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Effects of Nicotine Deprivation on Craving Response Covariation in Smokers

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Abstract

Most models of craving propose that when cravings are strong, diverse responses—thought to index an underlying craving state—covary. Previous studies provided weak support for this hypothesis. The authors tested whether nicotine deprivation affects degree of covariation across multiple measures related to craving. Heavy and light smokers ($N = 127$) were exposed to smoking cues while either nicotine deprived or nondeprived. Measures included urge ratings, affective valence, a behavioral choice task assessing perceived reinforcement value of smoking, and smoking-related judgment tasks. Results indicated higher correlations in the nicotine-deprived than in nondeprived group. The measures principally responsible for this effect loaded onto a single common Craving factor for nicotine-deprived but not nondeprived smokers. These findings suggest that, under certain conditions, measures of craving-related processes covary.

Understanding drug craving and its role in relapse remains a research priority. Progress has been impeded to some extent by a failure to reach consensus on just how to define or measure craving (Sayette et al., 2000). In humans, drug craving is generally defined as a desire, sometimes a strong desire, to use a drug (Kassel & Shiffman, 1992; Kozlowski & Wilkinson, 1987). We adapted from Baker, Morse, and Sherman (1987) the following working definition: Cravings are emotional states reflecting the activation of motivational (drug-acquisitive) systems that have particular response patterns involving self-report, behavioral, physiological, and cognitive correlates.¹ For instance, smokers who are craving are likely to report a strong urge to smoke on rating scales, increase the value of smoking immediately on a behavioral choice task, and reveal shifts in cognitive processing such that the decision to engage in drug use appears more likely (Sayette, 1999).

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¹Although cognition is not specified as a correlate of craving, information regarding drug use is considered to be coded into the urge network (Baker et al., 1987) and is included in the present study.

Most models of craving propose that particular stimuli (e.g., drug cues) induce a craving state, which in turn motivates drug use (Drummond, 2000; Niaura et al., 1988). Laboratory research indicates that manipulations designed to induce craving, such as drug cue exposure, increase the magnitude of self-reported urges (Carter & Tiffany, 1999). In addition, it is generally believed that craving can be indexed across multiple response systems, including selfreport, behavior and, in some cases, autonomic responding (Rankin, Hodgson, & Stockwell, 1979). Whether these responses are measures of craving per se, or just responses or processes related to craving, is beyond the scope of this article (cf. Baker et al., 1987; Rankin et al., 1979; Sayette et al., 2000; Tiffany & Drobos, 1991). The term *craving responses* is used herein to describe responses posited to relate to craving.

A further premise of several models relevant to craving, including conditioned withdrawal (Ludwig, Wikler, & Stark, 1974), conditioned compensatory response (Siegel, 1983), conditioned appetitive motivation (Stewart, de Wit, & Eikelboom, 1984), and social learning theory (Marlatt, 1985), is that these different response systems should covary (Niaura et al., 1988; Tiffany, 1990). Thus, an assumption of most craving models is that diverse responses should index an underlying “craving” state. Implicit in these models is the notion that these responses should load onto a single common factor.

The idea that different craving responses should covary has become a topic of debate (Kassel & Shiffman, 1992; Rohsenow, Niaura, Childress, Abrams, & Monti, 1990-1991). Tiffany (1990) noted that the literature provides weak support for this position (i.e., often craving response measures were either uncorrelated or weakly correlated). From a theoretical perspective, response discordance is compatible with his cognitive model, which suggests that cognitive processes supporting drug use behavior can operate independently of those that control cravings.

The absence of significant correlations among measures in previous published studies also could have resulted from weak craving manipulations. Baker et al. (1987) proposed that different craving-related responses should show relatively greater coherence during moments when motivation to use is strongest (see also Stockwell, 1987). That is, when conditions arise that elicit robust craving, diverse measures of craving should both increase in magnitude and reflect greater coherence. Moreover, under these circumstances, drug seeking presumably becomes more likely (see Baker et al., 1987). This position is compatible with Lang’s (1984) bioinformation approach to emotion in which the likelihood of accessing an emotion—and experiencing a coherent emotional response across multiple systems—is increased in contexts in which a maximal number of propositions (i.e., information related to emotional cues, interpretations of these cues, and emotional responses) are matched to the emotion prototype. There is clear evidence that during smoking cue exposure, urge to smoke is greater for nicotine-deprived than for nondeprived smokers (e.g., Sayette & Hufford, 1994). Accordingly, a smoker who is deprived of nicotine while being exposed to smoking cues should have a greater chance of activating a craving prototype than would a nondeprived smoker.

A review of cue reactivity studies indicates, however, that patients often report only mild urge states during drug cue exposure (e.g., less than 40% of the maximum value on their respective urge scales; Wertz & Sayette, 2001a). Few cue exposure studies have compared response covariation at different levels of presumed smoking motivation. These studies generally have examined the correlations between just two types of measures (e.g., self-reported urge and either a physiological or a cognitive response) and tended to find that response covariation was highest in experimental conditions featuring the strongest cravings (Juliano & Brandon, 1998; Rickard-Figueroa & Zeichner, 1985; Sayette & Hufford, 1994). Indeed, when responding is weak, significant correlations are unlikely. For instance, Drobos and Tiffany (1997) found cardiovascular reactivity to their urge manipulations to be minimal (e.g., a heart rate change

of about one beat per minute) and did not find measures of self-reported urge and cardiovascular reactivity to correlate.

Brandon, Wetter, and Baker (1996) examined response covariation across multiple measures; although most measures were uncorrelated, expectancies of smoking reinforcement did correlate with ad lib smoking consumption among deprived but not nondeprived smokers. Brandon et al. did not include an in vivo smoking cue exposure manipulation; moreover, deprived smokers' scores on the Withdrawal Rating Form (Shiffman & Jarvik, 1979) were only about 10% higher than those of their nondeprived counterparts. Consequently, it is unclear just how strong an urge was elicited in their study and whether optimal conditions were established to show response covariation. We have found that a combination of nicotine deprivation and drug cue exposure, including holding a lit cigarette, elicits reliably strong urge ratings (e.g., Sayette & Parrott, 1999). This occurred even when relatively light smokers were deprived of nicotine (Sayette & Hufford, 1994; Wertz & Sayette, 2001b). In the present study, we exposed both nicotine-deprived and nondeprived smokers to a potent smoking cue, namely the sight, touch, and smell of a lit cigarette.

