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Attention Bias in Nicotine Withdrawal and Under Stress

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Drug motivation models postulate that attention biasing toward smoking-related cues is a cognitive mechanism supporting continued or renewed drug use, and they predict that drug use history, deprivation, and distress should modulate the extent of this bias. The present study used the modified Stroop paradigm to extend past research regarding attention biasing toward smoking and unpleasant, pleasant, and neutral words among adult nonsmokers and daily smokers. Both nonsmokers and smokers showed differential attention toward unpleasant and pleasant cues, particularly pleasant cues, but did not show a unique bias toward smoking-related stimuli. Results suggested that, among smokers, nicotine deprivation and exogenous stress (threat of electric shock) have a nonadditive effect on attention toward pleasant cues but no effect on attention to smoking cues specifically. Similarly, instructing smokers that they would have an opportunity to smoke did not significantly increase the bias of nicotine-deprived smokers' attention toward smoking-related cues, relative to arousing unpleasant and pleasant cues. Overall, results suggest that smokers' attention may be biased toward both smoking-related and other salient cues when deprived of nicotine and anticipating an opportunity to smoke.

Keywords: tobacco, modified Stroop, nicotine withdrawal, attention

Cessation failure and relapse remain the norm in tobacco cessation attempts, with fewer than 35% of people typically achieving sustained abstinence, even with the aid of the most efficacious treatments (Fiore et al., 2008; Hughes, Stead, & Lancaster, 2004; Silagy, Lancaster, Stead, Mant, & Fowler, 2004). The reformulated negative reinforcement model of drug motivation posits that escape from negative affect is the dominant (although not the exclusive) motive for such cessation failures and relapse (Baker, Piper, McCarthy, Majeskie, & Fiore, 2004). Negative affect (e.g., anxiety, irritability, sadness) is the primary constituent of the nicotine withdrawal syndrome (Welsch et al., 1999) and emerges within the first 3 hr of abstinence from smoking (Hendricks, Ditre, Drobes, & Brandon, 2006). According to the reformulated negative reinforcement model, one mechanism by which negative affect predisposes addicted individuals to smoke is the biasing of information processing. Specifically, the model postulates that symptoms of withdrawal can bias addicted smokers' attention toward smoking-related cues, which may predispose them to relapse (Niaura et al., 1988; Waters & Sayette, 2006). Such biasing of attention is not a sufficient cause for smoking in most situations, however, as individuals can detect and resolve conflict between incompatible responses (i.e., smoking vs. maintaining abstinence) using inhibitory self-control mechanisms even when moderately distressed (Curtin, McCarthy, Piper, & Baker, 2006).

Research using the modified Stroop task (Stroop, 1935) among smokers is generally consistent with this account of the attention-modulating effects of drug motivation. In the Stroop smoking task, smokers are asked to name the color of the letters in smoking-related and neutral words. The degree to which smokers are slower to name the color of smoking-related words versus neutral words is thought to indicate interference due to attention to the meaning of the smoking-related words. Nicotine deprivation, which induces a withdrawal syndrome characterized primarily by negative affect (Welsch et al., 1999), has been shown to increase attention toward smoking-related versus neutral words in research using this task (Gross, Jarvik, & Rosenblatt, 1993; Waters & Feyerabend, 2000), and the degree of interference is positively associated with the duration of deprivation (Cox, Fadardi, & Pothos, 2006) and predictive of relapse (Waters, Shiffman, et al., 2003). Although results have not been consistent across all studies (Cox et al., 2006; Waters & Sayette, 2006), the failures to replicate deprivation-induced increases in attention toward smoking cues are not fatal to the negative reinforcement model of drug motivation, as negative findings occurred in studies using samples low in nicotine dependence (e.g., college students) or weak manipulations of nicotine deprivation (Mogg & Bradley, 2002; Munafò, Mogg, Roberts, Bradley, & Murphy, 2003; Rusted, Caulfield, King, & Goode, 2000).

Additional research supports the notion that such attention bias is subject to top–down control, consistent with the negative reinforcement model of addiction. In the area of smoking, Wertz and Sayette (2001) demonstrated that attention is more biased toward

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smoking versus neutral cues during nicotine deprivation when an opportunity to smoke is anticipated. When smokers received a brief instruction that they might (vs. definitely would not) have an opportunity to smoke during the experimental session, they did not show interference to smoking stimuli. When they were told that they *would* have an opportunity to smoke, a significant interference effect was observed. This moderating effect suggests that the effect of withdrawal on attention is influenced by context rather than an inevitable consequence of abstaining from drug use.

The study of the effects of smoking opportunity on affect and behavior is still in its infancy. As earlier research in this area has shown, instructing smokers that smoking opportunities would be available within 20 min increased urges to smoke and enhanced the urge-inducing effects of smoking cues (Juliano & Brandon, 1998). In the same study, reaction times on a simple tone detection task were longer when smokers were told they would not be able to smoke for at least 3 hr and were exposed to smoking-related cues (Juliano & Brandon, 1998). Manipulations of shorter time frames have suggested that the proximity of the smoking opportunity influences smokers' responses to availability manipulations in important ways. Opportunities to smoke a lit cigarette within 15 s elicited positive affect (as evinced by facial expression), whereas longer (e.g., 60 s) or ambiguous (e.g., "soon") delays elicited negative affect, relative to a no-smoking opportunity condition in laboratory studies (Sayette et al., 2003). Other research suggests that cravings, positive mood, and skin conductance increase as the probability of being able to take a puff from a lit cigarette within the next 20–30 s increases from 0% to 50% and to 100%, whereas negative affect and response latencies decrease and the probability of cigarette access increases (Carter & Tiffany, 2001). Taken together, these data suggest that smokers' attention, craving, affect, and behavior are influenced by instructions about availability in the very short term and that longer term availability also affects urges to smoke and reaction times. Thus, these results suggest that availability context can influence smokers in important ways. Future treatments may be able to help smokers take advantage of such contextual effects to maximize the likelihood of abstinence.

Another testable prediction derived from the reformulated negative reinforcement model of drug motivation is that repeated cycles of smoking followed by withdrawal relief should result in a narrowing of attention toward smoking-relevant stimuli in withdrawal, as smoking is the most efficient and rapid reliever of withdrawal distress. If this prediction is correct, then smokers should show an attention bias for smoking-related stimuli when deprived of nicotine but no bias toward other pleasant stimuli that have not been previously associated with withdrawal relief. To test this prediction, however, one needs to examine response times to name the color of other arousing stimuli that are not related to smoking. Only one previous study has assessed nicotine deprivation effects on attention bias toward nonsmoking threat and reward cues (Powell, Tait, & Lessiter, 2002). In this study, nicotine deprivation moderated attention bias for positively and negatively valenced cues among smokers so that continuing smokers showed interference to both reward- and threat-related words, relative to neutral words, whereas abstinent smokers did not. These results are consistent with the hypothesis that deprivation decreases attention to cues unrelated to smoking, even salient, motivationally relevant cues. However, the Powell et al. (2002) study cannot speak to the hypothesis of attention narrowing derived from the negative reinforcement model, because smoking-related stimuli were not presented.

