Published in final edited form as:

Exp Clin Psychopharmacol. 2009 August ; 17(4): 247–257. doi:10.1037/a0016658.

Attentional Bias Is Associated With Incentive-Related Physiological and Subjective Measures

Andrew J. Waters,

Department of Medical and Clinical Psychology, Uniformed Services University of the Health Sciences

Brian L. Carter,

Department of Health Disparities Research, University of Texas, M. D. Anderson Center

Jason D. Robinson,

Department of Health Disparities Research, University of Texas, M. D. Anderson Center

David W. Wetter,

Department of Health Disparities Research, University of Texas, M. D. Anderson Center

Cho Y. Lam,

Department of Behavioral Science, University of Texas M. D. Anderson Cancer Center

William Kerst, and

Department of Medical and Clinical Psychology, Uniformed Services University of the Health Sciences

Paul M. Cinciripini

Department of Behavioral Science, University of Texas, M. D. Anderson Center

Abstract

Drug cue reactivity is theoretically and clinically important. The modified Stroop task has been widely used to assess attention capture by drug cues (attentional bias). Attentional bias to drug cues is assumed to reflect the incentive value of those cues, but this has not been directly tested. The authors examined whether the smoking Stroop effect was associated with facial electromyography (EMG) assessed in real time. Heart-rate (HR) and skin conductance (SC) responses were also assessed. Smokers ($n = 79$) attended up to four experimental sessions. Pre-session Abstinence state and within-session Smoking were manipulated across sessions. Over all assessments, participants exhibited a robust smoking Stroop effect. Using Generalized Estimating Equations (GEE) analyses, the smoking Stroop effect was positively associated with zygomaticus major activity but not with corrugator supercilii activity, HR, or SC. The smoking Stroop effect was also positively associated with self-reported positive outcome expectancies from smoking and with craving. In sum, attentional bias was more strongly associated with appetitive responses (zygomaticus major activity, positive outcome expectancies) than with withdrawal responses (e.g., corrugator supercilii activity) or measures of physiological arousal (e.g., HR, SC).

Keywords

attentional bias; modified Stroop task; facial EMG; cue reactivity

Many theories of drug addiction assume that responses to drug-related cues maintain drug use and undermine cessation attempts (e.g., Niaura et al., 1988). Responses to drug cues can be assessed from self-report and from physiological responses (e.g., Carter & Tiffany, 1999). Drug cues can also impact cognitive processes, such as attention capture (attentional bias; e.g., Sayette & Hufford, 1994). A growing number of studies have examined attentional responses in the belief that such responses are both theoretically and clinically important (e.g., Field, Mogg, & Bradley, 2006; Waters & Sayette, 2006).

Theoretically, drug cues can produce either drug-like responses (Stewart, deWit, & Eikelboom, 1984) or drug-opposite responses (e.g., Wikler, 1948). The conditioned appetitive motivational model (Stewart et al., 1984) proposes that drug cues produce responses similar to those elicited by the drug, including increases in positive affect and decreases in negative affect. In the incentive-sensitization theory (IST; Robinson & Berridge, 1993), it is further proposed that the conditioned appetitive response consists of two components, a conditioned affective “liking” response (similar to the appetitive responses proposed by Stewart et al., 1984), and a conditioned “wanting” response that reflects the incentive salience of the drug cues (see Robinson & Berridge, 1993). Robinson & Berridge (1993) argue that the latter response mediates attention to drug cues, craving, and approach behavior. In contrast to the above models, the conditioned withdrawal model (Wikler, 1948) and conditioned compensatory response model (e.g., Siegel, 1983) predict that drug cues elicit drug-opposite responses, including decreases in positive affect and increases in negative affect. It should also be noted that drug cues might elicit both drug-like and drug-opposite responses in the same individual at different times (e.g., Drummond, Cooper, & Glautier, 1990). Thus, responses to drug cues may be complex and moderated by setting or individual difference variables. Finally, drug cues may also elicit covert motoric processing for drug taking behavior (Tiffany, 1990).

Recently, much research has examined attentional responses to drug cues (e.g., Cox, Fadardi, & Pothos, 2006). The modified Stroop task has been widely used to examine attention capture (“attentional bias”). In the modified Stroop task, participants are required to indicate the color of words presented to them as quickly as possible. They are instructed that they can ignore the meaning of the words themselves; they only need to respond to the color. The addiction Stroop task assesses time to respond to addiction and neutral words (Cox et al., 2006). Typically, drug-users are slower to indicate the colors of addiction words than neutral words. This suggests that attention is “captured” by the meaning of the addiction word (Williams, Mathews, & MacLeod, 1996). Numerous studies have reported that drug users exhibit attentional bias to drug-related cues whereas nonusers do not on this task (e.g., Cox et al., 2006; Munafo, Mogg, Roberts, Bradley, & Murphy, 2003). Moreover, attentional bias assessed on the addiction Stroop task has also been shown to prospectively predict clinical outcomes. Specifically, individuals who exhibit greater attentional bias (increasingly slower responses on addiction words compared to neutral words) prior to or

during a quit attempt are more likely to subsequently relapse (Carpenter, Schreiber, Church, & McDowell, 2006; Cox, Hogan, Kristian, & Race, 2002; Marissen et al., 2006; Waters et al., 2003) or to continue to drink heavily (Cox, Pothos, & Hosier, 2007).

Despite these findings, the psychological processes underlying attentional bias on the addiction Stroop task have remained unclear. From the perspective of the cue reactivity literature, there are several possible explanations for how smoking-related words may slow the reaction time of smokers on the smoking Stroop task. The addiction Stroop effect is commonly held to reflect the “incentive salience” of drug cues for that individual. That is, smoking-related cues capture attentional resources due to their incentive salience, leaving fewer resources available for the primary task (indicating the color of the word). In addition, other processes may play a role. Conditioned withdrawal or conditioned compensatory responses (Niaura et al., 1988) could produce a transient withdrawal state, which could cause slower responses (on smoking-related words). Smoking-related words might also activate covert motoric processing (e.g., in preparation for smoking), and these processes may interfere with the motoric aspects of task performance (e.g., pressing buttons). However, a detailed examination of the role of these potential processes has not been conducted.

In this study, we sought to gain further insight into the psychological processes underlying attentional bias by investigating whether changes in physiological measures – collected as participants completed the task – were associated with the smoking Stroop effect. Facial electromyography (EMG) is a useful tool for studying affective responses in real time. It has been found to differentiate between affective responses (e.g., Cacioppo, Petty, Losch, & Kim, 1986). Facial EMG is thought to be free of the biases that can confound self-report data. Moreover, facial EMG is also thought to be more reflective of affective state (valence) than physiological arousal (Dimberg, 1990).

