute to smoking and dependence (Doran et al., 2013; Pang et al., 2014).

The style in which an individual puffs a cigarette, or smoking topography, can be used as a behavioral index of smoking motivation (Perkins et al., 2012). Smokers tend to adjust puffing behavior in response to changing contextual situations in order to manipulate nicotine intake (e.g., Boren et al., 1990; Shahan et al., 1999). In response to acute negative distress states, smokers may experience nicotine as more reinforcing and, in turn, modify their puffing behavior to maximize nicotine administration (Perkins et al., 2010; Rose et al., 1983), which

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is evidenced by larger puff volumes (i.e., size of inhalation) and longer puff durations, greater puff velocity, and shorter inter-puff intervals (i.e., the time in-between successive puffs).

Smoking topography allows for the characterization of individual differences that may contribute to negative reinforcement smoking. For example, depression and anxiety symptoms have been linked to ‘atypical’ puff topography, including larger puff volumes and sustained puffing during the course of ad-libitum smoking (Farris et al., 2017; Perkins et al., 2010; Veilleux et al., 2011). Certain emotional vulnerabilities, like distress intolerance, have also been linked to smoking reinforcement, especially in the context of acute distress states (Bold et al., 2013; Farris et al., 2018; Perkins et al., 2010). No studies to date have examined NU in relation to smoking topography. Smokers with higher levels of NU may tend to demonstrate more persistent puffing behavior while smoking, in an effort to maximize the perceived distress-modulating properties of nicotine. Additionally, given that NU is conceptualized as an emotional vulnerability factor that confers risk for participation in maladaptive coping, specifically in the context of distress (Cyders and Smith, 2007), the relation between NU and reinforcement smoking may be unique to contexts wherein negative distress states are elevated.

The current study examined the effects of NU and acute subjective distress on smoking reinforcement during ad-libitum smoking. Smoking reinforcement was indexed via average-level and puff-level topography data. Based on previous research, we hypothesized that there would be a context-dependent effect of NU on smoking reinforcement, wherein NU would be associated with puff topography in the context of high, but not low, distress.

## 2. Method

### 2.1. Participants

Adult non-treatment-seeking daily smokers were evaluated for potential participation in an experimental study on smoking behavior and anxiety (Farris and Zvolensky, 2016). Participants were recruited for a study on smoking behavior through advertisements in the community and online (e.g., university website, online forums) and through word-of-mouth. Participants who completed the baseline assessment ( $n = 124$ ; 43.7% female) were included in the present analyses. Participation in the study was determined using the following inclusion criteria: (1) between 18 and 65 years of age, (2) smoking daily for at least the past year, (3) smoking an average of 10 or more cigarettes per day, (4) stability of daily cigarette use (i.e., had not decreased daily use by more than half in the past six months), and (5) smoking the first cigarette of the day within thirty minutes of waking. Participants were excluded from participation in the baseline screening during an initial telephone screen if they reported frequent drinking ( $\geq 9$  standard drinks/week) or illicit drug use ( $\geq 3$  days/week). Participants were excluded for other substance use at these frequency/quantity cut-offs due to potential use that may be contraindicated for study participation, which may require a higher level of care. Similarly, participants were excluded for unstable medical conditions or current psychotic symptoms. Participants were also screened for current pregnancy and nursing status during the phone screen and lab session, and those individuals were excluded from participation in the study. The sample identified as primarily black or African American (64.3%), white (29.4%), and other (6.3%). On average the sample was 43.94 years of age ( $SD = 9.71$ ). The sample reported smoking an average of 15.8 ( $SD = 5.9$ ) cigarettes per day, and scores on the Fagerström Test for Cigarette Dependence were 4.7 ( $SD = 1.49$ ), suggesting moderate levels of tobacco dependence. The average expired carbon monoxide level at baseline was 22.56 ppm ( $SD = 11.43$ ). The sample also reported use of alcohol and cannabis. The prevalence of any past-month alcohol or cannabis use was 50.8% ( $n = 63$ ) and 12.9% ( $n = 16$ ) of the sample, respectively. The percent days of use averaged 13.0% ( $SD = 22.5$ )

drinking days and 3.3% ( $SD = 13.3$ ) cannabis-use days. Among those who reported alcohol use, the average percent days drinking was 25.5% ( $SD = 26.1$ ). Among those reporting cannabis use, the average percent days of use was 25.4% ( $SD = 29.0$ ).