Weak associations across variables found in previous studies also could have resulted from use of unreliable or inappropriate craving measures (Kassel & Shiffman, 1992; Sayette et al., 2000). To determine if multidimensional responses covary and index a single craving factor, it is important that selected measures are both sensitive to craving manipulations and conceptually linked to a particular theory of craving (Kassel & Shiffman, 1992; Sayette et al., 2000; Zinser, Fiore, Davidson, & Baker, 1999).

In a recent study, we tested the sensitivity of several measures thought to be associated with craving (Sayette, Martin, Wertz, Shiffman, & Perrott, 2001). Heavy smokers (HS) and tobacco chippers (TC), who were either 7-hr nicotine deprived or nondeprived, were exposed to smoking cues while informed that they could not smoke. We used robust smoking cue exposure manipulations and multiple craving response measures.

Specifically, the assessment battery included several different measures of urge report, including traditional urge ratings and a magnitude estimation procedure in which participants rated their current urge compared with how they felt when they first began the experimental session (Sayette et al., 2000). We also included a behavioral choice measure thought to capture the reinforcement value of smoking. This type of measure requires participants to decide between varying amounts of money and the opportunity to smoke immediately. Because participants are led to believe that the decision matters (i.e., they actually will receive this additional money or be permitted to smoke), this type of measure is referred to as a *behavioroid* measure (see Aronson, Wilson, & Brewer, 1998). Unlike a hypothetical choice, a behavioroid measure is presented as having real implications. We also included a self-report measure of reported affective valence, which in the present study was believed to index urge. Specifically, we expected that the subjects in our study who were experiencing the strongest urge to smoke would report the least positive or most negative affect. In addition, we included several putatively implicit measures of craving. These latter measures included assessing the expected probability that certain smoking outcomes would occur for the participant and a task requiring the generation of positive and negative smoking attributes. Although relying on self-report, these latter measures are nonetheless considered to be implicit measures of craving because participants are thought to be unaware when they perform these tasks that it is their urges that are being measured (Schacter, 1987; Wilson, Lindsey, & Schooler, 2000). Judging the probability of smoking outcomes is considered to be an implicit measure of craving in the same way, for instance, that judging the loudness of background noise is used as an implicit measure of affective valence (Jacoby, Lindsay, & Toth, 1992). Finally, we included a divided-

attention task, posited to index the degree to which craving affected the distribution of limited-capacity, nonautomatic-processing resources (Sayette & Hufford, 1994; Tiffany, 1990).

Following smoking cue exposure, nicotine-deprived smokers reported higher scores than nondeprived smokers on each of our measures of self-reported urge (urge rating scale, magnitude estimation, and composite urge). Deprived smokers tended to report less positive affective valence and, compared with nondeprived smokers, expected positive consequences of smoking to be relatively more probable than negative consequences. Similarly, on the behavioral choice task, deprived smokers required more money to postpone smoking than did nondeprived smokers.

The present study examined the pattern of responding across these measures under conditions predicted to reveal differential levels of covariation. As posited by Rankin et al. (1979), investigation of the relationship between craving response systems under specific conditions should improve understanding of craving. Given the assumption of measurement covariation held by a number of craving models, the general failure to observe associations raises serious concerns. To our knowledge, this is the first smoking cue exposure study to examine covariation across several types of measures of craving responses under varying conditions. Consistent with the findings of Brandon et al. (1996), we hypothesized that nicotine-deprived smokers would reveal a more coherent response pattern than would nondeprived smokers (see also Zinser, Baker, Sherman, & Cannon, 1992). Specifically, we predicted that during smoking cue exposure, nicotine deprivation would affect both the level of covariation among the measures that were sensitive to nicotine deprivation and the degree to which the various measures loaded on a single common Craving factor, thus providing further validation of the construct of craving.

Method

Participants

Smokers ($N = 127$; 60 men and 67 women) between the ages of 21 and 35 were recruited through advertisements in local newspapers and on radio programs. Exclusion criteria included (a) medical conditions that ethically contraindicated nicotine and (b) illiteracy. Informed consent was obtained from all participants. TC ($n = 60$) reported smoking 5 or fewer cigarettes per day on at least 2 days/week and could not smoke more than 5 cigarettes on any day of the week. HS ($n = 67$) smoked an average of 21 or more cigarettes/day. Both groups had to report smoking at these rates for at least 24 continuous months (Shiffman, Paty, et al., 1994). Nicotinedeprived HS and nondeprived TC had to have carbon monoxide (CO) levels that did not exceed 16 ppm and 10 ppm, respectively. Age ($M = 24.7$, $SD = 4.2$), years of formal education ($M = 14.4$, $SD = 1.8$), and ethnic make-up (77% Caucasian, 17% African American, and 6% Hispanic or Asian American) did not differ significantly for the two types of smokers ($ps > .05$). TC reported smoking fewer cigarettes/day ($M = 3.7$, $SD = 1.4$) and fewer years of smoking ($M = 6.7$, $SD = 4.3$) than did HS ($M = 24.8$ cigarettes/day, $SD = 5.3$; $M = 9.2$ years, $SD = 5.1$), $F_s(1, 124) > 8.7$, $ps < .01$. Gender was unrelated to any of our cravingrelated measures and thus was not included as a factor in analyses.