The most commonly measured facial muscles are the zygomaticus major and corrugator supercilii. The zygomaticus major muscles are located in the cheeks and pull the corners of the mouth upward to create a smile. The corrugator supercilii muscles pull the brows down and together to create a frown. Activation of zygomaticus major EMG is maximal in response to positively valent stimuli. Activation of corrugator supercilii EMG is maximal in response to negatively valent stimuli (e.g., Dimberg, 1990; Larsen, Norris, Cacioppo, 2003). In passive viewing tasks, these responses are generally consistent for picture, sound, and word stimuli, although associations are smaller with word stimuli (Larsen et al., 2003).

Relevant to the current study, some studies have reported that facial EMG responses can be elicited by briefly presented unattended stimuli. For example, emotional faces can provoke changes in facial EMG when participants could not consciously identify the facial emotion (Dimberg, Thunberg, & Elmejed, 2000). Moreover, facial EMG responses can be detected when participants are instructed to suppress these responses (Dimberg, Thunberg, & Grunedal, 2002). One study has reported that facial EMG responses were affected by the emotional valence of the stimuli in a modified Stroop task. This effect was true when the stimuli were presented supraliminally and subliminally (Richards, Blanchette, Hamilton, & Lavda, 2007).

Addiction researchers have also used facial EMG to examine responses to drugs and drug cues (e.g., Drobles & Tiffany, 1997; Elash, Tiffany, & Vrana, 1995; Geier, Mucha, & Pauli, 2000; Newton, Khalsa-Denison, & Gawin, 1997; Robinson, Cinciripini, Carter, Lam, & Wetter, 2007). These studies have yielded mixed findings. However, Drobles and Tiffany (1997) reported that smoking cues increased zygomaticus major EMG and decreased corrugator supercilii EMG. (The smoking cues also increased self-reported negative affect and decreased positive affect, a finding that underscores the complexity of drug cue reactivity). Newton et al. (1997) assessed facial EMG before and after participants completed a standard cocaine use questionnaire. They reported that abstinent crack cocaine users exhibited a significantly greater increase in zygomaticus major EMG than did current cocaine users. Thus, there is evidence that changes in facial EMG can be elicited by drug cues. To the best of our knowledge, no studies have assessed facial EMG to drug cues as participants complete a modified Stroop task.

Previous studies investigating the effects of smoking and smoking cues have assessed autonomic nervous system (ANS) measures, such as heart rate (e.g., Niaura et al., 1988; Perkins, Grobe, Fonte, & Breus, 1992) and skin conductance (Edman & Schalling, 1991). Heart rate and skin conductance have been assessed in prior studies employing the addiction Stroop task (Stormark, Laberg, Nordby, & Hugdahl, 2000). We included heart rate and skin conductance measures to determine the extent to which physiological arousal is associated with attentional bias to smoking cues.

We also explored the effect of pre-session abstinence and within-session smoking on the study measures. In the tobacco addiction literature, the effect of abstinence on cue reactivity has remained unclear (e.g., David et al., 2007). However, consistent with IST (Robinson & Berridge, 1993), some studies have revealed that abstinence potentiates attentional bias to smoking cues as revealed by behavioral and brain imaging measures (e.g., McClernon, Kozink, Lutz, & Rose et al., 2009; Waters & Feyerabend, 2000). Studies using facial coding analysis have also indicated that abstinence potentiates appetitive facial responses to smoking cues (e.g., Sayette et al., 2003). Another study reported that within-session smoking reduced attentional bias in adolescent heavy smokers (Zack, Belsito, Scher, Eissenberg, & Corrigan, 2001). We therefore expected pre-session abstinence to increase attentional bias and within-session smoking to reduce attentional bias. We also explored the effect of pre-session abstinence and within-session smoking on facial EMG responses. Manipulation of pre-session abstinence and within-session smoking was also expected to generate wide ranges for study variables (e.g., self-reported mood, smoking Stroop effect). This increased the likelihood of detecting associations between the smoking Stroop effect and physiological/subjective measures.

In sum, we assessed physiological measures in real time as participants performed the smoking Stroop task. We also assessed subjective measures of craving and mood before and after the participants completed the smoking Stroop task. If attentional bias to smoking cues reflects conditioned appetitive responses, then the smoking Stroop effect should be associated with a) a facial EMG measure that reflects appetitive responses (zygomaticus major activity) and b) subjective measures of the incentive value of smoking (e.g., positive outcome expectancies, craving for positive effects of smoking). Moreover, the smoking cues

should increase positive affect and decrease negative affect. If attentional bias to smoking cues reflects the ability of smoking cues to elicit conditioned withdrawal or conditioned compensatory responses then the smoking Stroop effect should be most closely associated with a) an EMG measure that reflects a negative affective response (corrugator supercilii activity) and b) subjective measures of negative affect and craving for withdrawal relief. Moreover, the smoking cues should decrease positive affect and increase negative affect. If attentional bias to smoking cues reflects their propensity to elicit physiological arousal, then the smoking Stroop effect should be closely associated with physiological measures of arousal (increased heart rate, skin conductance).

Method

Participants

Participants were 79 smokers recruited from the Houston metropolitan area via newspaper and radio advertisements. The inclusion criteria were aged 18–59 years old, smoked at least 10 cigarettes per day, spoke English, and possessed a functioning telephone. Exclusion criteria were currently taking psychotropic medication, evidence of current psychiatric disorder, self-reported color-blindness, pregnant or nursing. Participants were not seeking treatment for smoking cessation. The current sample overlaps with the sample reported in Waters et al. (2007). In addition, the study was part of a larger study that examined the effects of nicotine and nicotine deprivation on affective and motivational processes. The results of the parent study will be reported elsewhere. The study was approved by the Institutional Review Board of the University of Texas M. D. Anderson Cancer Center.

In total, 225 participants completed the telephone screening. Sixty-two were disqualified due to inclusion/exclusion criteria. Of the 163 eligible participants, 92 attended a subsequent orientation session. Of these, 79 attended at least one experimental session and therefore completed at least one Stroop assessment. The final sample (55.9% black, 36.8% white) was comprised of 35 men and 44 women and had an average age of 42.7 ($SD = 9.73$). On average, participants smoked 21.1 cigarettes/day ($SD = 7.64$), scored 5.51 on the Fagerström Test for Nicotine Dependence (FTND; Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991; $SD = 1.75$), and had smoked for 22.3 years ($SD = 9.51$).