### 2.2. Measures

#### 2.2.1. Demographics

General demographic information was collected, including biological sex (reported as male or female), age, and race/ethnicity.

#### 2.2.2. Timeline Follow-back

The Timeline Follow-back (Sobell and Sobell, 1992) was used to assess past month use of alcohol, cannabis, cigarettes, and other substances. Participants indicated whether or not they used alcohol or other substances as well as the quantity of use on a given day.

#### 2.2.3. Urgency, premeditation, perseverance, and sensation seeking impulsive behavior

The Urgency, Premeditation, Perseverance, and Sensation Seeking Impulsive Behavior scale (Whiteside et al., 2005) is a 59-item measure assessing characteristics of personality and impulsivity. The urgency subscale was used to assess NU. Participants rated items on a 4-point Likert-type scale (1 = *agree strongly* to 4 = *disagree strongly*) to indicate how much each statement applied to them. The scale appears to be reliable (Weafer et al., 2013) and has been frequently used to assess dimensions of impulsivity within cigarette smokers (Lee et al., 2015; Spillane et al., 2010). Internal consistency of the items comprising the NU subscale was good within the current sample ( $\alpha = 0.88$ ).

#### 2.2.4. Subjective units of distress scale

The Subjective Units of Distress scale (Wolpe, 1958) was used to assess self-reported distress prior to ad-libitum smoking using a visual-analog scale ranging from 0 (*no distress right now*) to 100 (*extreme distress right now*).

#### 2.2.5. The Fagerström test for cigarette dependence

The Fagerström Test for Cigarette Dependence FTCD (Fagerstrom, 2012) was used to assess cigarette dependence. This measure has been found to be associated with other indices of dependence, such as cotinine levels and smoking history (Payne et al., 1994; Pomerleau et al., 1994). It also exhibits high test-retest reliability (Pomerleau et al., 1994).

#### 2.2.6. Smoking history questionnaire

The Smoking History Questionnaire (Brown et al., 2002) is a 30-item questionnaire that was used to assess participants' smoking history and pattern of cigarette use. For example, items assess onset of use, length of time being a daily smoker, and smoking frequency and intensity.

#### 2.2.7. Clinical research support system

The CReSS (CReSS device; Plowshare Technologies, Borgwaldt KC, Inc., Virginia) is a device used to measure topographical indices of cigarette smoking. The CReSS device has a sterilized flow meter mouthpiece that is connected to a pressure transducer, which converts pressure into a digital signal that is sampled at 1000 Hz. CReSS computer software transforms the signal to a flow rate (mL/s), from which puff topography data are computed. The reliability and acceptability of use of the portable CReSS device is well documented (Blank et al., 2009; Perkins et al., 2012), and it is recommended over direct observation as well as for use outside to increase ecological validity (Perkins et al., 2012). Puff topography as assessed via the CReSS appears to be similar to conventional smoking, and minimal differences have been reported between puff topography measured during conventional use and use with a portable device (Blank et al., 2009). Puff topography measured