Finally, the reformulated negative reinforcement model asserts that negative affective states that resemble withdrawal at an interoceptive level promote drug seeking (i.e., smoking) in a manner similar to that of withdrawal. That is, addicted smokers learn that smoking is negatively reinforced through the alleviation of withdrawal-induced negative affect; this learning is then generalized to similar negative affect states that arise from causes other than withdrawal. The chief symptoms of withdrawal (anxiety, anger, irritability, and sadness; Welsch et al., 1999) are influenced by myriad factors and may not be easily distinguishable from similar states elicited by different causes. For example, an individual who learns to smoke to reduce irritability due to withdrawal may experience a similar increase in smoking motivation when irritability is due to interpersonal conflict, presumably because the interoceptive affective stimuli are similar regardless of their origin. If this hypothesis is true, we should see similar increases in motivation to smoke, and associated attention bias toward smoking-related cues, after nicotine deprivation and presentation of an exogenous stressor. Stress is a potent precipitant of relapse (Kassel, Stroud, & Paronis, 2003; Shiffman, Paty, Gnys, Kassel, & Hickcox, 1996). Increases in drug motivation and associated attention biasing may partially explain this relation, along with occupation of limited mental work space, according to the negative reinforcement model of addiction. Although the extent to which stress induced by exogenous stressors (e.g., interpersonal conflict, physical pain) resembles that induced by tobacco deprivation on an interoceptive level is not fully known, evidence suggests that similar regions of the anterior cingulate and insula cortex are activated by both physical and emotional pain (Critchley, Wiens, Rothstein, Ohman, & Dolan, 2004; Eisenberger, Lieberman, & Williams, 2003; Seminowicz & Davis, 2007; Sewards & Sewards, 2002) and by craving for drugs of abuse, including tobacco (Bonson et al., 2002; Brody et al., 2002; Naqvi, Rudrauf, Damasio, & Bechara, 2007).

In the present study, we compared nonsmokers' and smokers' attention to neutral, unpleasant, pleasant, and smoking-related words, using a modified Stroop task, and examined the effects of manipulations of nicotine deprivation and smoking availability (among smokers), as well as an exogenous stressor, on attention bias. Unpredictable, uncontrollable electric shock was selected as the exogenous stressor because past research suggests that this effectively induces self-reported anxiety and increases in psychophysiological indices of negative affect, such as potentiated startle responses (Grillon, Baas, Cornwell, & Johnson, 2006; Hogle & Curtin, 2006), and can influence responding on modified Stroop tasks (e.g., Miller & Patrick, 2000). Inclusion of these manipulations allowed us to test the following hypotheses derived from the reformulated negative reinforcement model of drug motivation: (a) Smokers would show greater attention toward smoking-related versus other arousing pleasant stimuli than would nonsmokers, presumably because of the motivational relevance (and incentive salience) of smoking-relevant cues conferred by negative reinforcement learning. (b) Twenty-four hours of nicotine deprivation would result in greater interference to smoking-related vs. other salient and pleasant cues but only when a smoking opportunity was anticipated (i.e., the effect would be eliminated by instruction that one definitely could not smoke). Although one may expect increased frustration from being told that smoking is not permitted—and therefore increased interference due to distress—previous research suggests that deprived smokers respond to such instructions with lower rather than greater interference (Wertz & Sayette, 2001). We sought to replicate this finding. We also examined whether deprived smokers would show the same insensitivity to cues of reward (i.e., pleasant words) and threat (i.e., unpleasant words) as that reported by Powell and colleagues (Powell et al., 2002). (c) An exogenous stress manipulation (threat of shock) would prompt both deprived and nondeprived smokers, but not nonsmokers, to bias attention toward smoking cues, but not other arousing unpleasant or pleasant cues, presumably because of learning that smoking alleviates stress effects resembling nicotine withdrawal. In other words, we expected the exogenous threat of shock to bias smokers' attention toward smoking-related cues in a manner similar to that of nicotine deprivation, although we did not assess the putative mechanism of this similarity (i.e., learned generalization across similar interoceptive and mood states induced by deprivation and stressors).

It is important to note that these predictions are not unique to the negative reinforcement model of addiction. Indeed, other models, such as Robinson and Berridge's incentive sensitization model (1993) have also predicted that repeated drug use biases attention toward drug-related cues and have specified that background distress levels modulate the incentive salience of drug stimuli. As such, we cannot claim that this study tests predictions that distinguish the reformulated negative reinforcement model from alternative accounts of drug motivation. Instead, we claim that this study exposes some of the specific predictions about the effects of affective processing on smoking-relevant information processing postulated in the reformulated negative reinforcement model to risk of refutation.

Method

Participants

The final sample included 113 adults drawn from the community (see Tables 1 and 2 for sample characteristics). All participants were at least 18 years old and literate native speakers of English. Twenty-two nonsmokers (defined as smoking no more than 100 cigarettes over lifetime) and 91 heavy daily smokers (defined as smoking at least 10 cigarettes per day for the past year

Table 1
Demographics for the Final Sample of Participants ($N = 107$)

	Nonsmokers ($n = 22$)		Continuing smokers ($n = 46$)		Deprived smokers ($n = 39$)	
Demographic	*n*	%	*n*	%	*n*	%
Female participants	12	54.5	22	47.8	18	46.2
Race/ethnicity						
White	18	81.8	23	50.0	18	46.2
African American	3	13.6	17	37.0	17	43.6
Other	1	4.5	3	6.5	3	7.7
Hispanic	2	9.1	2	4.3	2	5.1
Education[a]						
0–11 grades completed	1	4.5	11	23.9	7	17.9
Grade 12 or GED	3	13.6	14	30.4	17	43.6
College 1–3 years	10	45.5	17	37.0	13	33.3
College 4 or more years	7	31.8	2	4.3	2	5.1
Employment						
Working outside home	15	68.2	21	45.7	16	41.0
Unemployed/disabled	3	13.6	20	43.5	23	59.0
Homemaker	1	4.5	3	6.5	2	5.1
Student	3	13.6	1	2.2	1	2.6
Retired	0	0	1	2.2	1	2.6
Income						
Less than $10,000	8	36.4	22	47.8	17	43.6
$10,000–$19,999	3	13.6	11	23.9	8	20.5
$20,000–$24,999	4	18.2	4	8.7	2	5.1
$25,000–$34,999	2	9.1	7	15.2	6	15.4
$35,000 or more	5	22.7	2	4.3	5	12.8
Marital status[b]						
Never married	15	68.2	17	37.0	13	33.3
Divorced or separated	0	0	15	32.6	12	30.8
Married	5	22.7	6	13.0	7	17.9
Living with partner	2	9.1	4	8.7	5	12.8
Widowed	0	0	1	2.2	1	2.6
Mean age (and *SD*)	28.09[c]	(11.03)	39.09	(10.88)	40.64	(10.25)

Note. Percentages do not sum to 100 because of missing data. GED = general equivalency diploma.
[a] Nonsmokers more likely than smokers to have some college education, $p < .05$. [b] Nonsmokers more likely than smokers to be never married and less likely to be separated or divorced, $p < .05$. [c] Nonsmokers younger than smokers, $p < .05$.

Table 2
Descriptive Statistics for the Sample of Smokers Who Complied With Experimental Instructions and Provided Reaction Time Data (n = 85)

Descriptive statistic	Continuing smokers, no availability (*n* = 25)		Continuing smokers, availability (*n* = 21)		Deprived smokers, no availability (*n* = 20)		Deprived smokers, availability (*n* = 19)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	40.32	11.09	37.62	10.69	42.40	8.93	38.79	11.43
No. of cigarettes per day	19.60	7.28	22.38	9.65	22.35	9.58	20.63	11.09
Age first smoked	14.16	2.43	13.33	3.80	12.80	6.33	12.74	2.90
Age first smoked daily	16.20	2.84	16.81	3.68	16.30	6.11	15.42	2.71
No. of years smoked daily	22.62	10.68	19.00	10.48	24.00	11.30	23.58	10.86
No. of past quit attempts	1.96	2.34	3.24	4.63	2.35	2.43	3.58	3.72
FTND total score	5.56	2.29	5.48	2.32	6.10	2.25	5.63	2.03
Pretask CO level*	30.50	16.32	26.68	10.37	4.30	3.03	3.32	2.07
Pretask total WSWS	2.19	0.63	2.19	0.58	2.48	0.50	2.28	0.69
Pretask WSWS, Urge subscale*	2.42	0.94	2.53	0.92	3.29	0.68	3.03	1.06
Posttask total WSWS	1.88	0.70	1.93	0.57	2.02	0.63	2.03	0.87
Posttask WSWS, Urge subscale	2.25	1.14	2.36	1.00	2.70	0.94	2.50	1.28
Posttask total QSU–Brief*	3.82	2.26	3.80	1.92	4.90	1.71	4.79	2.05