Experimental Design

Our main goal was to examine craving responses for groups of smokers predicted to experience varying levels of smoking motivation. Most of these responses could not be measured more than once because of carryover effects. Thus, affective valence, generation of smoking characteristics, evaluation of smoking consequences, and a behavioral choice task were administered only after smoking cue exposure. In addition to carryover effects, our behavioral choice task required that participants could smoke immediately afterward. A repeated

administration of that task would have meant that subjects would no longer be nicotine deprived during the second cue exposure (see below for details). Although both control and smoking cues were used, only urge ratings and reaction time (RT) were administered during both smoking cue and control exposure. These latter measures permitted comparisons with previous studies that assessed urge ratings during smoking and control cues (see Sayette et al., 2001). In addition, they provided a check to ensure that the main assessment battery was being administered during the time of peak craving.

The study used a mixed factorial design, with both groups of smokers randomly assigned to 7-hr nicotine deprivation ($n = 65$) or nondeprivation ($n = 62$) conditions. All participants were exposed to both control (a small roll of electrical tape) and smoking cues (the participants' own cigarettes), with control cue exposure preceding smoking cue exposure. Counterbalancing was not used because urge ratings following drug cue exposure tend to remain high, making it difficult to interpret effects of any subsequent control exposure (e.g., Hutchison, Niaura, & Swift, 1999). Methodological information regarding this study's participants, measures, and procedures are briefly outlined below and are described in greater detail elsewhere (Sayette et al., 2001).

Baseline Assessment Measures

To assess individual differences that may influence craving, data on age, gender, ethnicity, marital status, education, and income were obtained. Smoking history and patterns, and current interest in quitting also were assessed with standard forms.

Measures of Craving Responding

Reported urge to smoke—Participants' urge to smoke was assessed using an Urge rating scale ranging from 0 (*absolutely no urge to smoke at all*) to 100 (*strongest urge to smoke I've ever experienced*; Juliano & Brandon, 1998; Monti et al., 1993; Sayette & Hufford, 1994).² Concerns with ceiling effects during both precue baseline and postcue exposure assessment periods, which are common in smoking cue reactivity studies for nicotine-deprived heavy smokers (see Sayette et al., 2000), make it problematic to use either the absolute urge rating during smoking cue exposure or an urge rating score during cue exposure that is adjusted for initial baseline levels. This issue is addressed in detail elsewhere (Sayette et al., 2001). Accordingly, participants also reported a Magnitude Estimation urge score, in which they compared their current urge proportionately to their baseline urge. Finally a *composite urge* (the product of the initial urge rating and the magnitude estimation score during smoking cue exposure) was calculated. Thus, an individual who initially reported a 60 on the baseline urge rating scale, and who subsequently reported on the magnitude estimation that their urge during cue exposure was 2.5 times stronger than during baseline, would have a composite urge of $60 \times 2.5 = 150$. Both magnitude estimation and composite urge scores were square-root transformed to address positive skew.

To prevent the emergence of domain factors, we included just one of the three self-report urge measures in our analyses for this study: composite score. This score was the only urge rating that (a) was not subject to ceiling effects (urge rating scale) and (b) was not insensitive to initial baseline differences in urge. (Magnitude estimation scores by themselves do not account for initial baseline differences in urge ratings; see Sayette et al., 2001.) In addition, because it was

²Although a multi-item craving scale can improve reliability, it also may increase reactivity relative to a single-item scale (Juliano & Brandon, 1998; Sayette et al., 2000). Reactivity is of particular concern when there are multiple administrations of a measure. Relying on single items may still work well to capture cravings (Kozlowski, Pillitteri, Sweeney, Whitfield, & Graham, 1996; Sayette et al., 2000).

derived from both the magnitude estimation and urge rating measures, composite urge was also highly correlated with both ($r_s > .62$).

Affective valence—During smoking cue exposure, participants rated how they felt on a scale ranging from 0 (*I feel very bad right now*) to 10 (*I feel very good right now*). To ease interpretability, affective valence scores were reversed (i.e., subtracted from 10) so that for all variables in the analyses, higher scores were posited to be associated with greater craving.

RT—Participants responded to auditory tones (70 dB, 400 Hz) by pressing a mouse button as fast as possible before and during cue exposure (Sayette & Hufford, 1994).

Ad lib characteristics of smoking (AD LIB; Sayette & Hufford, 1997)—Participants received a blank sheet of paper and were asked to list everything over a 3-min period, that they liked and disliked about smoking. They were told to list an item only once. An experimenter reviewed the form following its completion to ask about items that were illegible. This measure was administered only once because it is susceptible to carryover effects.

Smoking Consequences Questionnaire—Brief (SCQ-B; Copeland, Brandon, & Quinn, 1995)—Beliefs about possible consequences of smoking a cigarette were rated on a scale ranging from -5 (*extremely undesirable*) to +5 (*extremely desirable*) and then on a 10-point scale to indicate the probability that they believed this consequence would occur. Copeland et al. (1995) examined probability levels and the cross product of probability and desirability (subjective expected utility). Their data provided more support for the validity of the probability version than the subjective, expected utility version. We used 24 items, including both desirable and undesirable consequences, from Copeland et al.'s (1995) scale (see Appendix). We subtracted the mean probability of negative outcomes from the mean probability of positive outcomes to create an index of the probability of positive outcomes relative to negative outcomes. This emphasis on relative probability of positive and negative outcomes is consistent with current decisional balance frameworks common in addiction research (e.g., Plummer et al., 2001).

Behavioral choice task—Participants were asked to choose between immediate access to a cigarette and delayed access with financial compensation. This task required participants to consider the minimum amount of money they would accept in order to postpone smoking for 5 min. If their minimum value was less than or equal to a previously set but undisclosed amount, they would receive the amount they requested in return for smoking delay. If their minimum value exceeded this preset amount, then they would receive no additional money but could smoke immediately. The critical variable was the minimum amount of money required to postpone smoking for five more minutes. Thus, although individuals reported a monetary value, we view this report to be a behavior, namely, the minimum amount of money for which participants sold five additional minutes of continued abstinence. Values were square-root transformed to address a positive skew. (Participants were led to believe that their choice would have actual consequences in that they would really be able to smoke immediately or in 5 min. Following this task, all participants were then informed that they could smoke immediately and would receive an additional \$5; for additional details, see Sayette et al., 2001.)