**Table 1**  
Correlations between relevant covariates, predictor variables, and smoking topography.

	1	2	3	4	5	6	7	8	9	10	11	12	13	M (SD)
1. Age	–	–0.17	0.03	–0.05	0.05	0.13	–0.17	–0.04	–0.07	0.07	0.02	–0.03	–0.02	43.94 (9.71)
2. Sex	–	–	0.05	0.05	–0.05	–0.05	–0.06	–0.18 <sup>†</sup>	–0.20 <sup>†</sup>	0.02	–0.15	–0.01	0.18 <sup>†</sup>	43.7% Female
3. Race	–	–	–	0.19 <sup>†</sup>	0.10	–0.09	–0.02	0.04	0.03	0.03	–0.08	–0.01	0.14	64.3% Black
4. Tobacco dependence	–	–	–	–	0.17	–0.08	0.17	0.02	–0.06	0.09	–0.22 <sup>†</sup>	–0.13	0.14	4.67 (1.49)
5. Carbon Monoxide	–	–	–	–	–	–0.07	0.01	–0.02	0.05	–0.07	0.02	–0.01	–0.06	22.63 (11.34)
6. Negative Urgency	–	–	–	–	–	–	–0.41 <sup>**</sup>	–0.11	–0.07	–0.08	0.10	0.04	–0.03	2.77(0.66)
7. Subjective Distress	–	–	–	–	–	–	–	0.08	0.09	–0.01	–0.11	–0.09	0.01	25.44(24.24)
8. Volume Avg (mL)	–	–	–	–	–	–	–	–	0.65 <sup>**</sup>	0.40 <sup>**</sup>	0.13	0.08	–0.13	66.21(26.29)
9. Duration Avg (s)	–	–	–	–	–	–	–	–	–	–0.38 <sup>**</sup>	0.27 <sup>**</sup>	0.06	–0.37 <sup>**</sup>	1.78 (0.68)
10. Velocity Avg (mL/s)	–	–	–	–	–	–	–	–	–	–	–0.24 <sup>**</sup>	0.01	0.36 <sup>**</sup>	39.86(11.42)
11. IPI Avg (s)	–	–	–	–	–	–	–	–	–	–	–	0.51 <sup>**</sup>	–0.63 <sup>**</sup>	12.94(5.28)
12. Time Smoking (s)	–	–	–	–	–	–	–	–	–	–	–	–	0.25 <sup>**</sup>	299.35 (86.13)
13. Number of Puffs	–	–	–	–	–	–	–	–	–	–	–	–	–	21.20 (7.77)

\*  $p < 0.05$ .

\*\*  $p < 0.01$ .

via the CReSS is also associated with biochemical measures of smoking, including plasma nicotine, exhaled carbon monoxide, and heart rate (Lee et al., 2003). Finally, there is evidence that the portable device results in reliable assessments of puff topography (Blank et al., 2009; Lee et al., 2003). In the current study, topography data was downloaded immediately after use. The puff topography indices of puff volume (mL of smoke), puff duration (length of puff measured in seconds), puff velocity (volume/duration), and inter-puff interval (seconds between puffs) were examined in the current analyses.

### 2.3. Procedures

Eligible participants were scheduled for an in-person appointment. Upon arrival to the laboratory, participants completed informed written consent. Participants then reported on their smoking history via the Smoking History Questionnaire and other smoking characteristics via the Fagerström Test of Cigarette Dependence and Timeline Follow-back. Biochemical verification of smoking was assessed through expired carbon monoxide breath analysis to determine smoking recency. Exhaled carbon monoxide was significantly associated with self-reported cigarettes smoked the day prior to the study session ( $r = 0.26$ ,  $p = 0.004$ ). All participants completed an assessment of past year psychopathology via the semi-structured clinical diagnostic assessment, the *Structured Clinical Interview of DSM-IV-TR Disorders/Non-Patient Version*. Participants also completed initial assessments of their distress using the Subjective Units of Distress scale as well as current cravings to smoke. Immediately following these assessments, participants completed an ad-libitum outdoor smoking trial using their preferred cigarette brand. Participants were instructed to bring their usual brand of cigarettes to the study appointment. Participants used the *Clinical Research Support System* (CReSS device; Plowshare Technologies, Borgwaldt KC, Inc., Virginia) to smoke their cigarette, and they were oriented to proper use of the CReSS prior to smoking. The experimenter accompanied the participant outside and instructed the participant to smoke a single cigarette as usual. Participants were given as much time as desired to smoke, and they were instructed to avoid distractions such as speaking with bystanders or using electronic devices. The experimenter then left the participant alone while observing them from inside to ensure they did not deviate from the instructions. On average, participants smoked for 299.35 s ( $SD = 86.13$ ; range = 115–572 s), or approximately four minutes and fifty-nine seconds. Following these procedures, participants who were determined eligible for the experimental portion of the study completed additional procedures that involved a biological stressor and a second ad-libitum smoking trial (Farris and Zvolensky, 2016). Only data from the initial baseline assessment were used in the current analyses. All participants who participated in baseline tasks were compensated \$25 for their time and

