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Manipulating Smoking Motivation: Impact on an Electrophysiological Index of Approach Motivation

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A chief goal of this research was to determine whether stimuli and events known to enhance smoking motivation also influence a physiological variable with the potential to index approach motivation. Asymmetry of electroencephalographic (EEG) activity across the frontal regions of the 2 hemispheres (left minus right hemisphere activation) was used to index approach motivation. In theory, if EEG asymmetry sensitively indexes approach dispositions, it should be influenced by manipulations known to affect smoking motivation, that is, exposure to smoking cues and tobacco deprivation. Seventy-two smokers participated in this research and were selectively exposed to a smoking-anticipation condition (cigarettes plus expectation of imminent smoking) following either 24 hr of tobacco withdrawal or ad libitum smoking. Results indicated that EEG asymmetry was increased by smoking anticipation and that smoking itself reduced EEG asymmetry. Results also suggested that smoking anticipation increased overall (bihemispheric) EEG activation. Results were interpreted in terms of major theories of drug motivation.

At present, very little is known about the nature of drug motive states; that is, little is known about the cognitive, affective, and physiological substrata of addictive drug approach dispositions. This lack of knowledge has important consequences both for assessment and treatment, as well as for addiction theory and research. For instance, if drug motivational states could be assessed more accurately, clinicians might be better able to gauge the need for treatment or to determine when an individual has received sufficient treatment. Also, characterization of drug motive states could foster research and theoretical development if the nature of drug motivational responses matches the predictions or tenets of particular motivational models.

The present research had two overarching, related goals. The first was to identify a physiological variable that appears to index the drug motive state. Specifically, we sought to determine whether stimuli and events known to enhance smoking motivation also influence an electrophysiological index of approach motivation. The second goal was to test differential predictions of leading models of drug motivation.

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Prior Research

A great deal of research has focused on characterizing the motivational state(s) produced by exposure to either drug cues or other events that enhance drug motivation. Unfortunately, this research has yielded equivocal results. For instance, it has been difficult to characterize the affective impact of drug-cue exposure. Some reports suggest that drug cues elicit self-reports of positive affect (Baker, Morse, & Sherman, 1987; O'Brien, Chaddock, Wood, & Greenstein, 1974), whereas other reports indicate that drug cues or images elicit self-reports of negative affect (e.g., Burton, Drobes, & Tiffany, 1992; Tiffany, 1995). Studies using psychophysiological measures such as skin conductance or cardiac response have been no more successful in characterizing the affective valence of associative responses to drug cues (see Glautier & Remington, 1995; Niaura, Abrams, Demuth, Pinto, & Monti, 1989; Sherman, Jorenby, & Baker, 1988; Tiffany, 1990).

The ambiguous findings obtained in earlier research may be attributed to certain features of research design (Glautier & Remington, 1995). For instance, in much of this research, participants were exposed to drug cues but were not permitted to self-administer drug. As is discussed later, this may have produced frustration or uncertainty that could have distorted responses to the drug cues themselves. Additionally, even when investigators allowed participants to ingest drug, there was no attempt to separate the effects of cue exposure from drug ingestion. Thus, cue-elicited and pharmacologic effects may have been confounded. Another

problem is that investigators often chose to use assessments that are only loosely related to motivational state. For instance, the frequently used skin conductance or cardiac measures can have ambiguous relations with respect to affective valence and approach motivation. Therefore, even when motivational manipulations affect these systems, it is difficult to interpret the effect (Glautier & Remington, 1995; Sherman, Jorenby, & Baker, 1988). Finally, much previous research has relied on self-report, and in some circumstances self-report may provide an incomplete or inadequate index of drug motive state (Brandon, Piasecki, Quinn, & Baker, 1995; Perkins, Grobe, & Fonte, 1997; Robinson & Berridge, 1993; Tiffany, 1990).

The goals of the present research demanded that we (a) manipulate drug (smoking) motivation in an effective manner, (b) use dependent variables that are sensitive to motivational states and that also allow us to test relevant theoretical models, and (c) examine the impact of smoking cues in the context of drug (smoking) anticipation.

Manipulating Smoking Motivation

We manipulated motivation to smoke by varying both exposure to drug anticipation (entailing exposure to smoking cues) and level of drug deprivation. There is substantial evidence that anticipation of drug use, drug cues, and drug deprivation all augment drug motivation (Baker et al., 1987; Brandon et al., 1995; Piasecki, Kenford, Smith, Fiore, & Baker, 1997; Sayette & Hufford, 1995; Shiffman, Paty, Gnys, Kassel, & Hickcox, 1996; Zinser, Baker, Sherman, & Cannon, 1992).

Dependent Variables

The two principal dependent measures used in this research were both measures of cortical electroencephalographic (EEG) activity: asymmetry of frontal activation (asymmetry) and bihemispheric frontal activation (activation). We chose these measures because we believed that, together, they would be both sensitive to motivational states and allow us to test specific model predictions. Asymmetry was the chief measure selected for study because considerable research shows that it indexes affective processing as it is related to approach versus withdrawal motivational states. Specifically, when people are presented appetitive stimuli, they tend to display relatively greater left than right frontal hemispheric activation as well as positive affect; conversely, people presented aversive stimuli or people in withdrawal-associated motivational states display relatively greater right hemispheric activation and negative affect (Davidson, 1984; Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Fox, 1991). Thus, greater left asymmetry is thought to index both the capacity of cues to elicit positive affect and the tendency of the organism to approach such cues. Our fundamental a priori prediction was that smokers would show maximal left frontal asymmetry (greater left than right frontal hemispheric activation) when anticipating smoking following a period of smoking deprivation.

Overall, or bihemispheric, frontal cortical activation (combined right and left hemispheric activation) was also assessed in this study. Considerable research has shown that cortical activation indexes both nicotine/tobacco agonist effects as well as nicotine/tobacco withdrawal effects. Specifically, nicotine tends to increase overall cortical activation, whereas nicotine withdrawal tends to decrease such activation (Knott & Griffiths, 1992; Knott & Venables, 1977; Pickworth, Herning, & Henningfield, 1986, 1989; Ulett & Itil, 1969). Although there is little evidence that bihemispheric activation is sensitive to motivational valence, its assessment allows us to test particular model-based predictions.

The limited literature on the effects of smoking on EEG asymmetry suggests that these effects may vary as a function of dose (Pritchard, 1991) and smoking time course (early vs. late in a cigarette; Norton, Brown, & Howard, 1992), stress level (Gilbert, Robinson, Chamberlin, & Spielberger, 1989), attentional demand (Hasenfratz & Bättig, 1992), personality (Gilbert, 1987), and degree of depression (Gilbert, Meliska, Welser, & Estes, 1994). The aforementioned research has spawned models that claim a variety of effects for nicotine. Gilbert (1985) proposed a left-hemisphere-priming hypothesis, suggesting that nicotine stimulates left-hemisphere-dominant cholinergic receptors, which in turn suppress right-hemisphere emotional processes. Later findings implicated the right hemisphere more prominently in nicotine's effects, leading to speculations that nicotine reduces right-hemisphere activity during stressful or arousing conditions but has the opposite effect (right-hemisphere activation) during relaxing conditions (Gilbert, 1995; Gilbert & Welser, 1989; cf. Knott, Hooper, Lusk-Mikkelsen, & Kerr, 1995). Gilbert (1995) also has proposed that nicotine activates left frontal regions that promote approach motivation and positive affect and that these effects are pronounced in those with greater resting levels of right-frontal activation. Another formulation holds that nicotine's impact is dose-dependent, with low doses activating a left-hemisphere reward motivational *go* system, and higher doses activate a right hemisphere *no-go* system (Norton et al., 1992). In sum, both data and theories in this area are varied and divergent. This situation may have arisen because the effects of nicotine per se are typically confounded with cue–expectation effects.