Procedure

Telephone screening and instructions—Participants who responded to advertisements underwent a telephone interview designed to exclude those not meeting selection criteria. Eligible smokers were asked to attend a 2-hr laboratory session. Those assigned to the nicotine deprivation conditions were instructed to refrain from smoking for at least 7 hr and were told

that breath samples would ensure that they had abstained. Participants were told to bring a pack of their preferred brand of cigarettes.

Laboratory set-up—Participants underwent cue exposure manipulations while seated in a comfortable chair behind a desk. On the desk were an intercom and a mouse button used in the RT task. Facing the desk was a mounted video camera. Participants were told that the camera and intercom facilitated communication and helped the investigator determine that instructions were understood throughout the study. Next to the desk was a small speaker connected to a computer in an adjoining room that was used to generate the tones for the RT task.

Baseline assessment—Experimental sessions began between 3:00 p.m. and 5:00 p.m. On arrival, written informed consent was obtained. To check compliance with abstinence instructions, participants reported the last time they smoked, and a CO reading (#1) was recorded. Participants presented their pack of cigarettes and lighter to the experimenter. They next completed baseline assessment, including the Urge rating scale (#1). At this time, all nondeprived participants smoked a cigarette. During this 5-min interval, abstinent participants sat quietly. Participants then provided CO #2 and rated their urge to smoke (#2) using both the Urge rating and Magnitude Estimation scales. From this point on, whenever self-reported urge measurement occurred, assessment included the Urge rating scale followed by magnitude estimation.

Cue exposure and RT task—Prior to cue exposure, participants placed the index finger of their nondominant hand on a computer mouse button and practiced responding to computer-generated tones. They were instructed to press the button as fast as possible whenever they heard a tone. During the control cue exposure sequence, a tray holding an inverted plastic bowl was placed on the desk. Participants responded to two tones, then lifted the bowl, which revealed a roll of tape. After picking up the tape in their dominant hand, participants responded to two additional tones, and then rated their urge to smoke (rating #3). Two minutes later, the experimenter replaced the tray and bowl with a second tray and bowl. Following two more tones, the participants provided another urge rating (#4), then removed the bowl, which revealed their pack of cigarettes, an ashtray, and a lighter. They were instructed to remove one cigarette from the pack and light it without putting it in their mouths. They then held the cigarette and looked at it while responding to two additional tones. Next, they rated their urge to smoke (#5) and affective valence and extinguished the cigarette. They completed the AD LIB and SCQ-B, followed by the behavioral choice task. The time between completion of affective valence and the behavioral choice task was about 7 min. (Additional details about the cue exposure procedure are reported in Sayette et al., 2001.) Finally, participants completed a form asking them about the study's purpose and were debriefed and paid \$45.

Results

Modeling was conducted using EQS (Bentler, 1995) and maximum likelihood estimation techniques. The correlation matrices for all six craving measures appear in Table 1 with their means and standard deviations.

Tests of the Equality of Measures of Craving

To test the hypothesis that the structure of responses differs as a function of experimental condition, an omnibus test of the equivalence of the covariance matrices was conducted using all six dependent variables.³ This was accomplished by (a) specifying each variable to be a function of its mean and specific or "error" variance, (b) estimating the variances and covariances for the observed variables in one group, and then (c) constraining these to be equal across groups. Without equivalence constraints, such a model provides a perfect fit to the data,

$\chi^2(0) = 0$, and reproduces the correlations among the observed variables as covariances among the error terms. When equality constraints are imposed, the result is a significant degradation of fit, $\chi^2(21) = 34.87$, $p < .05$.

Additional tests were conducted to identify the source of the observed between-groups difference more precisely. An omnibus test of the equivalence of the 15 correlations across the two groups yielded a near significant difference, $\chi^2(15) = 22.68$, $p = .091$. Although this test is nondirectional, an examination of the individual pairs of correlations revealed that 12 of the 15 correlations were more strongly positive in the deprived than nondeprived group. At the same time, only one of these differences achieved conventional levels of significance (the correlation between affect and perceived smoking consequences): deprived group, $r(N = 60) = .43$; nondeprived group, $r(N = 59) = -.19$; $z = 3.47$, $p < .001$.

An alternative approach to identifying sources of ill fit within the omnibus correlation test involves imposing constraints on subsets of the original measures. Sayette et al. (2001) reported that the deprivation manipulation used in the present study was associated with significant mean differences between the deprived and nondeprived groups for four of the six craving measures: self-reported composite urge, affective valence, behavioral choice, and perceived smoking consequences. In the present analyses, constraining the six correlations associated with just these four variables to be equal across groups yielded a significant degradation of fit, $\chi^2(6) = 13.69$, $p < .04$. On the other hand, constraining the nine correlations associated with the remaining two measures does not significantly degrade the fit of the model, $\chi^2(9) = 10.38$, $p > .25$. It would appear, therefore, that the former four variables are more sensitive to differences created by the craving state than the latter measures both in terms of mean differences (Sayette et al., 2001) and in terms of the extent to which the measures correlate with one another in the deprived versus nondeprived groups.

Confirmatory Factor Models of Craving Measures

Although these tests suggest differences in covariances among the variables and link these differences to four measures previously demonstrated to be sensitive to the craving state, they do not test for a particular structure underlying such differences. As a test of the hypothesis that the four measures of primary interest covary because they cohere as indicators of a single latent variable when participants are in a state of craving, we fit a one-factor model to the data in the deprived group. Models were evaluated using multiple fit criteria. Historically, overall fit has been evaluated using the chi-square goodness-of-fit test. In addition, we report Bentler's comparative fit index (CFI; Bentler, 1990) as representative of a class of incremental fit indexes that have achieved wide currency. Finally, we report the standardized root-mean-residual (SRMR) as a summary of the average covariance residuals. As noted by Hu and Bentler (1995), "If the discrepancy between the observed correlations and the model-reproduced correlations are very small, clearly the model is good at accounting for the correlations, no matter what the χ^2 test or fit indexes seem to imply" (p. 98).