Procedure

A 10- to 15-minute preliminary telephone screening was conducted during which participants were given an initial description of the study design. Data were collected on age, smoking history, other tobacco use, major medical history, medication use, and pregnancy/lactation status. Participants also completed a version of the PRIME-MD, which was modified for use over the telephone (Spitzer et al., 1994). The PRIME-MD screens for the five major mental disorders (*DSM-IV*) most commonly encountered in the general population (mood, anxiety, somatoform, alcohol, eating disorders). When compared with a subsequent SCID (Structured Clinical Interview for *DSM-III-R*; Spitzer, Williams, & Gibson, 1989), the phone-based PRIME-MD has been found to successfully eliminate virtually all smokers with current psychiatric disorders (Cinciripini et al., 2004).

Eligible participants were invited to attend a 90-min orientation visit conducted at the University of Texas M. D. Anderson Cancer Center. At this orientation visit, we administered a brief interview consisting of items based on the *DSM-IV* criteria for history of major depression (Cinciripini et al., 2006). Participants also completed a number of questionnaires assessing tobacco dependence, including the FTND.

Each participant was subsequently scheduled to complete four experimental sessions. The experimental sessions were scheduled at least 3 days apart. Each session began at the same time of day for each participant. Participants were asked to limit their intake of coffee (or equivalent) to no more than two cups prior to 8:00 a.m. on the day of the experimental sessions. The participant was instructed to abstain from smoking for 12-hrs before two of the sessions (AB) and to smoke normally before the other two sessions (NON). At one of the AB/NON sessions, they smoked a cigarette in the laboratory about 30 min before completing the smoking Stroop task (S). At the other session, they did not smoke in the laboratory before completing the smoking Stroop task (NS). Order of completion of the four conditions (AB-NS, AB-S, NON-NS, NON-S) was counterbalanced across participants. In total, 79 participants completed Session 1. Due to attrition, 71 participants completed Session 2; 70 participants completed Session 3; and 68 participants completed all sessions (1–4).¹

The procedure for each experimental session was as follows. Expired breath carbon monoxide levels were taken at the outset of the session. After the carbon monoxide assessment, at the NON sessions participants were required to smoke a cigarette. Participants subsequently completed the following assessments: a) a startle probe assessment; b) a second startle probe assessment (participants either smoked a cigarette, S, or rested, NS, between the two startle assessments); c) the Brief Questionnaire of Smoking Urges (QSU-Brief; Cox, Tiffany, & Christen, 2001) and the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988); d) the computerized smoking Stroop task (Waters et al., 2003); e) the QSU-brief, PANAS again; f) the Implicit Association Test (IAT); and g) five items assessing outcome expectations (OE) from smoking (described below). All questionnaires were administered by computer. Data from the startle probe and IAT assessments are reported in detail in Waters et al. (2007). These assessments will not be discussed further.

At the AB sessions, participants were considered nonabstinent if they reported having smoked on that day or if they had high carbon monoxide levels (>10 ppm). Under these conditions, the research assistant was required to reschedule the session.

Measures

Physiological assessment—EMG electrodes (Ag-AgCl) filled with saline gel were attached to the right corrugator supercilii and right zygomaticus major regions using a bipolar configuration (Fridlund & Cacioppo, 1986). EMG signals were acquired and amplified using BIOPAC Systems' (Goleta, CA) EMG100A Electromyogram Amplifier modules. A 10–500 Hz bandpass filter (Tassinary & Cacioppo, 2000) and a 60 Hz notch

¹As noted later, data from two assessments were excluded because of high error rates on the smoking Stroop task.

filter were used for EMG. Skin conductance response amplitude was acquired by placing an electrodermal response transducer on the fore and ring fingers of the participant's nondominant hand using BIOPAC Systems' GSR100C Electrodermal Response Amplifier. (Participants were instructed to use their dominant hand to make responses on the smoking Stroop task). We measured phasic increase in skin conductance following trial onset, with a high-pass filter set at 0.05 microsiemens (μS ; Dawson, Schell, & Filion, 2000). Heart rate was acquired by placing a photoelectric pulse plethysmogram transducer on the middle finger of the participant's non-dominant hand using BIOPAC Systems' PPG100C Photoplethysmogram Amplifier.

The physiological data were recorded and displayed using BIOPAC Systems' AcqKnowledge III data acquisition software (version 3.5.3). Recording resolution was 250 Hz. Sensors were attached at the beginning of each experimental session (prior to the startle probe assessment). After completing the smoking Stroop task, participants were unhooked from BIOPAC.

Scoring—Scoring was conducted using AcqKnowledge. Data on heart rate (HR), zygomaticus major EMG (ZY), corrugator supercilii EMG (CO), and skin conductance response (SC) were scored for every trial (including the intertrial interval). CO and ZY were rectified and integrated using a 20-ms time constant. The EMG measures were scored in microvolts (μV); SC was scored in microsiemens (μS); and HR in beats per minute (BPM). For each physiological measure, we computed a difference score to capture the change in that measure on the smoking words compared to the neutral words.

To minimize the impact of outliers, BPM values less than 40 and greater than 140 were excluded from analysis. In addition, we excluded 1% of observations from the upper side of the distribution for ZY, CO, and SC measures (Robinson et al., 2007). We estimated internal reliability of the physiological measures using a split-half approach. We split the data from each assessment into even and odd trials, computed means for each half, computed a Pearson's correlation between the two means, and applied the Spearman-Brown formula to derive the split-half reliability coefficient (Parrott, 1991). The mean estimated split-half (even vs. odd trials) reliability of BPM across the four sessions was .99 (range .99–.99) on both neutral and smoking trials. The mean estimated split-half reliability of the BPM difference score across the four sessions was .86 (range .85–.87). The mean estimated split-half reliability of ZY across the four sessions was .99 (range .98–.99) on both the neutral and smoking trials, and .88 (range .66–.96) for the ZY difference score. The mean estimated split-half reliability of CO across the four sessions was .99 (range .99–.99) on both the neutral and smoking trials, and .93 (range .84–.98) for the CO difference score. The mean estimated split-half reliability of SC across the four sessions was .98 (range .98–.99) on the neutral trials, .98 (range .96–.99) on the smoking trials, and .98 (range .96–.99) for the SC difference score.

Cognitive assessment—The smoking Stroop Task assesses the attention-grabbing properties of smoking cues (Waters et al., 2003). Participants were told that words written in different colors would be presented on a computer monitor, one after the other. Their task was to indicate as quickly and as accurately as possible the color the word was written in, by

pressing one of three colored buttons on a response device. They were instructed to ignore the meaning of the word itself and just to respond to the color. Each word remained on the screen until the participant made a response. As noted above, they used fingers on their dominant hand to make their responses. After a response was made, there was a 500 ms interval before the next word was presented. Participants responded to a block of neutral words (33 trials) followed by a block of smoking words (33 trials). We used the same materials and scoring methods used by Waters et al. (2003). The task was programmed using E-Prime (Schneider, Eschman, & Zuccolotto, 2002).