Relevance to Associative Models of Drug Motivation

Abraham Wikler's Pavlovian model of drug motivation (Wikler, 1980), as well as compensatory response theories (Siegel, 1983), suggest that drug-withdrawal symptoms provide the basis of drug reinforcement (e.g., O'Brien, 1976). According to these theories, drug cues elicit aversive withdrawal responses in addicts, and drug ingestion reduces these responses. Conversely, incentive-based accounts hold that drug cues, or the anticipation of drug use, elicit responses that resemble the positive reinforcing or appetitive effects of drugs (Baker et al., 1987; Stewart, deWit, & Eikelboom, 1984; cf. Wise, 1988). These theories suggest that drug cues act as incentive stimuli that promote drug use by activating or priming brain reward systems that lead to increased arousal or activity, positive affect or pleasure, and a heightened tendency to pursue reinforcing stimuli such as addictive drugs (e.g., Stewart et al., 1984). Moreover, such theories suggest that the direct effects of drugs are appetitive for addicts and that these effects increase activity in brain systems that mediate drug-approach behavior (Tiffany, 1995).

A third, recently proposed model yields unique predictions about the nature of conditioned and direct drug effects and their relation to drug motivation. According to Robinson and Berridge's (1993) incentive-sensitization theory of addiction, mesotelence-

phalic dopamine systems are sensitized by iterative drug exposure. These systems impart salience and incentive valence on rewarding stimuli and cause cues for reward to elicit the phenomenologic experiences of wanting or expectations of pleasure. Because the sensitization of these mesotelencephalic systems can become uncoupled from systems that mediate the rewarding effects of drugs, the addicted organism may experience cue-elicited expectation of pleasure, even after becoming tolerant or habituated to drug reward. Thus, this model yields the prediction that in the addicted organism, drug cues, but not necessarily drug ingestion per se, elicit responses associated with the activation of an approach motivational system. These three models yield distinct predictions regarding the effects of drug cues and drug ingestion on the dependent measures used in this research (see Table 1).

Table 1
Experiment-Specific Predictions of Models of Drug Motivation

Models	Effects of smoking cues		Effects of smoking	
	Left–right asymmetry	Overall activation	Left–right asymmetry	Overall activation
Associative-withdrawal	⇓	⇓	⇑	⇑
Appetitive-incentive	⇑	⇑	⇑	⇑
Incentive-sensitization	⇑	⇑	⇓	—[a]

Note. ⇑ means that model predicts that smoking or smoking-cue exposure will increase the measured response. ⇓ means that model predicts that smoking or smoking-cue exposure will decrease the measured response.
[a] The incentive-sensitization model does not yield a clear prediction for this cell.

Associative-Withdrawal Models

The associative-withdrawal models hold that, at the very least, drug cues should elicit a conditioned response emblematic of nicotine withdrawal, that is, decreased overall cortical activation. Additionally, such models suggest that drug cues should elicit decreased activation of left versus right frontal cortical regions because the models hold that drug cues elicit withdrawal responses and that negative affect is a hallmark of withdrawal (Piasecki et al., 1997). In theory, actual drug ingestion would decrease the negative affect produced by withdrawal and, therefore, increase the relative activation of the left frontal cortex. Thus, smoking should both increase overall cortical activation and increase the relative activation of left frontal regions.[1]

Appetitive-Incentive Models

Incentive or priming models yield the prediction that both drug ingestion and exposure to drug cues should elicit both increased overall cortical arousal as well as increased left asymmetry. These predictions arise from the claims of the theory that, for the addicted organism, both the direct actions of drug and drug cues generate or prime a central motivational state that outputs positive affect, increased behavioral activity/arousal, and a tendency to reinitiate pursuit of incentives—such as addictive drugs (cf. Stewart et al., 1984).

Incentive-Sensitization Model

The incentive-sensitization model (Robinson & Berridge, 1993) holds that, when presented to addicted organisms, drug cues activate neural systems that mediate the anticipation of pleasure and pursuit of rewarding stimuli. Therefore, consonant with incentive models, the incentive-sensitization model suggests that drug cues should elicit increased left-activation (greater cortical activity in the left vs. right hemisphere; Table 1). However, this model departs from incentive models in that it assumes that in an organism with extensive drug experience, drug itself will not activate approach systems. It is assumed that over the course of iterative drug use, organisms habituate to the rewarding actions of drugs at the same time that their incentive–reward neural systems are sensitized. Thus, drug *wanting* becomes uncoupled from drug *liking*. Therefore, in the current study, the pattern of findings that would be most compatible with the incentive-sensitization model is one in which smoking cues elicit increased left-activation, but smoking per se does not. Although the incentive-sensitization model does not yield specific predictions about bihemispheric cortical activation, its tenets are most consistent with the hypothesis that smoking cues will increase overall cortical arousal because of the activation of approach systems. It is relatively silent as to how smoking should affect overall activation.

Anticipation-Smoking Cue Complex

As noted previously, the present research did not use the smoking-cue exposure procedures typically used in smoking research. In most research, smokers are either shown cigarettes or are presented imagery scripts about smoking and are told (veridically) that they will not be allowed to smoke (e.g., Abrams, Monti, Carey, Pinto, & Jacobus, 1988; Drobes & Tiffany, 1997; Niaura et al., 1989). In the present research, smokers were presented smoking cues along with the expectation that they would be able to smoke rather than with the expectation that smoking would be prevented. We adopted this strategy because we believed that it permitted the purest, most appropriate tests of the contrasted theoretical models.

All of the models invoke Pavlovian associative mechanisms to explain the impact of drug cues on drug motivation response systems (Robinson & Berridge, 1993; Siegel, 1988; Stewart et al., 1984; Wikler, 1973). Consistent with this, all models assume that activation of motivational systems will occur in response to the organism's anticipation (Siegel, 1988) or expectancy (Stewart et al., 1984) of drug effects. Moreover, information signaling the nondelivery/unavailability of drug (e.g., information delivered via

[1] It might be argued that withdrawal models could predict that drug cues activate approach systems because they signal the availability of negative reinforcement. This view supports the prediction that drug cues should elicit greater relative left activation of frontal cortices. However, such a proposition really represents a bold departure from classic associative withdrawal models whose hallmark has been that drug cues elicit withdrawal symptoms such as negative affect (e.g., Siegel, 1983; Wikler, 1980). The classic withdrawal model would be incompatible with a finding that drug cues elicit responses associated with positive affect.

extinction or conditioned inhibition procedures) consistently attenuates or blocks drug-consequated conditioned responses (CRs; Siegel, Sherman, & Mitchell, 1980; Stewart, 1992). Therefore, we reasoned that information that drug would be unavailable/noncontingent with cue exposure, would attenuate or contaminate CRs. Specifically, we believed that verbal (second signal system) information regarding drug unavailability might have inhibitory properties similar to those produced by extinction or other inhibitory manipulations.[2]

All three models suggest that drug-cue presentation coupled with drug anticipation should activate drug motivational processes. The associative-withdrawal models emphasize counteradaptations or compensatory responses in anticipation of drug (Siegel, 1988; Wikler, 1973), whereas both incentive models are predicated—as are all incentive models—on the anticipation of reinforcement (Bolles, 1967). In sum, unambiguous tests of the models require an expectation of drug use (smoking).

Design Overview

To assess the relation between the motivation to smoke (approach disposition) and EEG asymmetry, we ran participants in two smoking trials during the experimental session. Prior to these trials, half of the participants were withdrawn from tobacco for 24 hr, and the other half smoked ad libitum. Moreover, all participants were exposed to a social interaction stressor prior to the first smoking trial. Both tobacco withdrawal and stress should induce negative affect and enhance smoking motivation (Baker et al., 1987; Gritz, Carr, & Marcus, 1991; Pomerleau & Pomerleau, 1987; Zinser et al., 1992). In the first smoking trial, half of the withdrawn smokers and half of the continuing smokers were exposed to smoking cues (a lit cigarette) with the knowledge that they would soon be allowed to smoke.

The second smoking trial provided an additional opportunity to investigate the relation between smoking deprivation and EEG asymmetry. In this trial, all participants were exposed to cigarettes during the exposure interval, and all participants were given the opportunity to smoke. Therefore, at this point, the major difference between groups was only their prior exposure to smoke—in this trial they did not differ in cue exposure or smoking opportunity. Our only a priori prediction involved the smoking trials because we believed that only these occasions constituted relatively pure tests of smoking motivation. We predicted that relative left-frontal asymmetry would be greatest among deprived smokers who were anticipating smoking.