Much has been written regarding cutoff criteria for evaluating the quality of model fit using these fit indexes. Lack of a statistically significant chi-square is evidence that the predicted associations among variables are not significantly different from the observed associations. Nonetheless, it has been noted that the chi-square significance test is sensitive to sample size, and failure to reject a model can be a consequence of insufficient power. With respect to the

³During control cue exposure, mean (standard deviation) self-reported urge ratings were 36.4 (24.9) for deprived smokers: 23.0 (21.4) for deprived TC, and 48.6 (21.4) for deprived HS. The same ratings were 10.8 (14.2) for nondeprived smokers: 11.7 (15.3) for nondeprived TC, and 10.1 (13.5) for nondeprived HS. During smoking cue exposure, mean (standard deviation) urge ratings were 58.1 (30.7) for deprived smokers: 44.2 (32.3) for deprived TC, and 70.7 (23.0) for deprived HS. The same ratings were 29.6 (24.0) for nondeprived smokers: 24.3 (23.0) for nondeprived TC, and 34.1 (24.3) for nondeprived HS. Further details are provided in Sayette et al. (2001).

CFI, it has been recommended that models should be evaluated as a good fit if the CFI exceeds .90 on the basis of comments by Bentler and Bonett (1980) with respect to its forerunner, the normed fit index. More recently, Hu and Bentler (1998) have recommended values “close to .95.” Finally, Hu and Bentler (1999) reported that when the sample size is 150, a value of CFI close to .95, with a value of SRMR close to .06, results in the rejection of a simple misspecified model 100% of the time (and complex misspecified models 94% of the time). They also noted that when the sample size is ≤ 250 , use of the popular root-meansquare error of approximation (RMSEA) tends to lead to overrejection of true population models.

Data from 4 participants who had been excluded from the six variable analyses because of missing data on the measures of RT and AD LIB were included in these analyses. For the purpose of modeling, measure-specific effects were not correlated and the variance of the common factor was set to 1.0. Consistent with predictions, a one-factor model showed a reasonable degree of fit in the deprived group according to multiple criteria, $\chi^2(2, N = 63) = 4.04, p > .10$, CFI = .94, SRMR = .06. In addition, all four of the factor loadings in this model were highly significant, all z s $\geq 3.28, ps \leq .001$. In contrast, the same model applied to the data in the nondeprived group showed multiple signs of poor fit, $\chi^2(2, N = 60) = 8.39, p < .05$, CFI = .39, SRMR = .12, including the necessity of constraining an error variance to be zero to avoid a negative estimate (i.e., a Heywood case; see Bollen, 1989). A two-group analysis in which the same factor structure is specified in both groups results in a poor fit according to multiple criteria, $\chi^2(4, N = 123) = 12.43, p = .01$, CFI = .80, SRMR = .09. Given this failure to demonstrate configural invariance, we did not proceed with additional invariance constraints (e.g., constraining factor loadings to be equal across groups).⁴

On the basis of these results, we conclude that (a) the correlation among craving measures tended to be greater in the nicotine-deprived than in the nondeprived condition; (b) this difference existed mainly among measures that had previously been shown to be sensitive to the deprivation manipulation, which in theory should influence responses indicative of craving; and (c) a one-factor model accounted for covariation among the latter measures among individuals in the deprived condition but not among those in the nondeprived condition.

Discussion

The main goal of this study was to test the pattern of craving responses for nicotine-deprived and nondeprived smokers following exposure to potent smoking cues. Previous studies have provided only limited support for response covariation, yet often they have not elicited robust urges (see Wertz & Sayette, 2001a). In addition, past studies rarely have included as broad a range of smoking dependence (i.e., heavy smokers and chippers) as did the present study. Thus, although exposure reliably induces statistically significant increases in urge report (Carter & Tiffany, 1999), it is not as clear that cravings have always been sufficiently potent to show significant response covariation. Based on previous research (Brandon et al., 1996), we predicted that response covariation would be greater among deprived than nondeprived smokers following cue exposure. The omnibus test of the correlation matrices for the deprived and nondeprived smokers revealed that, as predicted, correlations were significantly, albeit modestly, higher in the former than in the latter conditions. (The failure to demonstrate statistical significance for more than one correlation likely reflects a need for even larger samples than were provided in the present study.) Moreover, results revealed a coherent response pattern only among deprived smokers. That is, the various measures loaded onto a single factor for nicotine-deprived but not nondeprived smokers.

⁴Thanks to an anonymous reviewer for making this point.

These data are consistent with those of Rickard-Figueroa and Zeichner (1985), who found a higher correlation between urge ratings and diastolic blood pressure when smokers were in a smoking cue exposure compared with a nonexposure condition. Brandon et al. (1996) found performance on several scales of the SCQ to correlate with measures of smoking behavior only among deprived smokers. In the present study, the SCQ-B was associated with a behavioroid measure of smoking motivation among deprived smokers but not nondeprived smokers.

This study found that during craving states elicited by a combination of nicotine deprivation and smoking cue exposure, our craving responses tended to covary and thus provided support for an assumption implicit in many theories of craving, such as conditioned withdrawal, conditioned compensatory response, conditioned appetitive motivation, and social learning theory (Drummond, Cooper, & Glautier, 1994; Niaura et al., 1988). As has been suggested with emotional states such as fear, response covariation is more likely to appear during intense, rather than mild, emotional states (Hodgson & Rachman, 1974; Lang, 1984). Findings also were generally consistent with Baker et al.'s (1987) model of drug urge. These investigators posited two craving networks (a positive and a negative affect urge network) in which information pertaining to drug use is coded. Baker et al. proposed that, under certain conditions, diverse responses associated with a positive affect or negative affect urge network may produce coherent response patterns. Although both groups of smokers in the present study tended to report affect toward the positive end of the valence continuum, deprived participants did report more negative/less positive affect and stronger urge responses than did nondeprived smokers. This set of findings is in accord with Baker et al.'s (1987) position that the negative affect urge network should be activated during nicotine deprivation and when smokers perceive that the cigarette is unavailable for smoking. To better distinguish between reporting less positive versus more negative affect, future studies might measure positive and negative affect separately. For instance, Carter and Tiffany (2001) recently used a two-item affect scale to rapidly assess positive and negative affect during smoking cue exposure.