Note. FTND = Fagerström Test of Nicotine Dependence; CO = carbon monoxide; WSWS = Wisconsin Survey of Withdrawal Symptoms; QSU–Brief = Brief Questionnaire on Smoking Urges.
* $p < .05$

or more and having an expired-air carbon monoxide (CO) level at or above 10 parts per million [ppm]; see below for further details) were enrolled. Regular users of other forms of tobacco (including pipes, cigars, chew, and snuff) were excluded as were people actively trying to quit smoking with formal assistance (e.g., nicotine replacement therapy, counseling). Individuals who endorsed colorblindness or uncorrected hearing or vision problems were excluded because of the demands of the experiment. Individuals who reported having a pacemaker or an unstable cardiac condition or who reported a past or current diagnosis or treatment for generalized anxiety disorder, panic disorder, or chronic pain conditions (e.g., fibromyalgia) were excluded because of concerns regarding the effects of the threat manipulation. Women who reported being pregnant or at risk of becoming pregnant after a lack of protection since the last menses were excluded because of concerns about adverse effects of exposing these individuals to electric shock.

Design

The study used a mixed design. Between-participants factors included the following: (a) nicotine dependence (nonsmoker vs. daily smoker); (b) among smokers, nicotine deprivation (nondeprived vs. deprived for 24 hr); and (c) among smokers, smoking opportunity during the lab session (unavailable vs. available). Thus, there were five between-participants groups, a nonsmoking group, and four groups resulting from the full crossing of deprivation status and smoking opportunity among dependent smokers (22 nonsmokers, 25 nondeprived smokers not given an opportunity to smoke, 21 nondeprived smokers given an opportunity to smoke, 24 deprived smokers not given an opportunity to smoke, and 21 deprived smokers given an opportunity to smoke). Random assignment to deprivation status and smoking opportunity groups among smokers was matched on gender. Participants in each of the five groups were randomly assigned to one of eight stimulus presentation orders.

Two within-participant factors were manipulated: word set (neutral, unpleasant, pleasant, and smoking related) and threat (threat of shock vs. safety). Word sets were presented in blocked format. All participants saw each of the four word sets under both the safe and threat conditions (with the order counterbalanced across participants). The presentation order of word set blocks was constrained so that unpleasant and pleasant words were always separated by neutral words and smoking-related words always occurred in the first or last block to prevent carry-over effects related to seeing smoking-related words before neutral words documented in previous research (Waters, Sayette, & Wertz, 2003). Breaks were provided between blocks to reduce carry-over effects as well (Waters, Sayette, Franken, & Schwartz, 2005).[1]

Procedure

Recruitment and screening. Participants were recruited through television advertisements and flyers soliciting both nonsmoking and daily smoking volunteers for a research study regarding smoking. Interested individuals who telephoned the laboratory were offered a description of the study and screened for eligibility over the telephone.

Participants who met all inclusion criteria (described earlier) were invited to attend a one-hour group session at which informed consent for additional screening was obtained, smoking status and history were reassessed and verified through expired alveolar carbon monoxide (CO) testing, and individual difference variables

[1] Order of block presentation did not interact significantly with word set, shock, or any between-participants factor (i.e., smoking status, deprivation, or availability) in analyses.

were assessed using a battery of self-report measures. Nonsmokers were considered eligible if they confirmed smoking fewer than 100 cigarettes in their lifetime, had an expired CO concentration less than 10 ppm, and were willing to take part in the experiment. Smokers were considered eligible if they confirmed smoking at least 10 cigarettes per day for the past year or longer, had an expired CO concentration of at least 10 ppm, were willing to take part in the experiment, and agreed to be randomized to either continue smoking normally or to stop smoking 24 hr before the experimental session.

Experimental session. At the start of the experimental session, CO concentration was reassessed to verify smoking status and adherence to abstinence instructions. Deprived smokers instructed to abstain from smoking for 24 hr were considered abstinent if they reported no smoking in the past 24 hr and if the average of two CO readings was less than 10 ppm and at least 50% reduced from the baseline level. Six of the 45 smokers assigned to abstain had questionable abstinence (low levels of smoking were reported at the beginning of the abstinence period or CO levels were not at least 50% reduced from baseline) and were excluded from analyses.[2]

At the beginning of the experimental session, participants were informed about the nature of the experimental procedures, including the color-naming task and the electric shock and availability manipulations (although they were not told exactly how many shocks they would receive). Those who provided written informed consent to participate in the experiment and who passed screening for contraindications to the administration of electric shock completed affect and withdrawal measures. All participants then completed an electric shock sensitivity assessment procedure (discussed later).

Modified Stroop Task

During the experiment, all participants were instructed to name aloud the script color of the words as quickly as possible. Participants received standardized instruction in the task and then completed 20 practice trials with neutral words.

Word sets. Each word set contained 20 words matched for initial letter and number of letters (see Appendix). Smoking-related words were adapted from previous research (Wertz & Sayette, 2001) and modified to enhance matching of stimuli. Unpleasant and pleasant words were selected from a published database (the Affect Norms for English Words; Bradley & Lang, 1999). Words with extreme valence ratings were selected and matched for arousal rating. Unpleasant words had a mean valence of 2.7 ($SD = 0.7$) on the 9-point Pleasure Rating scale ranging from 1 (*very unpleasant*) to 9 (*very pleasant*), whereas the pleasant words had a mean valence of 7.5 ($SD = 0.6$). Arousal ratings made on a 9-point scale did not differ between the unpleasant ($M = 6.2$, $SD = 0.8$) and pleasant ($M = 6.2$, $SD = 0.9$) word sets, and all affective words selected were rated above the midpoint on the arousal scale. Words in the neutral, unpleasant, and pleasant word sets were also matched for frequency using tables from Kucera and Francis (1967). The frequency of smoking-related words was not matched because of the inherent inequality in frequencies for these words between smokers and nonsmokers, although the average frequency rating for smoking words for which frequency was available was equal to the average frequency for other types of words used in the study. Words were also matched in relation to a superordinate category. Because all smoking-related words are related to smoking, similarly related classes of words were selected for the other word sets to reduce the risk of unique priming effects in smoking-related blocks (Williams, Matthews, & MacLeod, 1996). Neutral words were related to writing; unpleasant words were related to violence, pain, and death; and pleasant words were related to sex and pleasure. Sex-related words were selected because this category of positive words comprised words rated as most arousing and most pleasant in previous research (Bradley & Lang, 1999) as is true for nonverbal stimuli as well (Bernat, Patrick, Benning, & Tellegen, 2006; Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley, Codispoti, Sabatinelli, & Lang, 2001). Alternative categories, such as money and success, did not offer as many words with extreme valence and arousal ratings as did the sex/pleasure category (Bradley & Lang, 1999) and thus were more difficult to match to the other groups of words on other dimensions (i.e., length, first letter, frequency).

Procedure. Words were presented individually in red, blue, or green script for 1,500 ms in the center of a 21-in. (53.34-cm) CRT monitor with DMDX stimulus control software (Forster & Forster, 2003). Words were presented in blocks by category because past research suggests that the blocked version is more sensitive to interference effects than is the interspersed version (Waters & Feyerabend, 2000). Latency to the onset of a vocal response was recorded for each trial, and an audio file was generated so that accuracy of the response could be coded by two independent raters ($\kappa = .84$, $SE = .01$, $t = 154.13$, $p < .001$) and discrepancies could be resolved by a third rater. Stimuli were separated by varying intertrial intervals (1,000 ms, 1,500 ms, 2,000 ms).