Method

Participants

Male and female smokers (N = 72) were recruited either from the introductory psychology participant pool at the University of Wisconsin—Madison or from advertisements in local newspapers. The former were offered points applicable to their final grade; the latter were offered $20. For both groups, recruitment notices requested habitual smokers for participation in a research project and listed the lab phone number. Only respondents who reported having smoked at least one pack per day for a minimum of 1 year were eligible. Moreover, in the acclimation and group assignment session, participants were required to provide a breath sample with CO greater than 12 ppm. Participants were randomly assigned to one of four groups (n = 18 per group) resulting from the crossing of withdrawal status (continuing/ad lib or withdrawing) with a smoke exposure variable—whether the participant smoked a cigarette in only the second smoking trial (smoke once) or in both smoking trials (smoke twice). Thus, these four groups were withdrawing/smoke once (WDR-Once), withdrawing/smoke twice (WDR-Twice), continuing/smoke once (CNT-Once), or continuing/smoke twice (CNT-Twice). There were no significant group differences on any demographic or smoking history variable ($ps > .05$). The gender compositions of the four groups did not differ significantly, $\chi^2(3, N = 72) = 3.28$, $p > .35$. Table 2 presents relevant participant information for these groups.

Self-Report Measures

Participants used a computerized joystick system to rate their pleasure, arousal, and urges as experienced at the moment (*right now*) on four occasions. The joystick device (TG Products, Plano, TX) consisted of a small arm mounted in a plastic box (12 cm × 8 cm × 4 cm) attached to the right arm of the recliner in which the participant sat. The joystick controlled a computer-generated horizontal bar graph that was displayed on a 30-cm monochrome monitor placed on a table to the participant's right. Each bar-graph rating provided a score between 1 and 20. The scores were recorded on computer disk. The low end of the pleasure rating was defined as *feeling terrible* and the high end as *feeling great.* For arousal, the low end of the scale was defined as *boredom, sleepiness, sluggishness, or great relaxation* and the high end as *very awake, stimulated, highly anxious, or alert.* The low end of the urge scale was defined as *absolutely no desire for a cigarette at the moment* and the high end as *wanting a cigarette more than you've ever wanted one before.*

Two paper-and-pencil assessments of mood were used in the study: an abbreviated version of the Mood Adjective Check List (MACL; Nowlis, 1965) and the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). The 31-item version of the MACL included scales for Aggression, Anxiety, Sadness, Skepticism, Vigor, Elation, Surgency, and Social Affection, and each item was presented in 9-point Likert format.

Smoking Topography Apparatus

A smoking meter was constructed to obtain temporal measures of puff topography. The meter consisted of two tubes extending from a 5-cm aluminum cigarette holder, extending to the ports of a cylindrical Grass volumetric pressure transducer (Model PT5 A; Quincy, MA) measuring 7.5 cm in diameter × 3.5 cm in depth; this unit was mounted on three 6-cm legs. Smoking meter output was fed to a Grass low-level DC amplifier, recorded on chart paper, digitized at 128 Hz and stored on computer disk.

Procedure

Acclimation and Group Assignment Session

After prospective participants passed phone screening, they were invited to an acclimation and group assignment session where their screening CO assessment and group assignment were done, and their informed consent was obtained. Qualifying participants were given an overview of the

[2] Pavlov (1997) himself noted the importance of this point. With respect to observing associative responses to food cues, he noted that "one has to reckon with the sense and cunning of the dog, a factor which is not lightly to be disregarded. Often the animals perceive at once that they are only being teased with the food, become annoyed thereat, and turn away offended at what is being done before them. We must, therefore, so arrange matters as if the animals were not going to be disappointed but fed in reality" (p. 939).

Table 2
Participant Characteristics Listed by Group

Characteristic	WDR-Once	WDR-Twice	CNT-Once	CNT-Twice
Age				
M	26.4	27.6	25.2	25.8
SD	13	10	10	10
Years smoking				
M	8.5	9.7	9.1	7.8
SD	8.1	9.6	8.8	9.6
Nicotine				
M	0.85	0.89	0.82	0.78
SD	0.3	0.3	0.3	0.2
Consumption				
M	22.2	24.9	24.6	24.8
SD	5	9	8	12
CO at acclimation/group assignment				
M	22.2	24.5	21.6	22.7
SD	6.8	9.6	6.9	9.8
Years of schooling				
M	13	14	14	14
SD	0.9	1.6	2.7	1.8

Note. Descriptive participant information for the four groups. Means and standard deviations for age, number of years of regular smoking, cigarette nicotine content (milligrams), consumption (number of cigarettes smoked per day), carbon monoxide (CO) level at acclimation/group assignment session, and years of schooling (inclusive of college). The four groups were withdrawn smokers who smoked only in smoke trial 2 (WDR-Once), withdrawn smokers who smoked in smoke trials 1 and 2 (WDR-Twice), continuing smokers who smoked only in smoke trial 2 (CNT-Once), and continuing smokers who smoked in smoke trials 1 and 2 (CNT-Twice). All *ns* = 18.

procedures, then measured for localization of EEG electrode placement. These measurements were intended to acclimate the participants to the procedures and to enhance reliability of electrode site placement. In addition, participants were shown the leads and told how and where they would be attached. Next, they were asked to complete a questionnaire detailing their smoking history, the Reasons for Smoking (Ikard, Green, & Horn, 1969), and the Chapman Handedness (Chapman & Chapman, 1987) questionnaires. Finally, participants were told of their randomly determined group assignment. Participants in the withdrawing conditions (WDR-Once and WDR-Twice) were asked to surrender their cigarettes and were asked to refrain for 24 hr from smoking substances of any sort and from use of any type of nicotine product. Participants in the continuing groups (CNT-Once and CNT-Twice) were told to continue smoking in their normal manner and to bring a pack of their cigarettes to the lab 24 hr later.

On returning to the lab the following day, CNT participants were asked for their cigarettes, and all participants provided a breath sample for CO determination. WDR participants whose CO level was greater than one half of the prior day's value were presumed to have smoked, were given extra credit points or paid $5, and were then thanked for their participation and dismissed. This CO criterion for abstinence has resulted in reliable differences between CNT and WDR smoker groups in prior research (e.g., Zinser et al., 1992). About 90% of participants were run in the early afternoon, between the hours of 12 noon and 5 p.m. Groups did not differ in terms of this variable.

Experimental Session

Baseline. Head measurements were repeated, and the electrodes were attached. Next, baseline mood measures (MACL and PANAS) were obtained. After the participant had completed these pencil-and-paper measures, the experimenter asked the participants to relax for 2 min, arms resting on the recliner chair and eyes open, as baseline electrophysiological data were collected.

When this baseline period of EEG collection was complete, the experimenter returned to the participant room to explain the purpose and handling of the smoking meter and to give the participant practice in its use. This exercise was also included to give the experimenter the opportunity to adjust polygraph amplifier sensitivity to accommodate differences in participant puff intensity. Participants were told that they would not be allowed to smoke at this time. The experimenter placed an unlighted cigarette in the meter and told the participant to take a few practice puffs through the device. The experimenter left the room for a 1-min period then returned and removed the cigarette.

The final event in this period was the explanation of the joystick self-report system and the collection of baseline ratings. The experimenter explained that at four points during the session, the participant would be asked to make ratings of his or her levels of pleasure, arousal, and craving by moving the joystick lever controlling a bar-graph display on a video monitor. The points at which joystick ratings were obtained and the sequence of experimental events are depicted in Figure 1.

Stress. Next, all participants were exposed to a stress condition. The experimenter informed the participant that in a few minutes a visitor would come into the room and introduce him- or herself. The participant was instructed to talk to the visitor, who was opposite in gender to the participant, in such a way as to make as favorable an impression as possible. The participant was further told that the visitor would not converse, and that she or he (the participant) was to sit quietly for a few minutes after the visitor left. The anticipation (prior to the entry of the interactor) and interaction periods both lasted 3 min; the post-interaction recovery interval lasted 2 min. After this manipulation was complete, the participant performed another set of joystick ratings. Our prior research, which produced strong smoking motivational effects, used a single application of such a stressor (Zinser et al., 1992).

Smoke trial 1. Participants in the smoke-once conditions were asked to sit quietly; the experimenter was careful not to suggest to them that participants in other conditions were allowed to smoke at this time. Participants in the smoke-twice conditions were shown a signal box that would cue them as to procedures to follow during this period. On the face of this 16 cm × 10 cm × 5 cm black plastic signal box were red and green light-emitting diodes (5 mm in diameter). Participants were told that while the green light was on, they were to observe and focus on the cigarette.