Scoring—RT data from incorrect responses were excluded from analysis (3.22% of trials). RTs <100 ms were also excluded from analysis. Data from two assessments (0.69% of assessments) were excluded because error rates exceeded 33%. The mean estimated split-half (even vs. odd trials) reliability of RTs across the four sessions was .94 (range .92–.96) on the neutral trials and .95 (range .94–.97) on the smoking trials. We computed the smoking Stroop effect as the difference in RTs on the smoking words and the neutral words. The mean estimated split-half reliability of the smoking Stroop effect was .54 (range .29–.76).

Questionnaire Measures

The Brief Questionnaire of Smoking Urges (QSU-Brief; Cox, Tiffany, & Christen, 2001)—The QSU-Brief assesses desire and intention to smoke “right now.” The 10-item QSU-Brief assesses desire for the positive effects of smoking (Factor 1 Craving; 5 items; e.g., “I have a desire for a cigarette right now”), and desire for relief of negative affect and an urgent need to smoke (Factor 2 Craving; 5 items; e.g., “I could control things better right now if I could smoke”). The QSU-Brief was administered immediately before and after the smoking Stroop task.

The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988)—The PANAS assesses Positive Affect (PA; 10 items, e.g., enthusiastic, strong) and Negative Affect (NA; 10 items, e.g., distressed, upset). These scales have been shown to represent orthogonal dimensions of affect (Watson et al., 1988). Participants were asked to report how they felt “right now.” The PANAS was administered immediately before and after the smoking Stroop task.

Smoking Outcome Expectancies (OE; Copeland, Brandon, & Quinn, 1995)—Five items, based on items from a validated questionnaire assessed positive outcomes from smoking: “Smoking now will help me relax”; “Smoking now will energize me”; “A cigarette will taste good now”; “Smoking now will satisfy my cravings”; and “Smoking now will help reduce boredom.” Participants responded on 11-point Likert-type scales, ranging from 1 = *No!!* to 11 = *Yes!!*. Responses to the five items were strongly intercorrelated (mean coefficient alpha across 4 sessions = .91, range .87–.93); we took an average score (OE) to represent positive outcome expectancies from smoking. OE scores were significantly moderated by abstinence state ($p < .001$; see Table 1).

Data Reduction and Analyses

We used Generalized Estimating Equations (GEE; Zeger, Liang, & Albert, 1988) models for all analyses. GEE analyses can accommodate the fact that each participant contributed up to four datapoints (data from each of the four sessions) on each measure. Because they do not exclude cases with missing observations, GEE analyses maximize the data available for analysis. GEE analyses also take into account the correlation of data within-subjects. Consistent with Waters et al. (2007), we used a compound symmetry structure, and empirically based robust estimates of standard errors and z-scores.

To determine whether changes in reaction time (smoking Stroop effect) or changes in physiological measures were significantly different from zero (across all assessments), we ran a GEE model containing no predictor variables. A significant intercept indicated that the dependent variable was different from zero. To examine the effects of pre-session Abstinence (two levels: AB, NON) and within-session Smoking (two levels: S, NS) on the smoking Stroop effect and physiological measures, we entered pre-session Abstinence and within-session Smoking as predictor variables in GEE models. Because previous research has indicated that the magnitude of the smoking Stroop effect can be attenuated by practice (Waters & Sayette, 2006), we included Session (Sessions 1–4; coded as a continuous variable) in the models. We also tested the interaction term between pre-session Abstinence and within-session Smoking.

To examine the associations between a physiological measure and the smoking Stroop effect, we added the physiological measure difference score (smoking minus neutral trials change score) into a model as a predictor variable. Consistent with the analyses of Waters et al. (2007), Session was also included in the model. To test whether the effect of a physiological measure persisted when controlling for abstinence state, we added pre-session Abstinence and within-session Smoking to the model (combined model). Each physiological measure was tested in separate analyses. Using the same approach, we also examined the associations between self-report measures (QSU, PANAS, OE) and the smoking Stroop effect.

To examine whether the association between a predictor variable and the smoking Stroop effect was moderated by pre-session Abstinence and within-session Smoking, we tested the interaction term between the predictor variable and these variables. A significant interaction term would indicate that the association between the predictor variable and the smoking Stroop effect differed across states.

Results

Biochemical Validation of Abstinence and Smoking

The mean expired carbon monoxide at the outset of the experimental session was 6.26 ppm ($SD = 2.41$), 6.64 ppm ($SD = 2.29$), 25.4 ppm ($SD = 10.7$), and 25.7 ppm ($SD = 11.4$) in the AB-NS, AB-S, NON-NS, NON-S conditions respectively.

Overall Summary Statistics

Across all 281 assessments, the mean smoking Stroop effect (computed using GEE) was 29.8 ms ($SE = 5.07$, $p < .001$). The mean change in BPM (271 assessments) was -0.31 BPM ($SE = 0.18$, $p = .09$); the mean change in ZY (270 assessments) was 0.10 μV ($SE = 0.04$, $p < .05$); the mean change in CO (269 assessments) was -0.00 μV ($SE = 0.09$, $p > .9$); and the mean change in SC (272 assessments) was -0.034 μS ($SE = 0.029$, $p > .2$). Thus, averaged over all assessments, participants were slower to indicate the colors of smoking words than neutral words. They also exhibited greater ZY activity on the smoking trials than the neutral trials.

On subjective measures (281 assessments), there was a significant decrease in NA ratings from pre- to posttask ($PE = -0.050$, $SE = 0.014$, $p < .001$). The increase in PA ratings was not significant ($PE = 0.036$, $SE = 0.020$, $p = .06$). There was a significant increase in QSU factor 1 ratings ($PE = 0.12$, $SE = 0.059$, $p < .05$), but not QSU factor 2 ratings ($PE = 0.10$, $SE = 0.061$, $p > .1$) from pre- to posttask.

Effects of Presession Abstinence and Within-Session Smoking

Tables 1 and 2 show the summary statistics of the study measures broken down by condition. Using GEE analyses, within-session Smoking significantly reduced the smoking Stroop effect (see Table 1). The smoking Stroop effect at S assessments ($M = 20.7$ ms, $SE = 6.03$) was smaller than the smoking Stroop effect at NS assessments ($M = 38.9$ ms, $SE = 7.52$). The effect of within-session Smoking was not significantly moderated by presession Abstinence. Presession Abstinence and within-session Smoking did not have any significant effects on the physiological change measures.