The finding that our deprived smokers' craving responses loaded onto a single factor still leaves open the possibility that craving states might also involve processing that is somewhat independent of drug use motivation. Most pertinent here is Tiffany's (1990) proposal that craving involves the activation of nonautomatic cognitive resources following the interruption of well-learned action sequences such as smoking. These nonautomatic resources are mobilized to cope with the interrupted routine (e.g., when a smoker runs out of cigarettes late at night). The present data support the assertion presented elsewhere (Sayette, 1999) that nonautomatic resources are likely to be directed toward several functions including, but not necessarily limited to, procedures involved in coping with an interrupted routine. Thus, craving may be accompanied by a wide array of cognitions including the following: monitoring the level of motivation or desire to smoke, the smoking cues themselves (e.g., thoughts of holding a lit cigarette), thoughts related to anticipated positive effects of smoking ("If I smoke a cigarette, then I will feel better"), feelings associated with the event (e.g., frustration that the cigarettes are unavailable), and problem-solving cognitions associated with completing the smoking action plan (e.g., "Where can I get cigarettes at this hour of the night?"). Different craving response measures likely vary with respect to their sensitivity to these different cognitions. Assuming that there is at least minimal motivation to smoke, for example, heart rate may increase as one anticipates the effort required to procure a late-night cigarette independent of just how strong the desire is to smoke. The present data do suggest, however, that under certain conditions a range of craving response measures can index a single underlying motivational state. Future research using a broader range of response domains would be useful to test further conditions under which craving response measures covary.

One could question whether our measures reflected craving rather than some other construct. Revealing that measures derived from multiple methods are similarly influenced by a

manipulation, while providing convergent validity (Campbell & Fiske, 1959), is just one step toward construct validation. Nevertheless, each of our measures has been proposed as a potential index of craving response in the literature. As predicted, the different measures showed greater covariation during nicotine-deprived than during nondeprived states, a finding that provides additional support for the validity of our craving construct. Moreover, it is not apparent to us that other constructs besides craving would have similarly affected these different measures. For example, in contrast to craving, negative affect should not necessarily produce a shift in the probability of positive outcomes anticipated from smoking and should not increase the monetary value associated with smoking a cigarette immediately (unless, of course, the construct of negative affect were to be merged with the construct of craving, which is compatible with the present conceptualization of craving as being affective in nature; Baker et al., 1987).

Ideally, all measures would be completed during both control and smoking cue exposure. Except for reported urge and RT, however, our measures were not administered during control cue exposure because of concerns with carryover effects. (In retrospect, however, assessment of affective valence during baseline and control exposure would have been useful.) We instead focused mainly on the smoking cue exposure period, when all measures were assessed. This approach allowed us to examine as many measures as possible, as completely as possible, without compromising their integrity. Nevertheless, we cannot determine conclusively whether the convergence of responses was specific to cue-elicited craving or to craving produced simply through nicotine deprivation.

A limitation of the present study is that the deprivation conditions were not conceptually equivalent for HS and TC: Over 7 waking hours, HS would normally have smoked more cigarettes than TC. In this sense, TC may have been under less deprivation. Even so, both TC and HS appear to be responsive to smoking cues (Sayette et al., 2001; Shiffman, Kassel, Paty, Gnys, & Zettler-Segal, 1994). We have found that following deprivation, even relatively light smokers report strong urges during smoking cue exposure (Sayette & Hufford, 1994; Sayette et al., 2001; Sayette & Parrott, 1999; Wertz & Sayette, 2001b).

There is a pressing need to develop new measures to assess craving (Sayette et al., 2000; Zinser et al., 1999). This cue exposure study included several novel measures (both implicit and explicit) posited to index craving responses and supported the proposition that nicotine deprivation affects response covariation. This finding does not suggest of course, that deprivation is the only factor affecting drug motivation. Our study did not include measures from all response domains (e.g., physiological responses, drug self-administration). Clearly, this area of research is just developing; studies that incorporate other types of conceptually derived measures under varying levels of craving are indicated. Inclusion of such measures would provide important data for further investigating the conditions under which craving-related measures covary.

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Appendix

The Smoking Consequences Questionnaire—Brief (SCQ-B)

The items (14 positive/desirable and 10 negative/undesirable) selected for the SCQ-B are as follows:

People think less of me if they see me smoking.

My throat burns after smoking.

A cigarette can satisfy my urge to smoke.

Cigarettes make my lungs hurt.

Smoking keeps my weight down.

When I smoke, the taste is pleasant.

By smoking I risk heart disease and lung cancer.

Smoking calms me down when I feel nervous.

The more I smoke, the more I risk my health.

Cigarettes keep me from eating more than I should.

Nicotine “fits” can be controlled by smoking.

When I’m angry, a cigarette can calm me down.

Smoking a cigarette energizes me.

I enjoy the taste sensations while smoking.

I feel more at ease with other people if I have a cigarette.

Smoking is taking years off my life.

Smoking will satisfy my nicotine cravings.

I look ridiculous while smoking.

Smoking irritates my mouth and throat.

Cigarettes can really make me feel good.

I feel like part of a group when I’m around other smokers.

Smoking is hazardous to my health.

Smoking temporarily reduces those repeated urges for cigarettes.

Smoking makes me seem less attractive.

Note. From “The Smoking Consequences Questionnaire—Adult: Measurement of Smoking Outcome Expectancies of Experienced Smokers,” by A. L. Copeland, T. H. Brandon, & E. P.