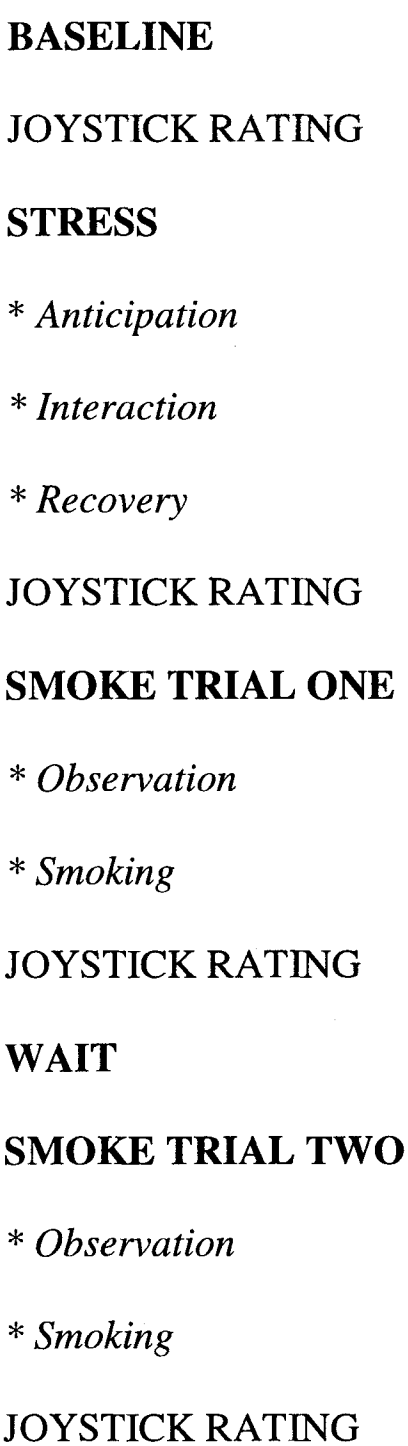

Figure 1. Sequence of experimental manipulations and joystick self-report ratings.

They were told that this period would last 60 s and that the red light would indicate that they were to pick up the meter and smoke as much as they desired at their own pace (a 6-min period). All participants were again encouraged to remain as still as possible and focus their eyes ahead. The experimenter lighted one of the participant's cigarettes, placed it in the smoking meter, and left the room. Additional joystick ratings were collected at the end of this 7-min period.

Wait period. At the end of the smoke-trial 1 period, the experimenter reentered the participant room and instructed the participant to sit quietly and relax, eyes open, for a few minutes. The participant was alone throughout this 5-min wait period.

Smoke trial 2. After the wait period, the experimenter returned to the participant room and told all participants that they would be allowed to smoke. For smoke-once participants, this was their first opportunity to smoke; for smoke-twice participants, this was their second opportunity. Given that the joystick ratings following smoke trial 1 took 1 to 2 min to complete and that the wait period was 5 min, the interval separating consecutive smoking episodes for smoke-twice participants was between 6 and 7 min. All participants were given the same instructions received by smoke-twice participants in the prior smoking trial. Procedures were identical to those used in the first smoking trial. The final set of joystick ratings completed the interval.

Following the second smoking trial, the participant was given the pencil-and-paper mood battery (MACL and PANAS), and a CO sample was obtained. The electrodes were then removed, and the participant was paid or given credit points as appropriate and debriefed.

EEG Recording and Quantification

The participant was seated in a comfortable recliner in the psychophysiological recording room; wiring was fed through a wall to the adjoining polygraph room. A white-noise generator masked distracting sounds. EEG was recorded from left and right midfrontal sites (F3 and F4), referenced to Cz. These electrodes were applied using the International 10-20 System (Jasper, 1958). Teca (Pleasantville, NY) 1.0 cm gold cup electrodes were attached to the three scalp sites with Elefix (Nihon Kohden, Tokyo, Japan) EEG paste; a Teca 1.0 cm gold ear-clip electrode was attached in the same manner to the right earlobe for grounding. The scalp and earlobe sites were abraded with a commercial EEG skin preparation paste (Omni Prep, Weaver, & Co., Aurora, CO) applied using cotton swabs. Electrode impedances were all under 5,000 ohms. Electrooculogram (EOG) was recorded from sites directly superior and lateral to the right eye using Teca 1.0 cm silver-silver chloride electrodes. Teca conductive electrolyte was used to establish skin-electrode contact. EOG was used solely for the purpose of artifact scoring.

Physiological signals were recorded with a Grass (Quincy, MA) Model 7A polygraph. EEG was processed using a Grass Model 7P511 amplifier with the 60-Hz notch filter in. The amplifier low-pass filter was set at 100 Hz; the high-pass filter was set at 1 Hz. The EOG signal was fed into a Grass wide-band A.C. pre-amplifier powered by a Grass DC power amplifier. The time constant was kept at .2. EEG and EOG analog signals were digitized at a rate of 125 samples/s using a 12-bit Lab Master board (Scientific Solutions, Solon, OH) in an ATT Model 6300 microcomputer. Artifact scoring was accomplished by visual inspection of the two EEG channels and the EOG channel for all participants at all points where data were stored. Discovery of artifact in any of these three channels resulted in rejection of data in both EEG channels. There were two artifact scorers blind to group membership whose scoring was adjudicated by an experienced artifact scorer.

EEG and EOG data were sampled continuously throughout both baseline minutes, the 1-min practice-puff period, and both observation and smoking segments of smoke trial 1 and smoke trial 2. Sampling during the social-stress period was done during s 90–120 of the anticipation period, s 30–60 and s 150–180 of the interaction period, and s 90–120 of the post-interaction period. All artifact-free data were subjected to a Discrete Fourier Transform (DFT), using 50% overlapping 1-s Hanning windows to arrive at power density (uV^2/Hz) in the alpha band (8–13 Hz). Selection of the alpha band was motivated by evidence that alpha power is inversely related to activation (e.g., Davidson, Chapman, Chapman, & Henriques,

1990; Shagass, 1972) and that measures of activation in this band yield the strongest associations between frontal asymmetry and measures of affect and approach (e.g., Davidson, Ekman, et al., 1990; Tomarken, Davidson, Wheeler, & Doss, 1992).

Data Reduction

Construction of Variables

DFT analysis yielded indexes of power in the alpha band from right (F4) and left (F3) midfrontal sites for each experimental period. Our measure of EEG asymmetry was a ratio: the difference between alpha power densities in the right (R) and left (L) midfrontal leads divided by the sum of these two quantities (R − L)/(R + L). Distributional analyses revealed adequate distributional properties and no need for transformation. To assess group differences in overall (bihemispheric) activation, a similar metric was computed, on the basis of the sum of R and L alpha power densities. To maximize the stability of these measures, analyses were restricted to epochs composed of a minimum of 15 DFT windows. Further, epochs where alpha power density exceeded 3.0 were excluded from analysis; these values tended to occur only when participants had their eyes closed. Finally, data were cleaned with extreme values (<1% of the total) replaced by group means.[3]

The variables used in analyses were activation and asymmetry measures for the following epochs: baseline, stress anticipation, stress recovery, smoke trial 1/observation, smoke trial 1/smoking, wait, smoke trial 2/observation, and smoke trial 2/smoking (see Figure 1). Observation periods were divided into two consecutive 30-s blocks; smoking periods were divided into three consecutive 2-min blocks.

Results

Analytic Strategy

Electrocortical Measures

The analytic strategies for both the asymmetry and the activation data were identical, except that a dichotomous handedness variable was added to all asymmetry analyses.[4] First, separate analyses of variance (ANOVAs) with main effects for withdrawal status and gender were performed on baseline data to determine whether withdrawing smokers showed electrocortical evidence of the abstinence syndrome and to check for gender effects.[5] Then, separate repeated measures ANOVAs across the various experimental periods were conducted. All of these analyses contained coding for withdrawal status (continuing vs. withdrawing), smoke exposure (smoke once vs. smoke twice), and all possible interactions. Focused univariate tests were used to explore significant omnibus effects and the a priori hypotheses. Unless specified, $\alpha = .05$.

Self-Report and Carbon Monoxide Measures

We analyzed paper-and-pencil (MACL and PANAS) measures obtained before baseline using one-way ANOVAs with coding for withdrawal status; those obtained at the end of the experiment were analyzed similarly, with the exception that the smoke exposure grouping variable was added. Baseline CO was analyzed by means of two-way ANOVA with both withdrawal status and smoke exposure as grouping variables.