GEE analyses conducted on QSU and OE ratings revealed the expected main effects of presession Abstinence and within-session Smoking (see Table 2). Presession Abstinence increased QSU factor 1, QSU factor 2, and OE ratings, and within-session Smoking reduced QSU factor 1, QSU factor 2, and OE ratings. For QSU ratings, results were comparable for pre- and posttask measures. For pretask QSU factor 1 ratings, and pre- and posttask QSU factor 2 ratings, there was a significant presession Abstinence by within-session Smoking interaction (see Table 2). This indicated that the effect of within-Session smoking on QSU ratings was greater in the presession AB state. For change in QSU ratings, the data indicated that the increase in QSU factor 1 (and factor 2) ratings was higher in the presession NON state.

For pre- and posttask NA, there was a main effect of within-Session smoking and a significant presession Abstinence by within-session Smoking interaction. The data indicated that smoking reduces NA primarily in the presession AB state (see Table 2).

Associations With Smoking Stroop Effect

Using GEE analyses, Table 3 shows that the smoking Stroop effect was significantly associated with change in ZY, but not change in CO. The association with change in ZY persisted when controlling for presession Abstinence and within-session Smoking (see Table 3). The association also remained robust ($p < .001$) if observations with change in ZY values

more than two SDs from the population mean (<-1.54 or >1.74) were excluded from the analysis. Thus, the association was not driven by extreme scores.

The association between the smoking Stroop effect and change in ZY is illustrated in Figure 1 (upper panel). We examined change in ZY for “low” smoking Stroop scores (<0 ms, $n = 97$), “medium” smoking Stroop scores ($0-50$ ms, $n = 70$), and “high” smoking Stroop scores (>50 ms, $n = 103$). Using GEE analyses, the change in ZY was significantly different from zero only for the “high” smoking Stroop scores ($PE = 0.23$, $SE = 0.10$, $p < .05$). As suggested by Figure 1, the change in ZY for the “high” smoking Stroop scores was significantly different from the change in ZY for the “low” smoking Stroop scores ($PE = -0.19$, $SE = 0.09$, $p < .05$). Figure 1 (lower panel) illustrates that change in CO was not associated with the smoking Stroop effect.

The smoking Stroop effect was not significantly associated with change in BPM or change in SC ($p > .1$; see Table 3).

The smoking Stroop effect was significantly associated with posttask QSU factor 1, posttask QSU factor 2, and OE (see Table 3). The smoking Stroop effect was also significantly associated with pretask QSU factor 1 and pretask QSU factor 2 (not shown in Table 3). The smoking Stroop effect was not associated with PA or NA (see Table 3). The smoking Stroop effect was also not significantly associated with change in QSU factor 1, change in QSU factor 2, change in NA, or change in PA (not shown in Table 3).

Tests of interaction effects revealed that the significant associations between the predictor variables listed in Table 3 (QSU ratings, OE ratings, change in ZY) and the smoking-Stroop effect were not significantly moderated by presession Abstinence and within-session Smoking (all $ps > .08$).

Discussion

Over all assessments, there was a robust smoking Stroop effect. The main finding of the study was that attentional bias to smoking cues was more strongly associated with appetitive measures (e.g., zygomaticus major activity, positive outcome expectancies) than with measures of withdrawal (e.g., corrugator supercilii activity), or measures of physiological arousal (e.g., HR, SC). The findings will be discussed in relation to the preceding three perspectives.

The following findings are consistent with the idea that a) smoking cues elicited conditioned appetitive responses (“liking” or “wanting”) and that b) conditioned appetitive responses were associated with slower responses on smoking words. First, over all assessments there was an increase in zygomaticus major activity on the smoking trials (vs. neutral trials). Second, there was a decrease in negative affect from pre- to posttask. Third, a positive association between the smoking Stroop effect and change in zygomaticus major activity was observed (see Table 3). Fourth, the smoking Stroop effect was associated with self-reported outcome expectancies (see Table 3). Last, the smoking Stroop effect was reliably associated with QSU factor 1 craving ratings. This would be expected because QSU factor 1 craving reflects craving for the positive effects of smoking.

There was little evidence that a) smoking cues elicited conditioned withdrawal or compensatory responses or that b) conditioned withdrawal or compensatory responses were associated with slower responses on smoking words. First, over all assessments there was no increase in corrugator supercilii activity on the smoking trials (vs. neutral trials). Second, as noted above, there was a decrease (not increase) in self-reported negative affect from pre- to posttask. If smoking cues elicit unpleasant conditioned withdrawal or compensatory responses, an increase in corrugator supercilii activity and an increase in self-reported negative affect would be expected. Third, the smoking Stroop effect was not positively associated with the change in corrugator supercilii activity (Figure 1, lower panel). Fourth, the smoking Stroop effect was not associated with posttask negative affect (see Table 3), pretask negative affect, or change in negative affect. One piece of supportive evidence was that the smoking Stroop effect was reliably associated with the pretask QSU factor 2 rating (see Table 3). However, this evidence is limited by the observation that the smoking Stroop effect was not significantly associated with change in QSU factor 2 ratings.

There was also little evidence that the smoking cues elicited physiological arousal or that physiological arousal was associated with attentional bias. Over all assessments, there was no increase in heart rate or skin conductance reactivity on the smoking trials (vs. neutral trials). In addition, the smoking Stroop effect was not associated with change in heart rate or with change in skin conductance reactivity (see Table 3).

It should be noted that some observations were less consistent with the idea that smoking cues elicited conditioned appetitive responses. First, although the QSU craving 1 rating was associated with the smoking Stroop effect, the change in QSU craving 1 ratings (from pre- to posttask) was not associated with the smoking Stroop effect. Second, if the smoking Stroop effect and change in zygomaticus major activity reflect the same underlying process, these two variables should be influenced by the same experimental manipulations. However, although the smoking Stroop effect, OE ratings, and QSU ratings were influenced by within-session Smoking in the expected direction (i.e., reduction in attentional bias, positive outcome expectancies, and craving), change in zygomaticus major activity was not influenced by within-session Smoking (see Table 1). Third, if smoking cues elicited conditioned appetitive responses, a decrease in corrugator supercilii activity might have been expected on the smoking trials. This was not observed. Fourth, if smoking words elicit drug-like responses, smokers should be faster (not slower) on smoking words (vs. neutral words) because nicotine tends to speed RTs (Heishman, 1998). However, in this study and elsewhere (e.g., Munafo, Mogg, Roberts, Bradley, & Murphy, 2003), smokers responded more slowly on smoking words. Presumably, this is because the smoking words also capture attentional resources due to their incentive salience (Robinson & Berridge, 1993), leaving fewer resources available for the primary task (indicating the color of the word; Cox et al., 2006). Last, no change in heart rate was observed on the smoking words; an increase would be expected if the smoking words elicit drug-like responses. These points notwithstanding, the evidence as a whole is more consistent with the idea that smoking cues elicited conditioned appetitive responses than conditioned withdrawal responses.