participation. The Institutional Review Board where the study took place approved all of the procedures.

### 2.4. Data analytic procedures

Linear regression models were conducted in SPSS Version 24, and multilevel models were conducted in Stata Version 14 to examine the moderating effects of distress on the relation between NU and smoking behavior via topographical indices by examining both average-level and puff-level data. Linear regression models were constructed to test the main effects of distress, NU, and a distress by NU interaction on average puff volume, average puff duration, average puff velocity, and average inter-puff interval. Second, multilevel modeling was used to examine the main and interactive effects of distress and NU on changes in puff volume, duration, velocity, and inter-puff interval over the course of a cigarette. Puff number was indexed as “time” in the model, and the models included the primary predictors of NU, distress, and time, as well as the interaction terms.

The intraclass correlation (ICC) values for puff-level volumes (ICC = 0.52, 95% CI = 0.46% to 0.59%), durations (ICC = 0.53, 95% CI = 0.46% to 0.59%), velocities (ICC = 0.60, 95% CI = 0.53% to 0.66%), and inter-puff intervals (ICC = 0.24, 95% CI = 0.19% to 0.30%) were above the conservative recommended value of 0.10, indicating these indices are appropriate for use in multilevel modeling. Linear, quadratic, and cubic effects of time were modeled, and model fit was examined using Akaike information criterion (AIC) and the Bayesian information criterion (BIC). All predictor variables were mean centered, and random intercepts and slopes were included in all models. Huber/White/Sandwich robust standard errors were estimated in order to adjust for heteroskedasticity in the error terms, and an unstructured covariance matrix was specified to allow for each covariance to be uniquely estimated.

#### 2.4.1. Model building

In the linear regression and multilevel models, self-reported distress and negative urgency were entered as continuous variables. Given significant correlations between sex and topographical indices (i.e., volume ( $r = 0.18$ ,  $p < 0.05$ ) and duration ( $r = 0.20$ ,  $p < 0.05$ ; Table 1), cigarette dependence and inter-puff interval ( $r = 0.22$ ,  $p < 0.05$ ), and puff number and topographical indices (i.e., duration ( $r = -0.37$ ,  $p < 0.01$ ), velocity ( $r = 0.36$ ,  $p < 0.01$ ), and inter-puff interval ( $r = -0.63$ ,  $p < 0.01$ )), we included sex, cigarette dependence, puff number, and a baseline measure of expired carbon monoxide in parts per million from breath analysis (i.e., an index of smoking recency) as covariates in the models. Age and race were not significantly correlated with any of the topographical indices and were not included in the final models. Continuous variables were mean centered prior to

model entry. Significance was determined based on  $p < .05$ .

Individual multilevel models were conducted in an incremental fashion to determine the significance of, first, the effects of time, intercepts, and covariates, followed by the predictor variables on the outcomes of interest. First, linear, quadratic, and cubic effects of time were examined to determine how to best define the trajectories of puff volume, duration, velocity, and inter-puff interval. The effects of time were entered as fixed and random effects to determine whether there was a significant fixed and/or random slope. Next, simplified intercepts-only models were examined to determine whether there was a significant fixed intercept (i.e., common starting point) or a random intercept (i.e., variable starting point) for each topographical index. This model also included covariates of sex, cigarette dependence, and expired carbon monoxide. The final models included significant covariates as well as the best-fitting time variable (i.e., linear, quadratic, and/or cubic).