Joystick ratings were obtained at four points: after baseline, after the stress recovery period, and after both smoking trial 1 and smoking trial 2 (see Figure 1). Repeated measures ANOVAs were conducted on these ratings in groups of two consecutive measures to assess change across the various manipulations: from baseline to the stress recovery, from stress recovery to the end of smoke trial 1, and from the end of smoke trial 1 to the end of smoke trial 2. Coding for withdrawal status was used in the first of these; the exposure status variable was added to the remaining analyses.

Baseline and Stress

Self-Report and Carbon Monoxide

Prior to the start of the experimental manipulations, the mean CO level of withdrawing smokers was substantially lower than that of continuing smokers (WDR $M = 7.1$, $SD = 4.3$; CNT $M = 20.8$, $SD = 8.3$). A two-way ANOVA using withdrawal status and smoke exposure as grouping factors confirmed that this difference was reliable, $F(1, 71) = 103.5$, and that there was no effect for smoke exposure, $F(1, 71) = 0.23$. Moreover, withdrawing smokers scored lower on both the PANAS and MACL positive affect scales than did CNT participants and higher on the negative affect scale of both measures (data not shown). Continuing smoker participants had similar COs at both their acclimation/group assignment ($M = 22.2$, $SD = 8.4$) and experimental sessions ($M = 20.8$, $SD = 7.3$), reflecting stable nicotine intake.

Ratings

At baseline, withdrawal status was related to baseline joystick measures: Withdrawing participants produced higher ratings on the joystick measure of urge and lower ratings on the pleasure measure (data not shown). We evaluated the stressor effect by a repeated-measure ANOVA of joystick measures obtained on two rating occasions: the post-baseline ratings and the post-stress ratings (see Figure 1). These revealed increases in urge and arousal ratings across the two time points, $Fs > 9.8$, and a decrease in pleasure, $F(1, 68) = 19.8$.

Electrocortical Measures

No significant group differences emerged in ANOVAs of either activation or asymmetry variables at baseline. Similarly, no sig-

[3] To ensure that principal findings were not dependent on the presence of replaced values, relevant asymmetry analyses were also conducted without data replacement. These yielded the same findings as the analyses composed of replaced values.

[4] The Chapman Handedness Questionnaire can yield continuous as well as a dichotomous measures of handedness. On the basis of the dichotomous handedness score the distribution of left handedness across groups was WDR-Once = 2, WDR-Twice = 2, CNT-Once = 1, CNT-Twice = 0. Using handedness as a covariate did not affect any of the between-subjects effects. However, there were occasional interactions between handedness and change across repeated measures. These are not reported because in all cases left- and right-handers showed isodirectional asymmetry effects, with left-handers showing greater effects. Whenever a handedness interaction was obtained, the effect was then tested with only right-handers in the analysis. In all cases, the effects were significant when analyses were restricted to right-handers.

[5] Gender effects were rare and did not affect central tests in rating and EEG analyses. Therefore, the reported analyses for post-baseline tests do not include gender as a factor.

nificant effects were found in repeated measures ANOVAs of electrocortical responses across the stress periods.

Smoke Trial 1: Observation

In this manipulation, smoke-twice participants (WDR-Twice and CNT-Twice) observed a cigarette for 1 min with the knowledge that they would be allowed to smoke immediately following this interval. The other participants (smoke-once participants), simply sat quietly.

Electrocortical Responses

Observation repeated measure ANOVAs tracked change across the post-stress recovery period and the two blocks of the smoke-trial 1 observation (see Figure 1).

Bihemispheric activation. The activation ANOVA showed no significant effects. Although the increase in activation (decreased alpha power) among WDR-Twice participants depicted in Figure 2 appears to be large, the three-way interaction involving the repeated measure and the two grouping variables did not reach significance, $F(2, 74) = 1.6$, $p = .199$.

Asymmetry. The repeated measures ANOVA revealed an interaction between smoke exposure and the repeated measure, $F(2, 68) = 4.6$. As shown in Figure 3, this is consistent with the relatively larger increase in relative activation of left frontal regions (RAL) from the post-stress recovery to the first block of observation among smokers exposed to smoking cues.

A central a priori hypothesis was that tobacco-deprived smokers anticipating smoking would show especially large increases in RAL. A paired t test revealed that only WDR-Twice participants showed increased RAL from the recovery period to the first observation period, $t(11) = 2.29$. In summary, there was a tendency for cigarette cues and smoking anticipation to increase RAL. At the level of the individual group, however, this effect was significant only among smokers in withdrawal.

Smoke Trial 1: Smoking

Ratings

Repeated measures ANOVAs were conducted in which post-stress and post-smoke 1 ratings, the two rating occasions that bracketed this smoking trial, served as repeated measures. These analyses revealed that participants who smoked in smoke trial 1 (smoke-twice participants) showed greater increases in pleasure, $F(1, 70) = 8.4$, and greater decreases in urge, $F(1, 70) = 45.9$, across the two measures than did other participants.

Electrocortical Responses

These repeated measures spanned the observation and smoking periods of smoke trial 1. The first of these measures was the final observation block, and the remaining measures were the three 2-min blocks of the smoking period.

Bihemispheric activation. The analysis of activation data revealed an interaction between the repeated measure and smoke exposure, $F(2.42, 109) = 5.1$.[6] This interaction is due to the fact that when they were given the opportunity to smoke, smoke-twice participants showed diminished alpha power (i.e., increased activation), whereas other participants showed the opposite pattern (see Figure 1).

[6] Because of heterogeneous covariance, Huyhn–Feldt adjustments were used for within-subjects degrees of freedom.

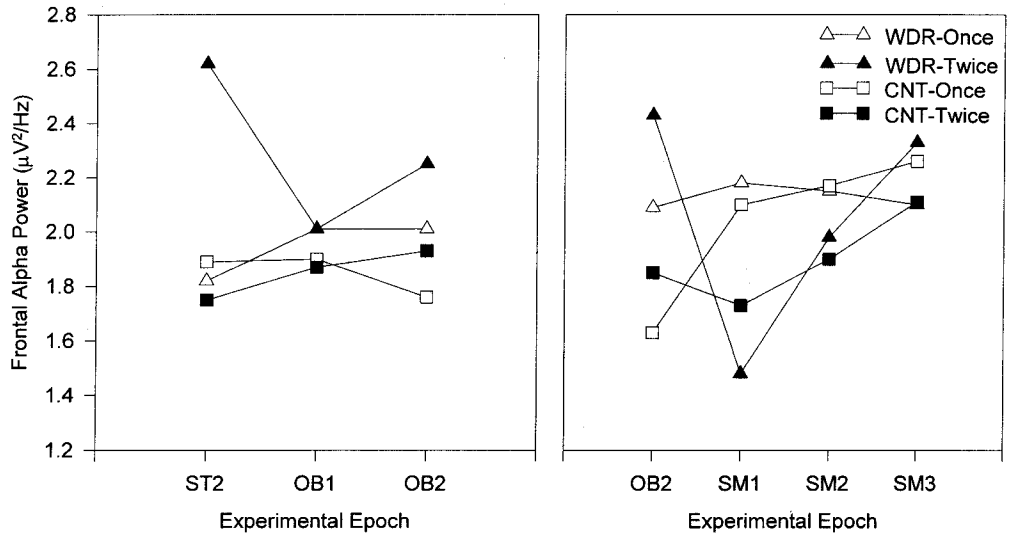

Figure 2. The left panel depicts frontal EEG activation attending the observation manipulation in smoke trial 1. Stress recovery (ST2), where the participant sat quietly, was followed by two 30-s observation blocks (OB1 and OB2). The right panel shows activation during smoking. SM1, SM2, and SM3 were the three consecutive 2-min periods where the participant was allowed to smoke ad lib. Activation is inversely related to alpha power. WDR-Once = withdrawing/smoke once; WDR-Twice = withdrawing smoke twice; CNT-Once = continuing/smoke once; CNT-Twice = continuing/smoke twice.