Although the data favor the conditioned appetitive model, from the perspective of IST it is difficult to determine whether a conditioned “liking” or “wanting” response underlies the

observed pattern of data. It is not known whether the changes in zygomaticus major activity to drug cues reflect conditioned “liking” or “wanting,” or both. However, one observation provides some support for the “wanting” hypothesis. The smoking Stroop effect was associated with self-reported craving (a measure of wanting) but not self-reported affect (a measure of liking). Further research is required to ascertain the meaning of the changes in facial EMG responses on the addiction Stroop task.

The study had limitations. First, the data speak only to the associations between physiological measures and the smoking Stroop effect. We do not know if the findings will generalize to other addiction Stroop effects. Moreover, we do not know whether the results would generalize to a modified Stroop task using pictorial stimuli or to other attentional bias tasks (such as dot-probe tasks). Second, it is known that reported activity in the zygomaticus major can reflect activity in neighboring muscle groups, including the buccinator and zygomaticus minor (Larsen et al., 2003). We cannot rule out the possibility that the smoking cues activate facial motor programs in preparation for smoking and that this diffuse EMG activity is captured in part in the reported zygomaticus major EMG. Studies using different methods (e.g., brain imaging) will be required to determine whether covert motoric processes underlie, at least in part, the smoking Stroop effect. Third, the study did not include a control group of nonsmokers. However, participants were required to smoke during two of the experimental sessions. Thus, the procedures used would not be directly applicable to this group. Future research should examine associations between physiological measures and the smoking Stroop effect in groups of smokers and nonsmokers. Fourth, to limit the influence of possible carry-over effects from smoking words to the neutral words (Waters et al., 2003), the neutral words always preceded the smoking words. We cannot rule out the possibility that changes in RT/physiology (or prepost changes in affect) reflect the effects of time or practice (rather than word type). However, these factors are unlikely to explain the pattern of associations reported in Table 3. Fifth, due to experimenter error, the recording resolution was set at 250 Hz rather than 1000 Hz. The EMG data may have been incomplete, though the data suggested that the physiological measures all had good reliability. Last, although the data suggested that attentional bias was more strongly associated with conditioned appetitive responses than with conditioned withdrawal responses, they should be interpreted with caution. The data are correlational, so it is not possible to conclude that conditioned appetitive responses cause attentional bias.

The study also had strengths. To the best of our knowledge, this is the first study to assess facial EMG and physiological responses as participants performed an attentional bias task. The study is the first to report that attentional bias is associated with zygomaticus major activity and positive outcome expectancies. The data showed that attentional bias on the smoking Stroop task is unlikely to be secondary to the conditioned withdrawal or compensatory responses. The data are consistent with the theoretical assumption that attentional bias assessed by the smoking Stroop task reflects the incentive value of smoking cues.

Data derived from other tasks and physiological measures have also indicated that smoking cues elicit conditioned appetitive responses. Using a passive viewing task, Geier et al. (2000) reported that smoking pictures influenced startle responses in smokers in a way that

was similar to that of pleasant pictures (i.e., reduced startles; but see Orain-Pelissolo, Grillon, Perez-Diaz, & Jouvent, 2004). In their integrative review of the cue reactivity literature, Niaura et al. (1988) reported that the appetitive model received more support than the conditioned withdrawal or conditioned compensatory response models. In sum, there is converging evidence from a variety of tasks that smoking cues can elicit conditioned appetitive responses. The present study shows that this is true when participants are instructed to ignore those cues.

Our data have theoretical implications. As noted above, changes in facial EMG may prove useful in discriminating between different theories of drug cue reactivity. For example, the data provide little evidence that drug-opposite responses underlie attentional responses to drug cues. Moreover, most cue reactivity research assesses responses when participants are required to attend to drug cues. The current study adds to this literature by assessing the impact of drug cues on responses when these cues are irrelevant to performing the required task and when participants are trying to ignore them. This may capture the influence of drug cues on mood and cognition when individuals seek to avoid drugs and drug cues (e.g., when trying to quit). Our data also have potential clinical implications. Speculatively, given the documented association between attentional bias and treatment outcomes, individuals who exhibit greater increases in zygomaticus EMG in response to drug cues may be at greater risk of relapse when attempting to quit a drug. Moreover, interventions that attenuate attentional bias and facial EMG responses to drug cues may prove useful in the treatment of addiction.

Acknowledgments

This work was supported by NIDA Grant R03 DA15221 (AJW), NCI Grant K07 CA92209 (BLC), and NCI Grant P50 CA70907 (PMC). We thank Dr. Tenko Raykov, Ph.D., for providing statistical consultation in the development of the manuscript. We thank Mary Carson, Amber de Jongh, Bradford Schneider, Veronica Torres, and Jack Tsan for their assistance in data collection, and Samuel Riley for administrative assistance.

References

- Cacioppo JT, Petty RE, Losch ME, Kim HS. Electromyographic activity over facial muscle regions can differentiate the valence and intensity of affective reactions. *Journal of Personality and Social Psychology*. 1986; 50:260–268. [PubMed: 3701577]
- Carpenter KM, Schreiber E, Church S, McDowell D. Drug Stroop performance: Relationships with primary substance of use and treatment outcome in a drug-dependent outpatient sample. *Addictive Behaviors*. 2006; 31:174–181. [PubMed: 15913898]
- Carter BL, Tiffany ST. Meta-analysis of cuereactivity in addiction research. *Addiction*. 1999; 94:327–340. [PubMed: 10605857]
- Cinciripini PM, Robinson JD, Carter BL, Lam CY, Wu X, De Moor CA, et al. The effects of smoking deprivation and nicotine administration on emotional reactivity. *Nicotine & Tobacco Research*. 2006; 8:379–392. [PubMed: 16801296]
- Cinciripini PM, Wetter DW, Tomlinson GE, Tsoh JY, De Moor CA, Cinciripini LG, et al. The effects of the DRD2 polymorphism on smoking cessation and negative affect: Evidence for a pharmacogenetic effect on mood. *Nicotine & Tobacco Research*. 2004; 6:229–239. [PubMed: 15203796]
- Copeland AL, Brandon TH, Quinn EP. The Smoking Consequences Questionnaire-Adult: Measurement of smoking outcome expectancies of experienced smokers. *Psychological Assessment*. 1995; 7:484–494.