2.4.2. Data cleaning

Raw puff-level smoking topography data were examined for range and outliers. The observed range of puffs during ad-libitum smoking ranged from 7 to 43 ( $21.3 \pm 7.56$ ). Due to the small number of data points with puff counts  $\geq 40$  ( $n = 0.5\%$  of data points), these data points were dropped from analyses to maintain the shape of the data distribution. Outlying values were identified using standard scores, with a criterion of  $z = 3.5$  to retain maximum data. A small number of outlying values were detected (2.1%). The outliers were then recoded as one unit higher than the next lowest non-outlying value via winsorizing methods. The patterning of results was unchanged when the outliers were removed (winsorized) versus retained (as-is). Winsorized variables were retained in analyses because the outliers affect the underlying assumptions of normality.

3. Results

3.1. Average-level smoking reinforcement

Results from the linear regression analyses are displayed in Table 2. The main effect of distress, NU, or their interactive effect were not statistically related to average puff volume ( $F(1,116) = 1.65, p = 0.20; R^2 = 0.01$ ), duration ( $F(1,116) = 1.40, p = 0.24; R^2 = 0.01$ ), velocity ( $F(1,116) = 0.07, p = 0.79; R^2 = 0.001$ ), or inter-puff interval ( $F(1, 116) = 0.01, p = 0.91; R^2 = 0.0001$ ).

3.2. Puff-level smoking reinforcement

3.2.1. Model fit

Results from each multilevel model are presented in Table 3, and results for each topographical index are reported in turn. Comparison of model fit indices indicated that a model with a quadratic effect of time best fit the data for puff volume (lowest AIC and BIC values: quadratic time [AIC = 23885.49, BIC = 23996.94]). A quadratic effect of time best fit the data for puff duration (quadratic time [AIC = 5036.346,

BIC = 5147.792]). A linear effect of time best fit the data for puff velocity (linear time [AIC = 18893.18, BIC = 18981.16]). A cubic effect of time best fit the data for inter-puff interval (cubic time [AIC = 18325.44, BIC = 18460.34]).

3.2.2. Puff volume

Results indicated that there was an effect of linear time ( $b = -1.06, p = 0.02$ ) and quadratic time ( $b = -0.07, p < 0.01$ ) on puff volume, suggesting a significant change in puff volume over the course of a cigarette. However, there were no main or interactive effects of NU, distress, or time.

3.2.3. Puff duration

Results indicated that there was an effect of linear time ( $b = -0.37, p < 0.001$ ) and quadratic time ( $b = -0.002, p = 0.001$ ) on puff duration. There were no significant main or interactive effects of NU, distress, or linear time. However, there was a significant effect of NU x distress x quadratic time on puff duration ( $b = -0.00004, p = 0.04$ ). Puff duration decreased over the course of a cigarette—rapidly decreasing at the end of the cigarette—for those lower in NU who reported less subjective distress. However, puff duration remained elevated over the course of a cigarette regardless of distress for smokers higher in NU (Fig. 1).

3.2.4. Puff velocity

Results indicated that there was an effect of linear time on puff velocity ( $b = 0.28, p < 0.001$ ). There were no main or interactive effects of NU, distress, or time on puff velocity.

3.2.5. Inter-puff interval

Results indicated that there was no effect of linear time on inter-puff interval ( $p = 0.21$ ); however, there was a significant effect of quadratic ( $b = -0.01, p = 0.002$ ) and cubic time ( $b = 0.002, p < 0.001$ ) on inter-puff interval. There was a significant NU x distress x linear time interaction ( $b = -0.01, p = 0.04$ ) on inter-puff interval; however, there were no other significant main or interactive effects. For smokers low in NU in the context of acute distress, inter-puff intervals increased linearly over the course of a cigarette. In contrast, smokers higher in NU, in the context of greater distress, also exhibited initial increases in inter-puff intervals; however, this was followed by shorter inter-puff intervals toward the end of the cigarette. This decrease in inter-puff intervals at the end of a cigarette was not observed in the context of low distress (Fig. 2).