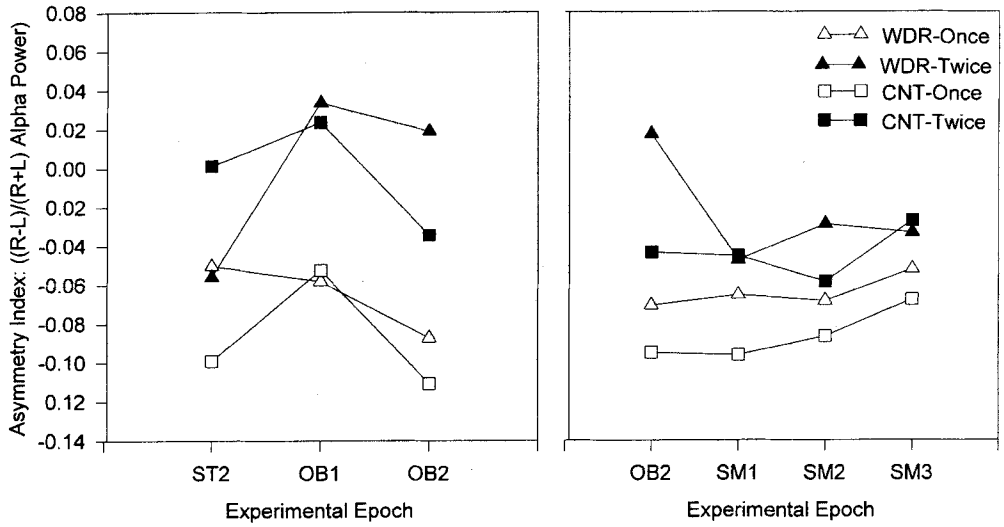

Figure 3. The left panel shows frontal EEG asymmetry during the observation manipulation in smoke trial 1. Stress recovery (ST2), where the participant sat quietly, was followed by two 30-s observation blocks (OB1 and OB2). The right panel shows EEG asymmetry during smoking. SM1, SM2, and SM3 were the three consecutive 2-min periods where the participant was allowed to smoke ad lib. Higher values of the asymmetry index indicate greater relative left-frontal activation. The asymmetry index is a ratio comprising the difference between alpha power densities in the right (R) and left (L) midfrontal leads divided by the sum of these two quantities (R + L). WDR-Once = withdrawing/smoke once; WDR-Twice = withdrawing smoke twice; CNT-Once = continuing/smoke once; CNT-Twice = continuing/smoke twice.

Asymmetry. The analysis of asymmetry data revealed an interaction between smoke exposure and the repeated measure, $F(3, 126) = 3.3$. A repeated-measures ANOVA across the observation period and the first 2-min block of the smoke period showed that this was due to the fact that only exposed (smoke-twice) participants showed significant reductions in RAL, $F(1, 44) = 10.2$. Focused t tests showed that this change was significant only for WDR-Twice participants, $t(11) = 3.06$. Thus, anticipation of smoking produced significant increases in RAL, especially among withdrawn participants, whereas smoking itself produced RAL decreases (see Figure 3).

Smoke Trial 2: Observation

At this point, only smoke-twice participants (WDR-Twice and CNT-Twice) had smoked in smoke trial 1. In smoke trial 2, all participants were exposed to cigarettes and allowed to smoke.

Electrocortical Responses

ANOVAs on the electrocortical measures contained repeated measures on the wait period and the two observations blocks of this smoke trial.

Bihemispheric activation. The analysis of overall frontal activation revealed a main effect for the repeated measure, $F(2, 82) = 3.2$, and an interaction between the repeated measure and smoke exposure, $F(2, 82) = 3.1$, $p = .053$. (Although the scores of smoke-once participants were somewhat elevated during the wait period, there was no effect of smoke exposure at this time.) Figure 4 shows an increase in activation (drop in alpha power) that occurred from the wait period to the first block of the observation period; this effect was greatest among participants who anticipated smoking for the first time in the session (WDR-Once and CNT-Once participants).

Asymmetry. The asymmetry ANOVA revealed an interaction between withdrawal status and the repeated measure that approached significance, $F(2, 76) = 2.8$, $p = .066$. This effect was caused by especially large increases in RAL among withdrawn participants on smoking anticipation/cue exposure (see Figure 5). We then tested the a priori hypothesis that deprivation would enhance RAL: separate paired t tests of change across the wait/observation interval showed significant increases in RAL only in WDR-Once participants, $t(13) = 4.54$, and WDR-Twice participants, $t(11) = 2.72$.

Smoke Trial 2: Smoking

Ratings

The analyzed joystick ratings were those that occurred just after smoke trial 1 and those occurring after smoke trial 2. These revealed interactions between the repeated measures and smoke exposure both for urge, $F(1, 64) = 50$, and pleasure, $F(1, 64) = 17.4$. This was due to the fact that participants smoking for the first time in the session (smoke-once participants) showed larger decreases in urge and larger increases in pleasure than did other participants.

Electrocortical Responses

As in smoke trial 1, these ANOVAs encompassed observation and smoking periods. Again, the first repeated measure was the

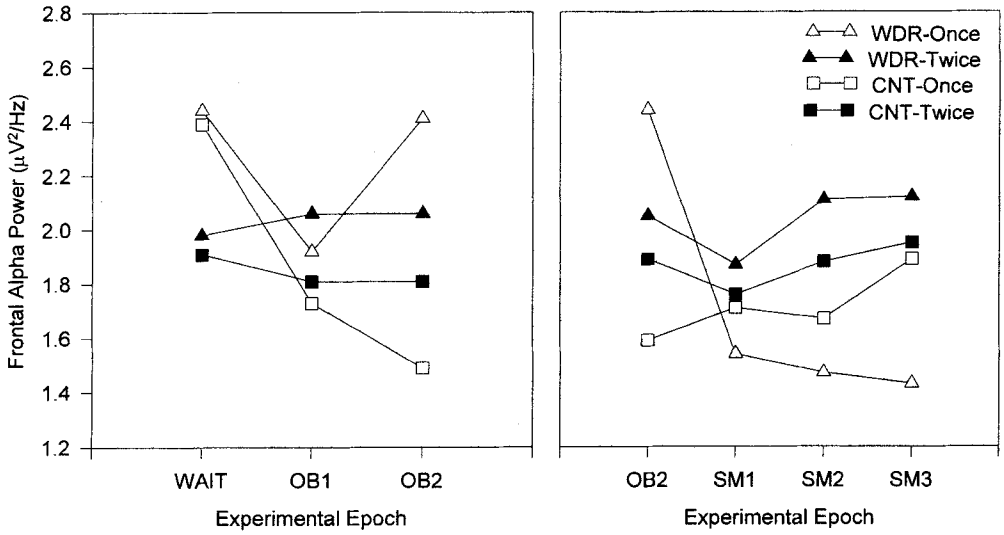

Figure 4. The left panel depicts frontal EEG activation attending the observation manipulation in smoke trial 2. The wait period, where the participant sat quietly, was followed by two 30-s observation blocks (OB1 and OB2). The right panel shows activation during smoking. SM1, SM2, and SM3 were the three consecutive 2-min periods where the participant was allowed to smoke ad lib. Activation is inversely related to alpha power. WDR-Once = withdrawing/smoke once; WDR-Twice = withdrawing smoke twice; CNT-Once = continuing/smoke once; CNT-Twice = continuing/smoke twice.

final observation block, and the remaining measures were the three 2-min smoking blocks. All participants smoked in smoke trial 2. Participants differed only in terms of their history of smoking deprivation.

Bihemispheric activation. There was a significant interaction between the repeated measure and withdrawal status, $F(1.81, 87) = 4.0$, and a three-way interaction involving the repeated measure, withdrawal status, and smoke exposure, $F(1.81, 87) = 4.3$ (see Footnote 6). The most notable trend involved in these effects was a significant decrease in alpha power (increased activation) from the second observation period to the first smoking epoch for the WDR-Once group, $t(12) = 2.61$ (see Figure 4).

Asymmetry. The asymmetry ANOVA also revealed a repeated measures main effect, $F(3, 135) = 3.3$. There was a reliable decrease in RAL across the second observation interval and the first smoking interval displayed by all groups (see Figure 5).