- Cox LS, Tiffany ST, Christen AG. Evaluation of the brief questionnaire of smoking urges (QSU-brief) in laboratory and clinical settings. *Nicotine and Tobacco Research*. 2001; 3:7, 16. [PubMed: 11260806]
- Cox WM, Fadardi JS, Pothos EM. The addiction-Stroop test: Theoretical considerations and procedural recommendations. *Psychological Bulletin*. 2006; 132:443–476. [PubMed: 16719569]
- Cox WM, Hogan LM, Kristian MR, Race JH. Alcohol attentional bias as a predictor of alcohol abusers' treatment outcome. *Drug and Alcohol Dependence*. 2002; 68:237–243. [PubMed: 12393218]
- Cox WM, Pothos EM, Hosier SG. Cognitivemotivational predictors of excessive drinkers' success in changing. *Psychopharmacology*. 2007; 192:499–510. [PubMed: 17333136]
- David SP, Munafo MR, Johansen-Berg H, Mackillop J, Sweet LH, Cohen RA, et al. Effects of acute nicotine abstinence on cue-elicited ventral striatum/nucleus accumbens activation in female cigarette smokers: A functional magnetic resonance imaging study. *Brain Imaging and Behavior*. 2007; 1:43–57. [PubMed: 18458752]
- Dawson, ME.; Schell, AM.; Filion, DL. The electrodermal system. In: Cacioppo, JT.; Tassinary, LG.; Berntson, GG., editors. *Handbook of psychophysiology*. 2nd ed. Cambridge University Press; Cambridge, England: 2000. p. 200-223.
- Dimberg U. Facial electromyography and emotional reactions. *Psychophysiology*. 1990; 27:481–494. [PubMed: 2274612]
- Dimberg U, Thunberg M, Elmehed K. Unconscious facial reactions to emotional facial expressions. *Psychological Science*. 2000; 11:86–89. [PubMed: 11228851]
- Dimberg U, Thunberg M, Grunedal S. Facial reactions to emotional stimuli: Automatically controlled emotional responses. *Cognition & Emotion*. 2002; 16:449–471.
- 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, Cooper T, Glautier SP. Conditioned learning in alcohol dependence: Implications for cue exposure treatment. *British Journal of Addiction*. 1990; 85:725–743. [PubMed: 2198966]
- Edman G, Schalling D. Effects of smoking on habituation of the electrodermal orienting response. *Journal of Psychophysiology*. 1991; 5:165–175.
- Elash CA, Tiffany ST, Vrana SR. Manipulation of smoking urges and affect through a brief-imagery procedure: Self-report, psychophysiological, and startle probe responses. *Experimental and Clinical Psychopharmacology*. 1995; 3:156–162.
- Field, M.; Mogg, K.; Bradley, BP. Attention to drugrelated cues in drug abuse and addiction: Component processes. In: Wiers, RW.; Stacy, AW., editors. *Handbook on implicit cognition and addiction*. Sage; Thousand Oaks, CA: 2006. p. 151-164.
- Fridlund AJ, Cacioppo JT. Guidelines for human electromyographic research. *Psychophysiology*. 1986; 23:567–589. [PubMed: 3809364]
- Geier A, Mucha RF, Pauli P. Appetitive nature of drug cues confirmed with physiological measures in a model using pictures of smoking. *Psychopharmacology*. 2000; 150:283–291. [PubMed: 10923756]
- Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerstrom Test for nicotine dependence: A revision of the Fagerstrom Tolerance Questionnaire. *British Journal of Addiction*. 1991; 86:1119–1127. [PubMed: 1932883]
- Heishman SJ. What aspects of human performance are truly enhanced by nicotine? *Addiction*. 1998; 93:317–320. [PubMed: 10328040]
- Larsen JT, Norris CJ, Cacioppo JT. Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii muscles. *Psychophysiology*. 2003; 42:604–610.
- Marissen MAE, Franken IHA, Waters AJ, Blanken P, van den Brink W, Hendriks VM. Attentional bias predicts heroin relapse following treatment. *Addiction*. 2006; 101:1306–1312. [PubMed: 16911730]

- McClernon FJ, Kozink RV, Lutz AM, Rose JE. 24-h smoking abstinence potentiates fMRI-BOLD activation to smoking cues in cerebral cortex and dorsal striatum. *Psychopharmacology*. 2009; 204(1):25–35. [PubMed: 19107465]
- Munafo M, Mogg K, Roberts S, Bradley BP, Murphy M. Selective processing of smoking-related cues in current smokers, ex-smokers and never-smokers on the modified Stroop task. *Journal of Psychopharmacology*. 2003; 17:310–316. [PubMed: 14513923]
- Newton TF, Khalsa-Denison ME, Gawin FH. The face of craving? Facial muscle EMG and reported craving in abstinent and non-abstinent cocaine users. *Psychiatry Research*. 1997; 73:115–118. [PubMed: 9463845]
- 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]
- Orain-Pelissolo S, Grillon C, Perez-Diaz F, Jouvent R. Lack of startle modulation by smoking cues in smokers. *Psychopharmacology*. 2004; 173:160, 166. [PubMed: 14726999]
- Parrott AW. Performance tests in human psychopharmacology (1): Test reliability and standardization. *Human Psychopharmacology: Clinical and Experimental*. 1991; 6:1–9.
- Perkins KA, Grobe JE, Fonte C, Breus M. “Paradoxical” effects of smoking on subjective stress versus cardiovascular arousal in males and females. *Pharmacology, Biochemistry and Behavior*. 1992; 42:301–311.
- Richards, A.; Blanchette, I.; Hamilton, V.; Lavda, A. In: Vosniadou, S.; Kayser, D.; Protopapas, A., editors. Cognitive, emotional and physiological components of emotional Stroop using associative conditioning; Proceedings of the twenty-eighth annual conference of the Cognitive Science Society; Cognitive Science Society: Delphi, Greece. May, 2007; 2007. p. 788-793.
- Robinson JD, Cinciripini PM, Carter BL, Lam CY, Wetter DW. Facial EMG as an index of affective response to nicotine. *Experimental and Clinical Psychopharmacology*. 2007; 15:390–399. [PubMed: 17696686]
- Robinson TE, Berridge KC. The neural basis of craving: An incentive-sensitization theory of addiction. *Brain Research Review*. 1993; 18:247–291.
- Sayette MA, Hufford MR. Effects of cue exposure and deprivation on cognitive resources in smokers. *Journal of Abnormal Psychology*. 1994; 103:812–818. [PubMed: 7822584]
- Sayette MA, Wertz JM, Martin CS, Cohn JF, Perrott MA, Hobel J. Effects of smoking opportunity on cue-elicited urge: A facial coding analysis. *Experimental and Clinical Psychopharmacology*. 2003; 11:218–227. [PubMed: 12940501]
- Schneider, W.; Eschman, A.; Zuccolotto, A. E-Prime user’s guide Pittsburgh. Psychology Software Tools, Inc; PA: 2002.
- Siegel, S. Classical conditioning, drug tolerance, and drug dependence. In: Israel, Y.; Glaser, EB.; Kalant, H.; Popham, RE.; Schmidt, W.; Smart, RG., editors. Research advances in alcohol and drug problems. Vol. 7. Plenum Press; New York: 1983. p. 207-246.
- Spitzer, RL.; Williams, JB.; Gibbon, M. Structured clinical interview for DSM-III-R, Non-patient version. New York State Psychiatric Institute; New York: 1989.
- Spitzer RL, Williams JBW, Kroenke K, Linzer M, deGruy FV, Hahn SR, et al. Utility of a new procedure for diagnosing mental disorders in primary care: The PRIME-MD 1000 study. *Journal of American Medical Association*. 1994; 272:1749–1756.
- Stewart J, deWit H, Eikelboom R. The role of unconditioned and conditioned drug effects in the self-administration of opiates and stimulants. *Psychological Review*. 1984; 91:251–268. [PubMed: 6571424]
- Stormark KM, Laberg JC, Nordby H, Hugdahl K. Alcoholics’ selective attention to alcohol stimuli: Automated processing. *Journal of Studies on Alcohol*. 2000; 61:18–23. [PubMed: 10627092]
- Tassinari, LG.; Cacioppo, JT. The skeletomotor system: Surface electromyography. In: Cacioppo, JT.; Tassinari, LG.; Berntson, GG., editors. Handbook of psychophysiology. 2nd ed. Cambridge University Press; New York: 2000. p. 163-199.
- 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]