4. Discussion

The current study examined the effects of NU and acute subjective distress on smoking reinforcement via ad-libitum smoking topography. Smoking was indexed via average-level and puff-level data in order to investigate the associations between NU in terms of puffing behavior generally and in terms of changes over the course of a cigarette. Findings indicated that NU was not related to average puff topography.

Table 2  
Linear regression models predicting puff volume, duration, velocity, and inter-puff interval.

Variable	Volume				Duration				Velocity				IPI			
	b	SE	t	p	b	SE	t	p	b	SE	t	p	b	SE	t	p
Sex (1 = female)	-9.73	4.83	-2.01	0.05	-0.20	0.12	-1.70	0.09	-1.30	2.01	-0.65	0.52	-0.50	0.76	-0.66	0.51
Carbon Monoxide	-0.18	0.22	-0.81	0.42	0.001	0.005	0.05	0.96	-0.06	0.09	-0.72	0.48	0.01	0.03	0.15	0.88
Tobacco Dependence	0.86	1.65	0.52	0.60	-0.01	0.04	-0.19	0.85	0.37	0.69	0.55	0.59	-0.43	0.26	-1.65	0.10
Puff Number	-0.29	0.32	-0.90	0.37	-0.03	0.01	-3.86	0.001	0.54	0.13	4.09	0.001	-0.41	0.05	-8.19	0.001
Distress	0.03	0.11	0.32	0.75	0.002	0.003	0.76	0.45	-0.03	0.05	-0.58	0.56	-0.02	0.02	-1.06	0.29
Negative Urgency	-4.65	3.95	-1.18	0.24	-0.07	0.10	-0.69	0.49	-1.68	1.64	-1.02	0.31	0.39	0.62	0.62	0.54
NU x Distress	0.21	0.16	1.29	0.20	0.005	0.004	1.19	0.24	-0.02	0.07	-0.27	0.79	0.003	0.03	0.11	0.91

**Table 3**  
Results from multilevel models for puff-level analyses.

Variable	Volume			Duration			Velocity			IPI		
	<i>b</i>	<i>z</i>	<i>p</i>									
Intercept	69.00	14.00	< 0.01	1.76	14.36	< 0.01	42.10	26.80	< 0.01	17.04	17.85	< 0.01
Sex	-10.03	-2.22	0.03	-0.25	-2.12	0.03	-0.20	-0.11	0.91	-1.72	-1.74	0.08
Carbon Monoxide	-0.03	-0.20	0.84	0.002	0.37	0.71	-0.03	-0.33	0.74	0.02	0.43	0.67
Cigarette Dependence (FTCD)	1.15	0.75	0.45	-0.02	-0.44	0.66	0.77	0.98	0.33	-0.66	-1.86	0.06
Linear Time	-1.06	-2.33	0.02	-0.04	-3.79	< 0.01	0.28	3.99	< 0.01	-0.13	-1.26	0.21
Quadratic Time	-0.07	-2.69	< 0.01	-0.002	-3.30	< 0.01	-	-	-	-0.01	-3.08	< 0.01
Cubic Time	-	-	-	-	-	-	-	-	-	0.002	5.01	< 0.01
Distress (i.e., SUDs)	0.06	0.32	0.75	0.004	0.98	0.33	-0.04	-0.70	0.48	-0.03	-0.97	0.33
NU	-4.95	-0.68	0.50	-0.01	-0.04	0.97	-2.51	-1.36	0.17	0.44	0.39	0.70
SUDs x NU	0.11	0.39	0.70	0.01	1.00	0.32	-0.09	-1.13	0.26	0.001	0.001	1.00
Linear time x SUDs	0.01	0.79	0.43	0.001	1.05	0.30	-0.001	-0.06	0.95	-0.01	-1.05	0.30
Linear time x NU	0.22	0.41	0.68	0.01	0.71	0.48	-0.09	-0.82	0.41	-0.11	-0.76	0.45
Linear time x SUDs x NU	-0.01	-0.69	0.49	-0.001	-1.07	0.28	-0.003	-0.70	0.49	-0.01	-2.04	0.04
Quadratic time x SUDs	0.001	1.16	0.25	0.001	1.10	0.27	-	-	-	-0.001	-0.56	0.58
Quadratic time x NU	0.02	1.05	0.29	0.001	0.71	0.48	-	-	-	-0.001	-0.01	1.00
Quadratic time x SUDs x NU	-0.001	-0.44	0.66	-0.001	-2.10	0.04	-	-	-	-0.001	-1.12	0.26
Cubic time x SUDs	-	-	-	-	-	-	-	-	-	0.001	0.59	0.56
Cubic time x NU	-	-	-	-	-	-	-	-	-	0.001	1.15	0.25
Cubic time x SUDs x NU	-	-	-	-	-	-	-	-	-	0.001	1.53	0.13