Post-Experiment: Self-Report and Carbon Monoxide

Two-way ANOVAs revealed that both withdrawal status, $F(1, 64) = 32.4$, and smoke exposure, $F(1, 64) = 5.2$ had significant effects on expired air CO. The mean CO levels of withdrawing smokers was lower than that of continuing smokers (WDR $M = 15.8$, $SD = 6.4$; CNT $M = 25.5$, $SD = 7.9$). Similarly, smoke-once participants had lower CO levels than did smoke-twice participants (Once $M = 18.8$, $SD = 8.2$; Twice $M = 22.3$, $SD = 8.8$). Most of the group differences in MACL and PANAS scales apparent at the outset had disappeared by the end of the experiment.

Self-Report Correlates

We correlated joystick visual analogue scale ratings of pleasure, arousal, and urge with electrophysiological measures. These revealed few significant relations and none that constituted any consistent pattern across the various groups and experimental periods. The only consistent patterns found in the electrophysiological correlates involved baseline measures of negative affect assessed with the MACL. Relations between the four negative affect MACL scales administered in the study at baseline were consistently inversely related to baseline RAL.

Smoking Topography

The present study is predicated on the assumption that tobacco deprivation and exposure to smoking cues enhance motivation to smoke. The smoking-topography data collected during the two smoking trials are relevant to the motivational impact of tobacco deprivation. In theory, more motivated smokers should take longer inhalations (puffs) on their cigarettes than less motivated smokers.

On the basis of evidence that manipulation of withdrawal would primarily affect the initial puffs on a cigarette (Comer & Creighton, 1978; Griffiths & Henningfield, 1982), the computer collected puff-duration data for the first three puffs of each smoking trial. These three-puff durations were averaged for each smoke trial.

Smoke Trial 1

The mean puff durations for WDR-Twice and CNT-Twice participants were 6.31 and 5.28, respectively.[7] We conducted a *t* test to test the a priori hypothesis that withdrawal would enhance

[7] Puff durations in the present study exceeded the mean determined in the 1988 Surgeon General's Report (U.S. Department of Health and Human Services, 1988). The most likely explanation for this difference is that the smoking meter we used altered participants' typical puff pattern.

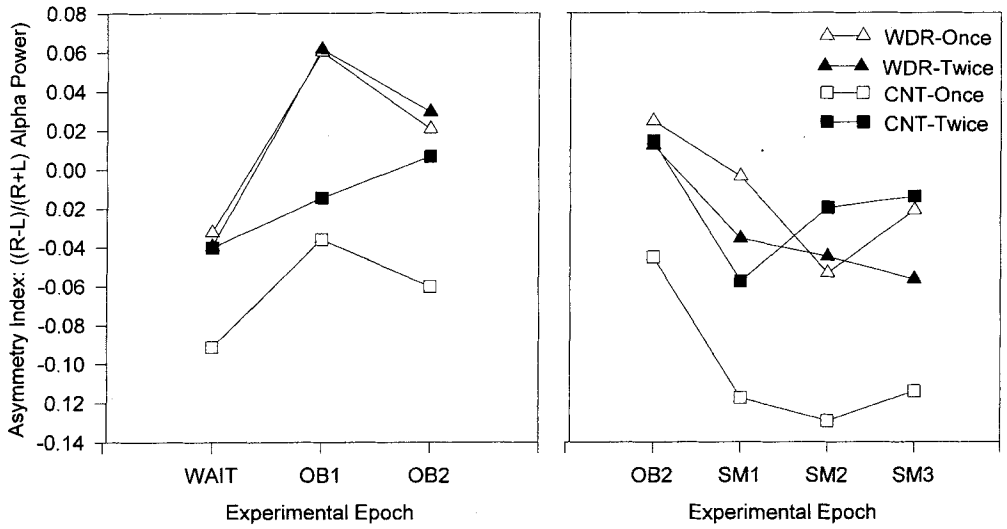

Figure 5. The left panel shows frontal EEG asymmetry during the observation manipulation in smoke trial 2. The wait period, where the participant sat quietly, was followed by two 30-s observation blocks (OB1 and OB2). The right panel shows EEG asymmetry during smoking. SM1, SM2, and SM3 were the three consecutive 2-min periods where the participant was allowed to smoke ad lib. Higher values of the asymmetry index indicate greater relative left-frontal activation. The asymmetry index is a ratio comprising the difference between alpha power densities in the right (R) and left (L) midfrontal leads divided by the sum of these two quantities (R + L). WDR-Once = withdrawing/smoke once; WDR-Twice = withdrawing/smoke twice; CNT-Once = continuing/smoke once; CNT-Twice = continuing/smoke twice.

puff duration. This yielded a significant outcome, $t(34) = 1.75$, $p < .05$ (one-tailed).

Smoke Trial 2

The puff duration means in smoke trial 2 were 6.90, 5.88, 8.89, and 5.50 s for groups WDR-Once, WDR-Twice, CNT-Once, and CNT-Twice, respectively. An analysis of variance with coding for smoke exposure and withdrawal status revealed an effect due to smoke exposure, $F(1, 70)$, 4.9, $p < .05$. Thus, individuals who had not been allowed to smoke in smoke trial 1 took significantly longer puffs than individuals who had been allowed to smoke.

Discussion

The results suggest that our deprivation manipulation was successful in producing tobacco withdrawal symptoms in the withdrawn smokers. Although complete abstinence cannot be assured, these smokers reported both greater negative affect and greater urges than the continuing smokers and had significantly lower carbon monoxide levels at the start of the assessment session. All of these changes are reliable indicants of tobacco withdrawal (Hughes & Hatsukami, 1986; Jorenby et al., 1996; Piasecki et al., 1997; Zinser et al., 1992). In addition, the stress manipulation appeared to boost arousal and urge ratings while decreasing pleasure ratings.

The results show that the anticipation of smoking had reliable effects on EEG asymmetry. In both smoke trials, anticipation of smoking produced increases in RAL, and this effect was most pronounced among smokers who had been withdrawn from tobacco. These findings represent the first demonstration that a measure of approach motivation, relative activation of the left frontal cortex, is sensitive to manipulations of smoking motivation. There is evidence that it is increased by both smoking-cue exposure and by tobacco deprivation, and these two factors work together to influence asymmetry magnitude. If frontal cortical asymmetry is indeed sensitive to drug motivational processes, it could be used to gauge treatment effects or predict relapse vulnerability.

Our results suggest that although smoking cues may enhance RAL, smoking itself tends to decrease RAL. When smokers were allowed to smoke cigarettes after observing them, they consistently showed decreased relative left activation over the first 2 min of smoking. In smoke trial 1, this reduction was most pronounced among the most deprived participants. These results are generally consistent with earlier findings that nicotine exerts primarily right-hemisphere effects (Gilbert, 1987; Gilbert et al., 1994; Gilbert et al., 1989; Knott et al., 1995; Norton et al., 1992). Our results appear to conflict with models in which nicotine exerts either relative left-frontal activating effects, or suppression of right-hemisphere activation in stressful conditions (e.g., Gilbert, 1995; Gilbert & Welser, 1989). However, it is important to note that such models accord personality, dose, and contextual factors roles in moderating nicotine's effects. If the asymmetry measure does indeed reflect motivational processes, as suggested by prior research (Davidson, 1984; Davidson, Ekman, et al., 1990; Fox, 1991) as well as by the present findings, the reliable decline in asymmetry attending smoking may have motivational significance. It might, for example, reflect a diminution in urge level or arousal that can follow self-administration (Zinser et al., 1992).

More research is required to determine the reliability and correlates of this phenomenon.[8]

There was also evidence that overall activation of the frontal cortices was influenced by smoking and exposure to smoking cues. For instance, during the initial 30 s that withdrawn participants were exposed to cigarettes in smoke trial 2, they showed reliable increases in overall frontal activation relative to other participants. Second, the opportunity to smoke also reliably increased overall activation. Although overall cortical activation was, apparently, responsive to smoking and smoking anticipation, the impact of anticipation was significant in only one smoke trial, and there was little evidence that this effect was influenced by withdrawal status.

Withdrawal did not affect EEG variables during the baseline period. We had expected that withdrawal would produce decreased bihemispheric frontal activation during baseline assessment. However, prior research suggests several explanations. First, the present assessment strategy may have been insensitive because EEG was sampled from anterior scalp sites. Research revealing deprivation-induced slowing has typically involved posterior placements (e.g., Knott & Venables, 1977; see Church, 1989). Research shows that frontal sites are less sensitive to the cortical deactivation produced by tobacco deprivation (Herning, Jones, & Bachman, 1983). Second, EEG slowing may simply be a poor marker of tobacco withdrawal. Instead, nicotine may activate EEG transitorily, but there may be no prolonged compensatory slowing on withdrawal (Foulds et al., 1994). Finally, individual variability may have masked any main effect of withdrawal (Gilbert, 1995). In contrast to the bihemispheric EEG, we did not expect to see asymmetry effects during the baseline period because participants are in an ambiguous motivational context; smoking cues were not present, and participants had not been told to expect smoking during this period.