Each set of 20 words was presented twice in each block of 40 trials. Each block of 40 trials was presented twice; once with the shock-delivering electrodes taped to the fingertips (threat) and once with the electrodes removed (safe), in counterbalanced order, for a total of 320 trials. Order of word presentation within each set of 20 words was randomized in each block.

Between blocks, participants received computerized feedback regarding their average response time to encourage sustained effort at the color-naming task and to facilitate detection of nonresponses due to failures of recording equipment (i.e., responses that were not detected yielded a response time of −2,500 ms, which prompted the experimenter to adjust equipment). During the interblock interval, participants were also asked to complete a brief self-report assessment of affect and withdrawal distress. After the fourth block, all participants took a 5-min break and had the electrodes removed or reapplied, as needed.

Electric shock. All participants completed a shock sensitivity assessment before the start of the main experiment. This procedure was used to calibrate the intensity of the shock to each individual to reduce individual differences associated with pain sensitivity. Participants were administered a series of 250-ms electric shocks of increasing intensity to the index and ring fingers on the nondominant hand. The shocks ranged in intensity from 0.5 to 7.0 mA. Participants reported the level of shock (a) that they first detected,

[2] Cases excluded because of questionable abstinence did not differ from the smokers who adhered to abstinence instructions in terms of smoking history or demographics. Including these cases in analyses did not change the pattern of results.

(b) that they first found uncomfortable, and (c) that was the most they could tolerate. Participants were informed that the shock sensitivity procedure would be discontinued when they rated a shock as the most they could tolerate (i.e., this would be the last shock they would receive).

Participants received a total of five electric shocks during the experimental session, with the intensity of each shock set at the midpoint between the level the participant considered uncomfortable and the maximum tolerable. Participants were not informed of this formula for setting the shock level for the experimental task until the debriefing at the end of the experiment. As this manipulation was intended to serve as a threat condition, participants were not informed that they would experience only five shocks before the experiment. Each 250-ms shock administered during the experiment was followed by a 2,000-ms interval. The timing of the shocks was held constant across all participants (after the 20th word in the first block, before the first word and after the 20th word in the second block, after the 40th word in the third block, and after the 20th word in the fourth block).

Measures

At the informational meeting, participants provided self-report data regarding smoking behavior, history, and general demographic information. Among these measures was the Fagerström Test of Nicotine Dependence (Heatherton, Kozlowski, Frecker, & Fagerström, 1991). Additional measures will not be discussed further in this report. Baseline characteristics of the enrolled sample are reported in Table 1.

At the start of the experimental lab session, participants completed the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) and the Wisconsin Survey of Withdrawal Symptoms (WSWS; Welsch et al., 1999). All participants also completed the PANAS after each of the eight blocks of trials. Craving items were not administered between blocks due to concerns about reactivity to repeated questioning regarding urges to smoke. After the eighth and final block, however, smokers were asked to complete the full WSWS and the 10-item Brief Questionnaire on Smoking Urges (QSU–Brief; Cox, Tiffany, & Christen, 2001). Each of these scales has published reliability and validity information. The PANAS yields two highly internally consistent scale scores (for momentary positive affect, $\alpha = 0.89$; for momentary negative affect, $\alpha = 0.85$; Watson et al. 1988). The WSWS has a seven-factor structure and a second-order single factor structure. Each of the seven subscales has acceptable internal consistency (αs ranged from 0.75 to 0.90; Welsch et al., 1999). The QSU–Brief has a two-factor structure and a higher order factor, the total scores of which have excellent internal consistency (αs = 0.87–0.97; Cox et al., 2001).

We conducted analyses of Stroop task response times for correct trials only (97.3% of trials). Extremely fast reaction times ($\leq$200 ms; 1.1% of correct trials) were excluded. To reduce the influence of exceptionally slow responses, trials that were slower than each participant's mean plus 3 standard deviations were set to equal the mean plus 3 standard deviations.[3]

Smoking availability manipulation. Following Wertz and Sayette (2001), we used a simple instructional manipulation of smoking availability. Just before the first block of experimental trials, the experimenter either informed the participant that he or she would have the opportunity to smoke at some point during the 2-hr session or informed the participant that he or she would not be able to smoke until after the 2-hr session ended. For those who were randomly assigned to have an opportunity to smoke, experimenters provided the opportunity immediately after completing the self-report measures following the eighth (final) block of trials.

Data Analytic Strategy

The nature of the three primary between-participants factors in this experiment—smoking status (smoker vs. nonsmoker), nicotine deprivation (deprived vs. non-deprived smokers), and cigarette availability (available vs. unavailable)—precluded the use of a fully crossed factorial design. For example, nonsmokers could not be included in nondeprived cells of a factorial design. Instead, we relied on orthogonal contrasts among the five smoking groups. Specifically, four orthogonal contrasts were coded to test the effects of smoking status, nicotine deprivation, and cigarette availability:[4]

1. A *smoking status* contrast: nonsmokers vs. the four smoker groups.

2. A *deprivation* contrast: the two nondeprived smoker groups versus the two deprived smoker groups.

3. A *nondeprived availability* contrast: nondeprived smokers with cigarettes available vs. nondeprived smokers with cigarettes unavailable.

4. A *deprived availability* contrast: deprived smokers with cigarettes available versus deprived smokers with cigarettes unavailable.

We adopted a similar orthogonal contrast approach to test within-participant effects of word set in the analyses of response times from the main task. Analysis of the four word sets (neutral, threat, reward, and smoking) was accomplished by the following orthogonal Helmert contrasts:

1. A *motivationally relevant word* contrast: neutral words versus the three motivationally relevant types of words (unpleasant, pleasant, and smoking).

2. A *reward word* contrast: unpleasant words versus pleasant and smoking words.

3. A *smoking-specific word* contrast: sex/pleasure pleasant words versus smoking words.

[3] A total of 1.1% of trials exceeded 3 standard deviations above the participant's mean response time. The pattern of results did not change when these trials were treated as missing or set to the fence.

[4] The pattern of results was similar when the main effects of and interaction between deprivation and availability were tested in a factorial ANOVA, although the significance level for the Threat $\times$ Word Set $\times$ Deprivation interactions for motivationally relevant and reward words were marginally significant in this approach ($p = .07$). The overall Threat $\times$ Word Set $\times$ Availability interaction was nonsignificant ($p = .33$).

We used this contrast-based analytic strategy to test the hypotheses of interest by means of orthogonal tests that partition the overall effects of the manipulation in the most meaningful way for our model without increasing family-wise error (because the multiple planned comparisons simply partition the overall effect detected in an omnibus test without representing more tests). Complete orthogonality of the between-participants contrasts is not guaranteed, however, because of inequality in cell sizes. Hypothesis 1 is tested by the interaction between the nonsmoker/smoker contrast and the smoking-specific word contrast, which indicates whether smokers differentiate between smoking-related and other reward-related words more than do nonsmokers. The first part of Hypothesis 2 regarding deprivation effects on attention bias toward smoking cues is tested by the interaction between the nondeprived smokers/deprived smokers contrast and the contrast between smoking-related words and other pleasant, reward-related words. This will indicate whether deprivation increases bias toward smoking words specifically overall. The second part of Hypothesis 2 will be tested by the interaction between the availability conditions within the deprived group and the smoking-related word/pleasant word contrast. This will determine whether the deprivation effect on attention bias toward smoking-related vs. other pleasant words depends on availability. Hypothesis 3 regarding the shock manipulation is tested by two interaction contrasts. First, the three-way interaction between the shock manipulation, the nonsmoker/smoker contrast, and the smoking-related word/pleasant word contrasts tells us whether smokers showed greater bias toward smoking-related words under threat of shock than did nonsmokers overall, as we predicted. A second three-way interaction with the deprivation, shock, and smoking-related word/pleasant word set contrasts tell us whether the effect for smokers depends on deprivation status. We predicted that this would be nonsignificant.