However, in the context of acute subjective distress, NU was related to the course of puffing behavior while smoking a cigarette in terms of puff duration and inter-puff interval.

The analyses indicate that there was a significant interaction between NU and acute subjective distress on puff duration and inter-puff interval during the ad-libitum smoking period. The observed pattern of puff duration and inter-puff interval over the course of a cigarette may be indicative of alterations in tobacco reward for smokers reporting greater NU in the context of distress. In particular, puff durations remained elevated over the course of a cigarette, and inter-puff intervals decreased at the end of a cigarette for smokers higher in NU and acute distress. Whereas puff durations may be expected to decrease and inter-puff intervals may be expected to elongate (Kolonen et al., 1992), which may be consistent with satiation, deviations in these patterns may suggest smoking serves a different function for smokers who tend to react rashly in the context of affective distress. Specifically, smokers higher in NU in the context of distress may take longer puffs over the course of a cigarette and reduce time between puffs by the end of a cigarette to modulate the effects of smoking.

These findings are broadly consistent with research examining individual difference factors, such as the presence of psychopathology (Farris et al., 2017; Perkins et al., 2010) and emotional vulnerabilities like distress intolerance (Farris et al., 2018), that are predictive of differences in behavioral smoking indices. The significant interaction effects and lack of main effects provide evidence of the context-dependent nature of NU in terms of reinforcement smoking. That is, NU appears to only confer risk for negative reinforcement smoking in the

context of acute distress (Cyders and Smith, 2007). The current findings extend prior self-report evidence of the association between NU and smoking negative reinforcement expectancies (e.g., smoking reduces tension; Doran et al., 2013; Pang et al., 2014) by providing behavioral support of modulated smoking in response to distress. They further support a motivational model of cigarette smoking indicating that emotional vulnerabilities may serve to amplify the anxiolytic effects of cigarette smoking (Leventhal and Zvolensky, 2015; Pomerleau and Pomerleau, 1987). The patterning of results suggests that the relationship between NU and smoking reinforcement may only be evident when nuanced (i.e., puff-to-puff data) information is available about puffing behavior relative to average-level data. That is, NU in the context of acute distress may contribute to variability in the reinforcing efficacy of nicotine over the course of a cigarette.