Relevance to Theory

The present study is by no means a definitive test of any of the three drug motivational models reviewed earlier. However, the obtained data do seem more congruent with the incentive-sensitization model than with the associative-withdrawal or incentive models. The associative-withdrawal models hold that drug cues should elicit drug compensatory or withdrawal responses, and these should be directly related to motivation to use drug. In the present study, cigarette cues elicited increased overall cortical activation, an effect generally consistent with the direct initial effects of tobacco and opposite to the typical withdrawal effect. Moreover, to the extent that relative left activation reflects positive affect/decreased negative affect, the elicitation of increased left activation by smoking cues conflicts with the withdrawal models.

The incentive models are consistent with the fact that cigarette cues elicited increased overall EEG activation and increased left activation but are inconsistent with the decreased left activation produced by smoking. Incentive models hold that direct drug effects, at least the initial effects, should prime subsequent drug administrations by producing pleasure and stimulating approach or foraging/expectancy mechanisms. Thus, according to incentive theories, if left-activation indexes approach motivation, then smoking should have augmented asymmetry scores at some point over the 6-min smoking period. Of course, it is possible that the temporal resolution of the electrophysiological measures was inadequate to detect any initial priming effects of smoking.

The incentive-sensitization model is unique in that it holds that over the course of iterative drug administrations the incentive properties of drug cues become uncoupled from the direct rewarding effects of drug. Therefore, drug cues will have the capacity to engage approach mechanisms even though drug ingestion has lost the capacity to yield pleasure or instigate approach. This basic tenet of the model is consistent with the observation in this study that cigarette cues/smoking anticipation elicited increased asymmetry but that smoking did not. This pattern, observed across two smoking trials, is reminiscent of the patterns of dopaminergic activity in the nucleus accumbens as assessed with high-speed chronamperometry. In animals trained to administer psychomotor stimulants, such activity increases prior to self-administration and then decreases immediately following drug infusion (Gratton, Wise, & Kiyatkin, 1992; Kiyatkin, Wise, & Gratton, 1992). Moreover, the fact that cue-elicited left activation was enhanced by tobacco deprivation is also consistent with the model because incentive salience of drug stimuli can be increased by physiological drive cues such as might be produced by withdrawal (Robinson & Berridge, 1993).

The incentive-sensitization account appears to be inconsistent with the self-reported urge data. There was no consistent relation between urge ratings made using the joystick apparatus and the asymmetry (or overall activation) measures. The relations varied in directionality and were typically nonsignificant. The lack of a consistent relation is not damning to an incentive-sensitization account for several reasons. First, Robinson and Berridge (1993) anticipated that self-report measures would be poor or unreliable indexes of approach or wanting system activation. They argue that this might occur for a variety of reasons. For instance, humans might be unable to distinguish reliably between wanting (craving) and liking (pleasure). Moreover, in this study there were no urge ratings made during the observation periods when smokers were anticipating smoking. We feared that introducing such ratings might have disrupted motivational processing during this critical interval. Second, the single-item joystick assessment of craving may simply have been inadequate to index urge level accurately (Tiffany & Drobes, 1991).

It is possible that asymmetry was not highly related to urge reports simply because it is an insensitive index of approach/wanting disposition. This issue may revolve around the extent to which asymmetry reflects affect per se versus approach motivation (Harmon-Jones & Allen, 1998). Several observations suggest that asymmetry does indeed reflect approach disposition. First, there is a wealth of evidence that mesotelencephalic brain regions mediate approach information-processing (Robinson & Berridge, 1993)

[8] The decreases in RAL seen in response to smoking may be of motivational significance. That is, they appear to reflect level of prior tobacco deprivation. The smallest decreases were seen among participants who were least deprived of smoking prior to each smoking trial (e.g., among CNT-Twice participants in smoke trials 1 and 2). It is possible that the RAL decreases represent some sort of homeostatic adjustment (e.g., an opponent process) that occurs in reaction to RAL increases seen during the observation periods. This hypothesis would hold that such decreases might occur regardless of subsequent smoking opportunity. Determination of the nature of smoking-induced RAL decreases must await further research.

and also that such systems are lateralized (Giardino, 1996; Louilot & Le Moal, 1994). There is also considerable evidence of asymmetries in dopaminergic activation of these brain regions in response to psychomotor stimulants. For instance, measures of asymmetry of dopaminergic systems predict rate of behavioral sensitization to psychomotor stimulants and initiation of opiate self-administration (Glick et al., 1992; Glick & Hinds, 1985). Moreover, mesotelencephalic structures such as the nucleus accumbens yield asymmetric dopaminergic responses to affectively valenced conditional stimuli, suggesting that such asymmetries may be "implicated in the inner, subjective experiences of the affective value of a stimulus" (Besson & Louilot, 1995, p. 967). Also, it is clear that such regions have strong inhibitory connections with prefrontal cortical regions (Sesack & Bunney, 1989), perhaps accounting for the asymmetrical involvement of prefrontal regions in pharmacologic and nonpharmacologic motivational phenomena (Davidson, Ekman, et al., 1990; Glick et al., 1992; Tucker & Williamson, 1984). In addition, asymmetries in cholinergic systems may account for cortical asymmetries in response to nicotine or nicotine cues (Knott & Harr, 1997). Finally, further investigation of frontal cortical asymmetry is supported by the fact that it reflected the impacts of motivational manipulations in this study.

It is possible that frontal asymmetry does indeed reflect drug-instigated approach dispositions but that urge self-report is itself an unreliable index of approach. Although there is evidence that urge reports can predict self-administration (e.g., Shiffman et al., 1997), there is also evidence that in many situations they do not (Brandon et al., 1995; Perkins et al., 1997; Tiffany, 1990). This may be because such self-reports have heterogeneous origins, for example, perhaps reflecting intention to use drug, level of negative affect/withdrawal, anticipated pleasure, verbal habits, and frustration because of disruption of proceduralized self-administration routines, and so on. Moreover, urge self-reports may be more related to decisions to use drug rather than to subelements of a proceduralized self-administration topography (e.g., Brandon, Tiffany, Obremski, & Baker, 1990; Shiffman et al., 1997). Unfortunately, only the latter were assessed in the present research. In sum, using urge self-reports as a gold standard of drug motivation may divert attention from response systems that are more tightly integrated with drug approach mechanisms. This suggests that in their incentive-sensitization model, Robinson and Berridge (1993) may have placed undue emphasis on explaining the phenomenology of the addict.

Caveats

The results of this research must be interpreted cautiously because of a variety of significant limitations. For instance, because of the requirements for a minimal number of chunks of useable data for EEG analyses, we were unable to achieve a high temporal resolution in these analyses. Also, because only a small number of channels was recorded, we could not compute measures of power at each electrode site residualized for the influence of whole head power (Pivik et al., 1993; Wheeler, Davidson, & Tomarken, 1993).

Other concerns are that because we didn't standardize nicotine dose delivery, some of the effects of smoking may have been produced or mediated by smoking style. We cannot separate out participants' responses to nicotine per se versus their response to their own delivery style. Also, some repeated-measures effects are complex and not easily attributable to a single manipulation. For instance, the effects of smoking could not be isolated from the prior effects of observing a cigarette. Although this ambiguity muddies causal attributions, it may reflect processes organic to the transition from anticipation to smoking.

In summary, asymmetry of frontal cortical activation appears to index manipulations designed to enhance smoking motivation, namely, anticipation of smoking in the presence of smoking cues and tobacco withdrawal. There was some evidence that overall EEG activation was also affected by the anticipation of smoking. Both EEG measures should be evaluated further to determine their sensitivity to other manipulations of smoking motivation. In addition, when both EEG asymmetry as well as overall activation of the frontal cortex are considered, the results of this research provide some support for the incentive-sensitization theory of drug motivation. The above conclusions are tentative and must be replicated by additional research if they are to be accepted.

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