In addition to focusing analyses on our questions of interest, these contrasts also provide attractive controls to help establish the specificity of observed effects. For example, contrasting neutral words with the composite of unpleasant, pleasant, and smoking-related words allows us to determine whether participants are responding to the broad motivational relevance or salience of words and whether our manipulations alter this bias. In addition, contrasting unpleasant words with the composite of pleasant sex/pleasure and smoking-related words allows for a test of interference to reward words, controlling for arousal. This set of orthogonal contrasts was considered more attractive than an alternative in which reaction times to pleasant words were contrasted with the composite of reaction times to both unpleasant and smoking-related words, and we compared reaction times to unpleasant words versus smoking-related words because we expected drug cues to function as appetitive rather than aversive cues.

Results

Characteristics of Smokers and Nonsmokers

The nonsmoking and smoking samples were not comparable in all ways, as shown in Table 1. Nonsmokers tended to be younger, less likely to have been married, and more likely to have attended college than smokers. Removing variability related to age and college attendance in analyses did not alter the results of the hypothesis testing reported later. Marital status was found to be redundant with both of these other covariates and thus was not included as a covariate. Given the interpretation problems inherent in using covariates to attempt to reduce the influence of preexisting group differences (Miller & Chapman, 2001), we elected to present the results of models unadjusted for covariates.

Smoking-Related Individual Differences

The four groups of smokers were similar in terms of smoking history and nicotine dependence levels. None of the three contrasts among smokers (nondeprived vs. deprived smokers; nondeprived smokers with an opportunity to smoke vs. those without an opportunity to smoke; or deprived smokers with an opportunity to smoke vs. those without an opportunity to smoke) was significant for any of the smoking history and nicotine dependence variables listed in Table 2.

Manipulation Checks

Nicotine deprivation. We conducted analyses of CO level and pretask WSWS scores among the four smoker groups to confirm successful manipulation of nicotine deprivation among dependent smokers. Means and standard deviations by smoking group are presented in Table 2. Univariate smoking group contrasts for CO level revealed the expected significant deprivation contrast, $F(1, 80) = 117.51$, $p < .001$, $\eta_p^2 = .60$; with CO level lower among deprived smokers ($M = 3.82$, $SD = 2.62$) than among nondeprived smokers ($M = 28.80$, $SD = 13.97$). Neither the nondeprived nor the deprived availability contrast was significant, indicating comparable deprivation status across the availability groups as expected.

Multivariate analyses of smoking group contrasts across six subscales of the WSWS[5] revealed the expected significant multivariate deprivation contrast, $F(7, 75) = 2.34$, $p = .032$, $\eta_p^2 = .18$; with scale scores generally elevated for deprived smokers relative to nondeprived smokers. As expected, neither the nondeprived nor the deprived availability contrast was significant in this multivariate analysis. Follow-up univariate contrasts on individual WSWS scales confirmed the expected significant deprivation contrast for the Urge scale, $F(1, 81) = 11.78$, $p < .001$, $\eta_p^2 = .13$; with increased urge among deprived smokers ($M = 3.2$, $SD = 0.9$) relative to nondeprived smokers ($M = 2.5$, $SD = 0.9$) but no significant difference in negative affect ($\eta_p^2 = .02$). In addition, total urge as assessed by the QSU–Brief was significantly higher for deprived smokers ($M = 4.84$, $SD = 1.86$) than nondeprived smokers ($M = 3.81$, $SD = 2.10$, $F(1, 80) = 5.47$, $p = .02$, $\eta_p^2 = .06$) at the end of the task as well, suggesting that the deprivation effects were not eliminated over the course of the experiment, although the difference between groups on the WSWS Urge scale declined (as did WSWS Urge ratings overall) during the experiment. After the task, deprived smokers ($M = 2.60$, $SD = 1.11$) had WSWS Urge scores that were not significantly different than those of nondeprived smokers ($M = 2.30$, $SD = 1.07$, $F(1, 81) = 1.53$,

[5] The Sleep subscale was excluded from the MANOVA because smokers were deprived for only one night, and we considered it unlikely that the subscale would be sensitive to deprivation lasting only 24 hr.

p = .22, η_p^2 = .02). The availability manipulation did not significantly influence any of these ratings.

Threat of shock. We conducted a Smoking Group × Threat mixed-model ANOVA for all participants to confirm that the shock threat manipulation increased negative affect. There was a significant medium-sized main effect of threat, $F(1, 101) = 8.50$, $p = .004$, $\eta_p^2 = .08$; with negative affect scores from the PANAS higher in the shock threat condition (M = 16.4, SD = 7.0) than in the no-shock condition (M = 15.1, SD = 6.9). Neither the smoking group contrasts nor the interaction of these contrasts with threat was significant, confirming that the threat manipulation was comparable across all groups. Similarly, shock intensity did not differ significantly across groups.[6]

Modified Stroop Task

Replication of smoking Stroop effect. Before conducting our targeted contrast-based analyses, we conducted simple comparisons of reaction times to neutral and smoking-related words in the safety condition to determine whether our results replicated past research on smoking interference (e.g., Gross et al., 1993; Waters & Feyerabend, 2000). As expected, response latencies were greater for smoking-related words than for neutral words among smokers, $F(1, 81) = 7.07$, $p = .009$, $\eta_p^2 = .08$. This effect was significantly greater among deprived smokers (mean difference = 37.1 ms) than among continuing smokers (mean difference = 4.6 ms, $F(1, 81) = 3.99$, $p = .049$, $\eta_p^2 = .05$. The interaction with availability condition was not significant.

Full repeated measure ANOVA. Next, we conducted a Smoking Group × Threat × Word Set mixed-model ANOVA on response times from the modified Stroop task.[7] The smoking group and word set contrasts described earlier were used. Response time data are displayed in Table 3 as a function of smoking group, threat, and word set.

Between-participants main effects. Overall smoking group contrasts (see Figure 1) revealed a significant smoking status contrast, $F(1, 102) = 7.41$, $p = .008$, $\eta_p^2 = .07$, with smokers (M = 644.7, SD = 119.0) displaying slower response times than nonsmokers overall (M = 574.1, SD = 79.3). A significant deprivation contrast was also observed, $F(1, 102) = 5.12$, $p = .026$, $\eta_p^2 = .05$, with deprived smokers (M = 673.4, SD = 121.0) displaying slower response times than nondeprived smokers overall (M = 620.4, SD = 112.9). Neither the nondeprived nor the deprived availability contrasts was significant.

Within-participant main effects. With respect to overall word set contrasts collapsed across groups, a significant motivationally relevant word contrast was observed, $F(1, 102) = 9.62$, $p = .002$, $\eta_p^2 = .09$; with overall slower response time during motivationally relevant words (i.e., unpleasant, pleasant, and smoking; M = 633.3, SD = 116.6) than during neutral words (M = 620.9, SD = 116.6). A significant reward word contrast was also observed, $F(1, 102) = 7.73$, $p = .006$, $\eta_p^2 = .07$; with slower response times overall for the composite of pleasant and smoking words (M = 637.7, SD = 118.0) than for unpleasant words (M = 624.3, SD = 120.2). The smoking-specific word contrast was not significant ($\eta_p^2 = .004$). A significant main effect of threat was also observed, $F(1, 102) = 3.90$, $p = .051$, $\eta_p^2 = .04$; with overall slower response times during shock threat (M = 637.0, SD = 122.0) than during no-shock blocks (M = 623.3, SD = 114.7).

Hypothesis testing: Hypothesis 1. The interaction between the smoking status contrast (nonsmokers vs. smokers) and the smoking-related/pleasant word contrast was not significant, $F(1, 102) = 0.36$, $p = .55$, $\eta_p^2 = .004$, indicating that neither nonsmokers nor smokers showed significantly different reaction times to smoking-related and pleasant words.