There are several study limitations. First, smoking recency was not standardized prior to ad-libitum smoking; however, by adjusting for expired carbon monoxide, we attempted to statistically address this issue. Second, smokers were not previously exposed to the CRESS device, which could have potentially contributed to differences in smoking behavior. Despite these limitations, this is the first study to our knowledge to evaluate NU in terms of behavioral smoking reinforcement. In addition, we utilized an ecologically valid smoking trial, wherein participants smoked outdoors with their usual brand of cigarettes, which we believe strengthens the real-world relevance of this work. Finally, distress was not experimentally manipulated in this study, and natural variation in pre-smoking stress was utilized as an index of acute distress. The null effects of NU on puff volume and

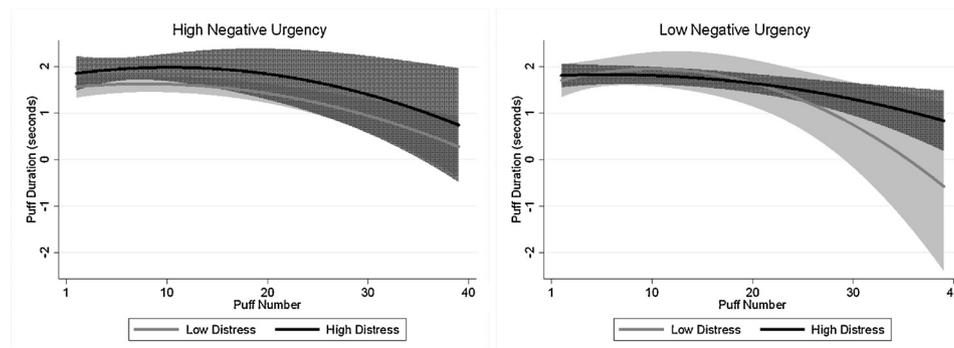


Fig. 1. Interaction between negative urgency (NU) and distress on puff duration trajectory.

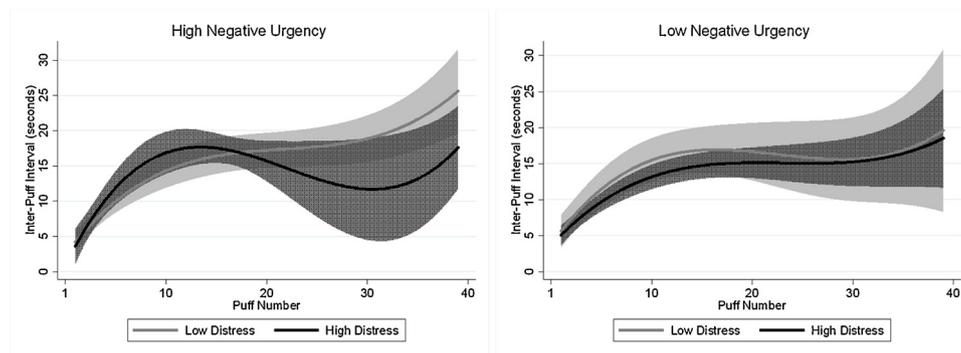


Fig. 2. Interaction between negative urgency (NU) and distress on inter-puff interval trajectory.

velocity may be due to a lack of direct manipulation. Future research will need to examine the effects of an experimental manipulation of stress on NU and puff topography in order to examine the specific effects of timing, or acute versus general stress, intensity of distress, as well as the effects of the nature of distress. Although there is limited research on the effects of NU in the context of changes in physiological arousal, it is possible that a similar relation may be observed. For cigarette smokers, this may be particularly relevant in the context of withdrawal.

NU appears to be a promising individual difference factor that might undergird smoking reinforcement and persistently elevated reinforcing efficacy of nicotine. Evidence suggests that individuals adjust cigarette smoking in response to contextual cues in order to manipulate nicotine intake (Boren et al., 1990; Perkins et al., 2010; Shahan et al., 1999). The current findings expand on this observation by identifying a specific individual difference factor that predicts puff behavior in the context of distress. Both sustained puff duration and decreasing inter-puff intervals at the end of a cigarette may indicate that nicotine is experienced as more reinforcing in the context of high distress for smokers reporting greater NU. Therefore, NU may be an important mechanism in smoking maintenance, as it increases the rewarding value of smoking. Future research could examine the effects of NU on various stages of smoking behavior. NU may alter cigarette dependence through its association with the reinforcing properties of cigarettes as well as predict an increased likelihood of lapse in the context of stress.

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