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References

- Aronson, A.; Wilson, TD.; Brewer, MB. Experimentation in social psychology. In: Gilbert, D.; Fiske, ST.; Lindzey, G., editors. The handbook of social psychology. Vol. 4th ed.. Vol. 1. McGraw-Hill; Boston: 1998. p. 99-142.
- Baker, TB.; Morse, E.; Sherman, JE. The motivation to use drugs: A psychobiological analysis of urges. In: Rivers, C., editor. Nebraska Symposium on Motivation: Vol. 34. Alcohol use and abuse. University of Nebraska Press; Lincoln: 1987. p. 257-323.
- Bentler PM. Comparative fit indexes in structural models. *Psychological Bulletin* 1990;107:238–246. [PubMed: 2320703]
- Bentler, PM. EQS Structural Equations Program manual. Multivariate Software; Encino, CA: 1995.
- Bentler PM, Bonett DG. Significance tests and goodness of fit in the analysis of covariance structures. *Psychological Bulletin* 1980;88:588–606.
- Bollen, KA. Structural equations with latent variables. Wiley; New York: 1989.
- Brandon T, Wetter D, Baker T. Affect, expectancies, urges, and smoking: Do they conform to models of drug motivation and relapse? *Experimental & Clinical Psychopharmacology* 1996;4:29–36.
- Campbell DT, Fiske DW. Convergent and discriminative validation by the multitrait-multimethod matrix. *Psychological Bulletin* 1959;56:81–105. [PubMed: 13634291]
- Carter BL, Tiffany ST. Meta-analysis of cue reactivity in addiction research. *Addiction* 1999;94:327–340. [PubMed: 10605857]
- Carter BL, Tiffany ST. The cue-availability paradigm: The effects of cigarette availability on cue reactivity in smokers. *Experimental and Clinical Psychopharmacology* 2001;9:183–190. [PubMed: 11518094]
- Copeland AL, Brandon TH, Quinn EP. The Smoking Consequences Questionnaire—Adult: Measurement of smoking out-come expectancies of experienced smokers. *Psychological Assessment* 1995;7:484–494.
- Drobes DJ, Tiffany ST. Induction of smoking urge through imaginal and in vivo procedures: Physiological and self-report manifestations. *Journal of Abnormal Psychology* 1997;106:15–25. [PubMed: 9103714]
- Drummond DC. What does cue-reactivity have to offer clinical research? *Addiction* 2000;95:S129–S144. [PubMed: 11002908]
- Drummond DC, Cooper T, Glautier SP. Conditioned learning in alcohol dependence: Implications for cue exposure treatment. *British Journal of Addiction* 1994;85:725–743. [PubMed: 2198966]
- Hodgson R, Rachman S. Desynchrony in measures of fear. *Behaviour Research and Therapy* 1974;12:319–326. [PubMed: 4155622]
- Hu, L.; Bentler, PM. Evaluating model fit. In: Hoyle, RH., editor. Structural equation modeling: Concepts, issues, and applications. Sage; Newbury Park, CA: 1995. p. 76-99.
- Hu L, Bentler PM. Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological Methods* 1998;3:424–453.
- Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling* 1999;6:1–55.
- Hutchison KE, Niaura R, Swift R. Smoking cues decrease prepulse inhibition of the startle response and increase subjective craving in humans. *Experimental and Clinical Psychopharmacology* 1999;7:250–256. [PubMed: 10472513]
- Jacoby LL, Lindsay DS, Toth JP. Unconscious influences revealed: Attention, awareness, and control. *American Psychologist* 1992;47:802–809. [PubMed: 1616180]
- Juliano LM, Brandon TH. Reactivity to instructed smoking availability and environmental cues: Evidence with urge and reaction time. *Experimental and Clinical Psychopharmacology* 1998;6:45–53. [PubMed: 9526145]

- Kassel JD, Shiffman S. What can hunger teach us about drug craving? A comparative analysis of the two constructs. *Advances in Behaviour Research and Therapy* 1992;14:141–167.
- Kozlowski LT, Pillitteri JL, Sweeney CT, Whitfield KE, Graham JW. Asking questions about urges or cravings for cigarettes. *Psychology of Addictive Behaviors* 1996;10:248–260.
- Kozlowski LT, Wilkinson DA. Use and misuse of the concept of craving by alcohol, tobacco, and drug researchers. *British Journal of Addiction* 1987;82:31–36. [PubMed: 3470042]
- Lang, PJ. Cognition in emotion: Concept and action. In: Izard, C.; Kagan, J.; Zajonc, R., editors. *Emotions, cognition, and behavior*. Cambridge University Press; New York: 1984. p. 128–200.
- Ludwig AM, Wikler A, Stark LH. The first drink: Psychobiological aspects of craving. *Archives of General Psychiatry* 1974;30:539–547. [PubMed: 4131353]
- Marlatt, GA. Cognitive factors in the relapse process. In: Marlatt, GA.; Gordon, JR., editors. *Relapse prevention: Maintenance strategies in the treatment of addictive behaviors*. Guilford Press; New York: 1985. p. 128–200.
- Monti PM, Rohsenow DJ, Rubonis A, Niaura RS, Sirota AS, Colby SM, Abrams DB. Alcohol cue reactivity: Effects of detoxification and extended exposure. *Journal of Studies on Alcohol* 1993;54:235–245. [PubMed: 8384678]
- Niaura RS, Rohsenow DJ, Binkoff JA, Monti PM, Pedraza M, Abrams DB. Relevance of cue reactivity to understanding alcohol and smoking relapse. *Journal of Abnormal Psychology* 1988;97:133–152. [PubMed: 3290304]
- Plummer BA, Velicer WF, Redding CA, Prochaska JO, Rossi JS, Pallonen UE, Meier KS. Stage of change, decisional balance, and temptations for smoking: Measurement and validation in a large, school-based population of adolescents. *Addictive Behaviors* 2001;26:551–571. [PubMed: 11456077]
- Rankin H, Hodgson R, Stockwell T. The concept of craving and its measurement. *Behaviour Research and Therapy* 1979;17:389–396. [PubMed: 486042]
- Rickard-Figueroa K, Zeichner A. Assessment of smoking urge and its concomitants under an environmental smoking cue manipulation. *Addictive Behaviors* 1985;10:249–256. [PubMed: 4083102]
- Rohsenow DJ, Niaura RS, Childress AR, Abrams DB, Monti PM. Cue reactivity in addictive behaviors: Theoretical and treatment implications. *International Journal of the Addictions* 1990;25:957–993. [PubMed: 2131326]
- Sayette, MA. Cognitive theory and research. In: Leonard, K.; Blane, H., editors. *Psychological theories of drinking and alcoholism*. Vol. 2nd ed.. Guilford Press; New York: 1999. p. 247–291.
- Sayette M, Hufford M. Effects of cue exposure and deprivation on cognitive resources in smokers. *Journal of Abnormal Psychology* 1994;103:812–818. [PubMed: 7822584]
- Sayette MA, Hufford MR. Effects of smoking urge on generation of smoking-related information. *Journal of Applied Social Psychology* 1997;27:1395–1405.
- Sayette MA, Martin CS, Wertz JM, Shiffman S, Perrott MA. A multidimensional analysis of cue-elicited craving in heavy smokers and tobacco chippers. *Addiction* 2001;96:1419–1432. [PubMed: 11571061]
- Sayette MA, Parrott DJ. Effects of olfactory stimuli on urge reduction in smokers. *Experimental and Clinical Psychopharmacology* 1999;7:151–159. [PubMed: 10340155]
- Sayette MA, Shiffman S, Tiffany ST, Niaura RS, Martin CS, Shadel WG. The measurement of drug craving. *Addiction* 2000;95:S189–S210. [PubMed: 11002914]
- Schacter D. Implicit memory: History and status. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1987;13:501–518.
- Shiffman S, Jarvik ME. Smoking withdrawal symptoms in two weeks of abstinence. *Psychopharmacology* 1979;50:35–39. [PubMed: 827760]
- Shiffman S, Kassel JD, Paty JA, Gnys M, Zettler-Segal M. Smoking typology profiles of chippers and regular smokers. *Journal of Substance Abuse* 1994;6:21–35. [PubMed: 8081107]
- Shiffman S, Paty JA, Kassel JD, Gnys M, Zettler-Segal M. Smoking behavior and smoking history of tobacco chippers. *Experimental and Clinical Psychopharmacology* 1994;2:126–142.