Hypothesis testing: Hypothesis 2. The two-way interaction between deprivation status among smokers (nondeprived vs. deprived) and word set was not significant, which indicated no difference in reaction times to smoking-related versus reward words as a function of deprivation status, collapsed over availability and threat conditions, $F(1, 102) = 0.75$, $p = .39$, $\eta_p^2 = .007$. Smoking availability moderated the response time to motivationally relevant (neutral vs. unpleasant, pleasant, and smoking words) words among deprived smokers, however. There was a Deprived Availability × Motivationally Relevant Word interaction, $F(1, 102) = 4.40$, $p = .038$, $\eta_p^2 = .04$, (see Figure 2). To follow-up this two-way interaction, we conducted pairwise comparisons of the composite of motivationally relevant and neutral words separately within deprived smokers. Among deprived smokers with smoking availability, response time to motivationally relevant words was significantly slower than to neutral words ($p = .036$). In contrast, among deprived smokers with no smoking availability, the contrast between response times for motivationally relevant versus neutral words was not significant ($p = .514$). Availability did not significantly affect response times and did not interact with word set among nondeprived smokers.

Response times to pleasant words were also contrasted against neutral words to determine whether deprivation and threat differentially influenced attention to these word types (in addition to the pleasant vs. smoking contrast that was nonsignificant). Results revealed no significant two-way interaction between deprivation and word set but did reveal a three-way interaction between deprivation, threat condition, and word set, $F(1, 102) = 6.15$, $p = .02$, $\eta_p^2 = .06$. Deprivation and word set interacted significantly so that interference to positive words was significantly greater among deprived than among nondeprived smokers in the absence of shock, $F(1, 102) = 4.77$, $p = .03$, $\eta_p^2 = .05$ (mean difference = 27.53 ms), but not in the presence of shock, $F(1, 102) = 0.45$, $p = .50$, $\eta_p^2 = .004$ (mean difference = −9.58 ms).

Hypothesis testing: Hypothesis 3. Smoking status did not interact significantly with the smoking-related vs. pleasant word set contrast and threat condition, $F(1, 102) = 2.40$, $p = .12$, $\eta_p^2 = .02$; indicating that smokers were not significantly more likely to show a narrow bias of attention toward smoking-related cues under shock than nonsmokers were. However, nicotine deprivation and threat moderated the effect of word motivational relevance on response time: There was a Nicotine Deprivation × Threat × Motivationally Relevant Word interaction, $F(1, 102) = 3.79$, $p = .054$, $\eta_p^2 = .04$ (see Figure 3). To follow up this interaction, we

[6] Excluding 3 individuals whose shock tolerance exceeded the maximum level of shock used in this study did not change the main or interactive effects of threat reported later, so these participants who never reported that the shock was uncomfortable were retained in analyses.

[7] Supplemental analyses included gender as a factor in this analysis model. However, gender did not moderate any of the significant reported effects. Therefore, it was dropped from the final report.

Table 3
Reaction Time Data (in Milliseconds) for Each of Eight Experimental Blocks, by Group

Threat condition and word set	Nonsmokers (n = 22)		Continuing smokers, no availability (n = 25)		Continuing smokers, availability (n = 21)		Deprived smokers, no availability (n = 20)		Deprived smokers, availability (n = 19)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
No shock										
Neutral	555.44	74.09	626.47	121.23	596.77	137.82	654.65	134.48	639.87	107.65
Unpleasant	557.31	71.77	632.01	109.43	590.04	135.47	651.28	125.02	659.02	137.14
Pleasant	587.81	89.42	620.75	111.14	604.12	122.40	667.35	129.69	683.50	142.86
Smoking	570.62	83.42	623.65	93.33	610.21	120.38	684.01	134.04	685.18	137.45
Shock										
Neutral	566.17	80.59	646.71	121.92	586.28	131.59	685.09	128.75	660.43	106.88
Unpleasant	573.94	95.16	645.19	137.61	590.95	117.38	680.52	125.23	677.75	152.20
Pleasant	591.24	92.46	648.27	140.56	632.99	160.04	685.47	129.23	685.87	158.06
Smoking	589.85	103.01	647.08	114.60	600.32	119.92	677.00	125.61	697.83	138.05

conducted simple comparisons of nicotine deprivation groups for the neutral and motivationally relevant word sets in the no-shock and shock conditions. Deprived smokers displayed significantly slower response times than nondeprived smokers did to motivationally relevant word sets (all nonneutral words) in both shock (mean difference = 54.8 ms; p = .049) and no-shock (mean difference = 57.1 ms; p = .028) conditions. Deprived smokers were also slower to color-name neutral words during shock than were nondeprived smokers (mean difference = 54.0 ms; p = .048). No significant deprivation effect was observed for neutral words during no-shock blocks (mean difference = 34.5 ms). To further examine the deprivation effect, we tested pairwise comparisons between the four combinations of word type and threat among deprived smokers only. Response times among deprived smokers were significantly slower during motivationally relevant/no shock (p = .013), motivationally relevant/shock (p = .002), and neutral/shock (p = .013) conditions versus the neutral/no-shock condition. No other condition contrasts were significantly different among deprived smokers. In summary, deprived smokers displayed slower response times than nondeprived smokers during all conditions that involved a motivationally important manipulation (i.e., either presentation of motivationally relevant words or threat of electric shock). Similarly, among deprived smokers, response times were slowed to motivationally important stimuli relative to the neutral word/no-shock control condition. Nondeprived smokers did not show this sensitivity to the motivational relevance of stimuli.

Nicotine deprivation also moderated the effect of the valence (unpleasant vs. pleasant and smoking) of words and threat on response times: There was a Nicotine Deprivation × Threat × Reward Word interaction, $F(1, 102) = 3.98$, $p = .049$, $\eta_p^2 = .04$ (see Figure 4). To follow up this interaction, we conducted simple

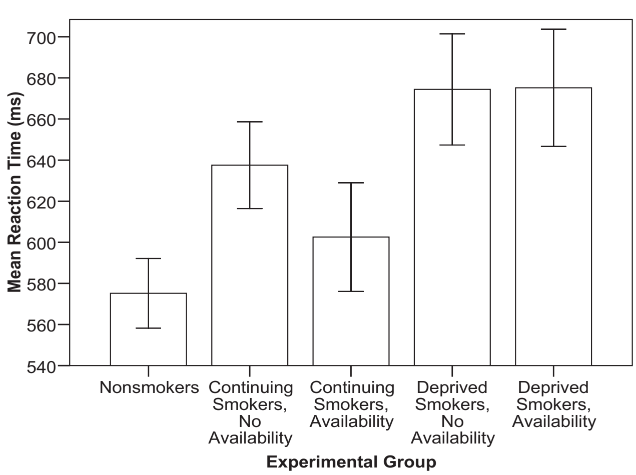

Figure 1. Mean color-naming reaction time, in milliseconds, by experimental group (n = 106), excluding nonresponses and with extremely long reaction times corrected toward the idiographic mean. Error bars reflect the between-participants standard error.

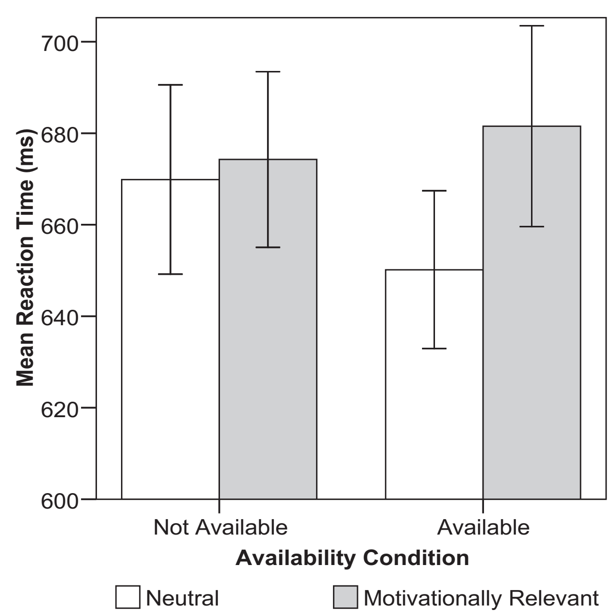

Figure 2. Deprived smokers' (n = 39) mean color-naming reaction times for neutral words versus all motivationally relevant words as a function of smoking availability. Error bars reflect the between-participants standard error.

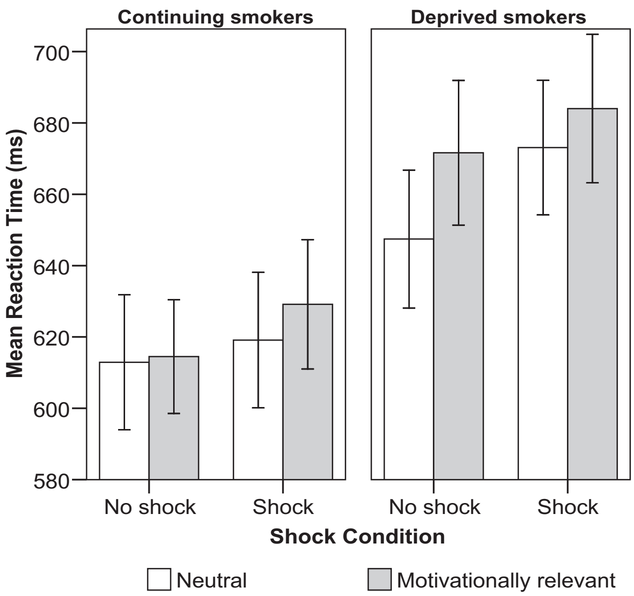

Figure 3. Smokers' (n = 85) mean color-naming reaction times for neutral words versus the composite of all motivationally relevant words, by deprivation and shock condition. Error bars reflect the between-participants standard error.

comparisons of nicotine deprivation for the unpleasant and reward word sets in the no-shock and shock conditions. Deprived smokers displayed significantly slower response times than did nondeprived smokers to the following: unpleasant words during the shock condition (mean difference = 58.7 ms; p = .046); reward (pleasant and smoking-related) words during the no-shock condition (mean difference = 64.6 ms; p = .013); and a trend for slower responding to reward words during shock (mean difference = 52.9 ms; p = .062). No significant nicotine deprivation effect was observed for unpleasant words during no-shock (mean difference = 42.2 ms). To further examine the deprivation effect, we tested pairwise comparisons among the four combinations of word type and threat among deprived smokers only. Relative to the unpleasant/no-shock condition, response times among deprived smokers were generally slower during reward word/no-shock (p = .003), reward word/shock (p = .002), and unpleasant word/shock (p = .069) conditions. No other condition contrasts were significantly different among deprived smokers (deprivation and threat did not interact to influence responses to pleasant vs. smoking-related words). In summary, deprived smokers displayed generally slower response times than nondeprived smokers when either viewing reward words or threatened with electric shock. Similarly, among deprived smokers, response times were generally slowed to these same manipulations relative to the unpleasant word/no-shock control condition.

Discussion

In this study, we sought to test hypotheses regarding factors and conditions influencing attention to smoking cues derived from the reformulated negative reinforcement model of drug motivation (Baker et al., 2004). We tested the hypothesis that both tobacco deprivation and an exogenous stressor would bias smokers' attention narrowly toward smoking-related cues in a modified smoking and emotion Stroop task. Results indicated that deprivation and stress influenced attention toward salient or motivationally relevant cues broadly, and reward-relevant cues specifically, although the biasing effects observed were not restricted to smoking-related stimuli. Results also confirmed that smoking availability moderated attention bias in nicotine-deprived smokers so that greater bias toward all nonneutral words (but not pleasant or smoking-specific cues specifically) was observed among deprived smokers who anticipated an opportunity to smoke but not among those who were told that smoking would not be permitted.

Results did not support our first hypothesis, that smokers overall would show a bias toward smoking-related words compared with other arousing pleasant words, whereas nonsmokers would not. Smoking words did not appear to have greater salience than other reward-related words in this sample, contrary to our expectations.

In this study, we found support for the second hypothesis, that nicotine deprivation influences attention. The present findings run counter to Powell and colleagues' (2002) research suggesting insensitivity to threat (unpleasant words) and reward (pleasant words) in withdrawal. The present findings show that deprived smokers showed greater interference to all motivationally relevant and both smoking-related and other pleasant words than did continuing smokers in this study when not under stress. Rather than being insensitive to threat (unpleasant words) and reward (pleasant and smoking words), deprived smokers appeared to be more attentive to the motivational relevance and reward value of cues than did nondeprived smokers, even though the two groups showed roughly equivalent response latencies to neutral words in the absence of threat. These experimental reaction time data may reflect similar processes that result in increased reactivity to recent exposure to stress or smoking-related stimuli in real-time reports collected in the field (McCarthy, Piasecki, Fiore, & Baker, 2006). A similar pattern of results emerged when bias toward reward-related words was assessed relative to arousing unpleasant words.

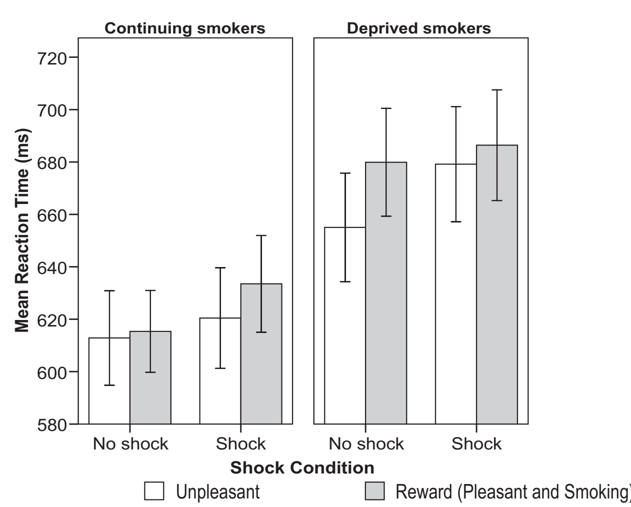

Figure 4. Smokers' (n = 85) mean color-naming reaction times for negative words versus the composite of pleasant and smoking-related words, by deprivation and shock condition. Error bars reflect the between-participants standard error.

Although these results were not specific to smoking-related stimuli, they add to the research demonstrating greater interference to motivationally relevant words, particularly reward words, when deprived of nicotine than when smoking at will (e.g., Gross et al., 1993; Waters & Feyerabend, 2000; for a review, see Cox et al., 2006).

Our third hypothesis, regarding the effects of an exogenous stressor on smokers' attention, requires further clarification on the basis of these data. We predicted that both deprived and nondeprived smokers would show a bias toward smoking-related words when stressed and that deprivation and stress would have additive effects on attention. Instead, we found that deprivation status and threat had interactive effects on performance. Although the threat of shock had a medium-sized effect on negative affect and slowed responses across all smoking groups, nondeprived smokers did not show greater attention toward motivationally relevant, reward, or smoking-related cues when stressed than when safe. Deprived smokers, in contrast, exhibited sensitivity to the threat manipulation, so that response times were slower to neutral cues and the bias toward nonneutral words was reduced under threat of shock, compared with the safe condition. Suppression of attention bias toward concern-relevant words has been noted in research in veterans with posttraumatic stress disorder, such that anticipating a stressor after the task eliminated the usual bias toward combat-related words relative to neutral words in an emotion Stroop task (Constans, McCloskey, Vasterling, Brailey, & Mathews, 2004). These results differed from our own, however, in that no significant slowing to all word types was noted in the threat conditions among veterans. Taken together, these results suggest that anticipating a stressor may somehow interfere with or supersede the attention bias toward concern-relevant stimuli typically exhibited on the modified Stroop task. As such, it appears as though deprivation and stress have interactive, rather than additive, effects on attention among smokers, contrary to our expectations and previous research suggesting that attention bias toward threat-related words in people high in trait anxiety persists even under threat of shock (Miller & Patrick, 2000).