- Siegel, S. Classical conditioning, drug tolerance, and drug dependence. In: Israel, Y.; Glaser, F.; Kalant, H.; Popham, R.; Schmidt, W.; Smart, R., editors. Research advances in alcohol and drug problems. Vol. 7. Plenum; New York: 1983. p. 207-246.
- Stewart J, de Wit H, Eikelboom R. Role of unconditioned and conditioned drug effects in self-administration of opiates and stimulants. *Psychological Review* 1984;91:251–268. [PubMed: 6571424]
- Stockwell T. Is there a better word than “craving”? *British Journal of Addiction* 1987;82:44–45.
- Tiffany ST. A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review* 1990;97:147–168. [PubMed: 2186423]
- Tiffany ST, Drobes DJ. The development and initial validation of a questionnaire on smoking urges. *British Journal of Addiction* 1991;86:1467–1476. [PubMed: 1777741]
- Wertz JM, Sayette MA. A review of the effects of perceived drug use opportunity on self-reported urge. *Experimental and Clinical Psychopharmacology* 2001a;9:3–13. [PubMed: 11519632]
- Wertz JM, Sayette MA. Effects of smoking opportunity on attentional bias in smokers. *Psychology of Addictive Behavior* 2001b;15:268–271.
- Wilson TD, Lindsey S, Schooler TY. A model of dual attitudes. *Psychological Review* 2000;107:101–126. [PubMed: 10687404]
- Zinser M, Baker T, Sherman J, Cannon D. Relation between self-reported affect and drug urges and cravings in continuing and withdrawing smokers. *Journal of Abnormal Psychology* 1992;101:617–629. [PubMed: 1430600]
- Zinser M, Fiore M, Davidson R, Baker TB. Manipulating smoking motivation: Impact on an electrophysiological index of approach motivation. *Journal of Abnormal Psychology* 1999;108:240–254. [PubMed: 10369034]

Table 1
Correlations (Probability Levels), Means, and Standard Deviations Among Craving Measures in Nicotine-Deprived and Nondeprived Smokers

Measure	1	2	3	4	5	6
Deprived group (<i>N</i> = 60)						
1. Choice	—					
2. Affect	.370 (.004)	—				
3. Consequences	.340 (.008)	0.428 (.001)	—			
4. Urge	.358 (.005)	0.396 (.002)	0.081 (.538)	—		
5. Ad lib	.397 (.002)	.203 (.121)	.143 (.277)	.218 (.095)	—	
6. RT latency	.259 (.047)	.337 (.009)	.023 (.865)	.290 (.025)	-0.043 (.744)	—
<i>M</i>	1.169	6.183	-0.053	8.369	-1.533	0.061
<i>SD</i>	1.166	2.288	1.874	5.185	2.600	0.098
Nondeprived group (<i>N</i> = 59)						
1. Choice	—					
2. Affect	.046 (.729)	—				
3. Consequences	.236 (.072)	-.193 (.143)	—			
4. Urge	.282 (.030)	.298 (.022)	-0.059 (.658)	—		
5. Ad lib	.095 (.475)	-.101 (.446)	.243 (.064)	.179 (.175)	—	
6. RT latency	.364 (.005)	.092 (.491)	.040 (.764)	.263 (.044)	-.055 (.681)	—
<i>M</i>	0.676	7.119	-0.459	4.824	-2.034	0.062
<i>SD</i>	1.180	2.450	1.723	3.615	2.593	0.079

Note. Correlations that appear in boldface in the top portion of each matrix were used in tests of one-factor model. These matrices were used for tests of the equality of correlations across groups. The tests of the one-factor models were conducted on matrices with slightly larger samples. Choice behavioral choice (square-root transformed); Affect affective valence; Consequences SCQ-B, the brief version of the Smoking Consequences Questionnaire; Urge Self-reported composite urge (square-root transformed); Ad lib ad lib characteristics of smoking; RT latency response-time latency.