Taken together, the results indicate that nicotine deprivation increases smokers' sensitivity to manipulations of word type, such that interference effects are greater when deprived than when smoking freely, at least in the absence of acute stress. Expression of deprivation effects depends on perceived drug availability, however. Interference to words with broad motivational significance was greater when deprived smokers anticipated an opportunity to smoke than when informed that smoking would be restricted for the next two hours. This result is somewhat consistent with previous research documenting interactions between word type and smoking availability (Wertz & Sayette, 2001), although the effect was not specific to stimuli related to smoking in the present study.

In summary, the results of this study provide partial support regarding factors that influence attention in addiction but also challenge the specificity of these attention-processing effects. Previous modified Stroop tasks contrasted either smoking and neutral cues or emotion and neutral cues. When we compared response times between smoking-related and neutral words, we replicated the finding that deprivation increases attention bias to smoking cues among smokers (Gross et al., 1993; Waters & Feyerabend, 2000). When we compared response times to smoking words with response times to other arousing, pleasant stimuli, we found no effect, however. This null result may be due to strong association between smoking and sex-related stimuli, heightened salience of all stimuli (apart from motivational significance), or a more substantive reason. The bias toward sex and pleasure-related words is surprising, given the inflation of reward thresholds to nondrug stimuli that occurs in withdrawal (Epping-Jordan, Watkins, Koob, & Markou, 1998). Our results also challenge the prediction derived from the negative reinforcement model that negative affect, regardless of the source of the distress, induces a narrowing of attention toward drug-related cues. If the lack of differential bias toward smoking-related cues versus other highly arousing pleasant cues observed in this study is replicated with other pleasant reward stimuli, this will challenge current accounts of the effects of drug dependence and deprivation on incentive and motivational processing and may have important clinical implications (Baker et al., 2004; Robinson & Berridge, 2003). For example, drug deprivation may not reduce interest in alternative reinforcers (e.g., food), although it does reduce sensitivity to the reward once obtained (Epping-Jordan et al., 1998). We must take care in interpreting these null results, however, although we note that a significant bias toward pleasant versus neutral cues was observed among deprived smokers when safe from shock (i.e., the effect is not an artifact of the contrast strategy used).

Limitations

We must take care in reaching conclusions about the factors and conditions that influence smokers' attention from these data, however, in light of the limitations of the present study. Methodological factors such as sampling strategy may have influenced results. Eliciting volunteers for a study with an explicit focus on nicotine may have attracted atypical nonsmokers with a particular interest in nicotine. Likewise, our requirement that smokers agree to be randomized to a deprivation condition may have deterred the most dependent or withdrawal-prone smokers from participating. Lack of balance between nonsmokers and smokers in terms of age and education may also have contributed to the overall difference in response times observed between these groups, although such differences may also be related to individual differences related to the risk of becoming a smoker.

Stimulus selection also may have contributed to the unexpected results. Several participants commented on the sexual nature of the pleasant words, and some were observed to blush during the pleasant word blocks or to make otherwise rare reading errors with relatively explicit words such as "breast." The bias toward sex-related words in this study may not generalize to other pleasant words, as sex-related words may have unique salience, particularly in a laboratory setting. It is also possible that our deprivation manipulation was insufficient to induce clinically significant levels of withdrawal distress, perhaps because participants knew the deprivation would end within 2 hr of the start of the experiment. Deprivation appeared to affect urges to smoke primarily, with marginal effects on other symptoms, despite a longer period of deprivation than that used in much previous research in this area (e.g., Gross et al., 1993) and strict biochemical verification of abstinence. Such background expectations regarding the duration of the experiment may also have weakened the availability manipulation. All explanations for the surprising similarity in the pattern of responses observed in smokers and nonsmokers and the lack of differentiation of smoking versus other reward cues must remain tentative until additional research that includes nonusers and other motivationally relevant stimuli is conducted. Similarly, comparisons across groups (i.e., nonsmokers and smokers) are stronger when cross-over patterns in reaction times to concern-relevant versus -irrelevant words are compared across groups (i.e., reaction times to both tobacco-related and alcohol-related words are compared in groups of nondrinking smokers and nonsmoking drinkers). Robbins and Ehrman (2004) have argued that this type of cross-over design offers a better control condition and allows stronger inferences than the nonsmoker-versus-smoker design used here.

Finally, it is important to consider whether the paradigm used here is sensitive to the aspects of information processing that are most relevant to drug motivation. Other paradigms that can isolate specific information-processing components, such as the orienting or shifting of attention or the detection and resolution of response conflict (Curtin et al., 2006; Robbins & Ehrman, 2004), may be more sensitive indices of processes critical to drug motivation and behavior than is the modified Stroop task.

Conclusion

Despite the limitations noted earlier, the present study contributes important findings to the extant research regarding the attention bias for drug-relevant cues among addicted individuals. First, the present results raise questions about the specificity of the effects of nicotine deprivation and availability reported in previous research. Our comparison conditions and contrast-based analytical strategy revealed that our manipulations affected reaction times to cues of broad motivational relevance, rather than in a smoking-specific manner as previously assumed. The present study also tests an important hypothesis about a cognitive pathway by which smoking history, deprivation, stress, and contextual variables such as smoking availability may influence addicted individuals and bias them toward smoking. The findings that deprivation and exogenous stress both appear to influence smokers' attention toward reward cues, albeit in a nonadditive manner, suggest that distress does indeed bias attention in ways that may increase the likelihood of smoking but also in ways that may increase pursuit of alternative rewards. If sufficiently attractive and healthy alternative rewards can be identified for individuals attempting to curtail their smoking, this nonspecific attentional bias may be harnessed to increase the likelihood of success. In addition, the findings regarding the availability manipulation highlight the importance of evaluating the effect of formal manipulations of smoking opportunities and assessing informal perceptions of such opportunities in future research, as this contextual variable appears to significantly affect attention toward environmental cues.

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(*Appendix follows*)

Appendix

Words Used in the Modified Stroop Task

Neutral	Unpleasant[a]	Pleasant[a]	Smoking[b]
antonym	assault	aroused	ashtray
byline	bomb	bold	burn
binder	bullet	breast	butt
colon	coffin	caress	carton
comma	crime	cute	cigarette
diction	drown	desire	drag
files	fight	fantasy	filter
font	flood	flirt	flavor
italic	injury	intercourse	inhalation
leaflets	leprosy	lust	lighter
margin	massacre	magical	matches
metaphor	maniac	merry	menthol
narrator	needle	naked	nicotine
printer	panic	passion	pack
prose	poison	pleasure	puff
simile	snake	sexy	smell
syntax	spider	spouse	smoke
thesis	terrorist	taste	tar
text	torture	terrific	taste
typed	trauma	thrill	tobacco

[a] From "*Affective Norms for English Words (ANEW): Stimuli, Instruction Manual and Affective Ratings*," by M. M. Bradley & P. J. Lang, 1999, Gainesville, FL: Center for Research in Psychophysiology, University of Florida. Copyright 1999 by the University of Florida. Adapted with permission. [b] From "*Effects of Smoking Opportunity on Attentional Bias in Smokers*," by J. M. Wertz & M. A. Sayette, 2001, *Psychology of Addictive Behaviors, 15,* 268–271. Adapted with permission.

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