- Waters AJ, Carter BL, Robinson JD, Wetter DW, Lam CY, Cinciripini PM. Implicit attitudes to smoking are associated with craving and dependence. *Drug and Alcohol Dependence*. 2007; 91:178–186. [PubMed: 17658701]
- Waters AJ, Feyerabend C. Determinants and effects of attentional bias in smokers. *Psychology of Addictive Behaviors*. 2000; 14:111–120. [PubMed: 10860110]
- Waters, AJ.; Sayette, MA. Implicit cognition and tobacco addiction. In: Wiers, RW.; Stacy, AW., editors. *Handbook on implicit cognition and addiction*. Sage; Thousand Oaks, CA: 2006. p. 309-338.
- Waters AJ, Shiffman S, Sayette MA, Paty JA, Gwaltney CG, Balabanis MH. Attentional bias predicts out-come in smoking cessation. *Health Psychology*. 2003; 22:378–387. [PubMed: 12940394]
- Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Personality*. 1988; 54:1063–1070.
- Wikler A. Recent progress in research on the neurophysiological basis of morphine addiction. *American Journal of Psychiatry*. 1948; 105:329–338. [PubMed: 18890902]
- Williams JGW, Mathews A, MacLeod C. The emotional Stroop task and psychopathology. *Psychological Bulletin*. 1996; 120:3–24. [PubMed: 8711015]
- Zack M, Belsito L, Scher R, Eissenberg T, Corrigall WA. Effects of abstinence and smoking on information processing in adolescent smokers. *Psychopharmacology*. 2001; 153:249–257. [PubMed: 11205427]
- Zeger SL, Liang KY, Albert PS. Models for longitudinal data: A generalized estimating equation approach. *Biometrics*. 1988; 44:1049–1060. [PubMed: 3233245]

Figure 1. Relationship between smoking Stroop effect and change in zygomaticus major activity (upper panel) and change in corrugator supercilii activity (lower panel). *ns* indicate number of assessments that contribute to the mean.

Table 1

Mean (SD) of Physiological, Cognitive Measures

	AB-NS	AB-S	NON-NS	NON-S	z1	z2	z3
Change in HR (BPM)	0.08 (3.54)	-0.84 (1.99)	-0.27 (2.44)	-0.13 (2.41)	-0.64	1.34	1.61
Change in ZY (μ V)	0.13 (0.73)	0.02 (0.51)	0.04 (0.75)	0.23 (1.17)	-0.72	-0.55	1.17
Change in CO (μ V)	-0.23 (1.02)	0.21 (1.63)	0.03 (1.32)	-0.04 (1.29)	-0.06	-1.16	-1.81
Change in SC (μ S)	0.002 (0.056)	-0.013 (0.048)	-0.005 (0.045)	0.004 (0.061)	-0.90	0.49	1.79
Change in RT (ms) (Stroop)	41.1 (103.5)	18.6 (69.7)	37.0 (81.5)	22.5 (71.7)	0.01	2.00 *	0.41

Note. Mean (SD) of state measures (ns vary across measures, ns = 69, 72, 71, 69 for the AB-NS, AB-S, NON-NS, NON-S conditions respectively for smoking Stroop data). z1, z2 = z values for parameter estimates (PEs) for main effect of pre-session Abstinence, within-session Smoking respectively in GEE analyses; z3 = z value for PE for pre-session Abstinence by within-session Smoking interaction. Significant effects are bolded.

BPM = Beats per minute; ZY = Zygomaticus major activity; CO = Corrugator supercilii activity; SC = skin conductance reactivity. Change in HR = BPM on smoking words minus BPM on neutral words; Change in ZY = ZY on smoking words minus ZY on neutral words; Change in CO = CO on smoking words minus CO on neutral words; Change in SC = SC on smoking words minus SC on neutral words; Change in RT (smoking Stroop) = RT on smoking words minus RT on neutral words.

* $p < .05$.

Table 2

Mean (SD) of Subjective Measures

	AB-NS	AB-S	NON-NS	NON-S	z1	z2	z3
Pretask QSU factor 1 (0–10)	7.01 (2.71)	3.83 (2.97)	4.70 (3.04)	2.36 (2.82)	9.98 **	10.8 **	2.11 *
Posttask QSU factor 1 (0–10)	6.96 (2.64)	3.93 (2.94)	4.88 (3.24)	2.62 (3.07)	8.44 **	10.5 **	1.96
Change in QSU factor 1 (0–10)	–0.050 (0.61)	0.010 (0.93)	0.18 (0.77)	0.26 (1.13)	–2.04 *	–1.17	–0.32
Pretask QSU factor 2 (0–10)	6.42 (3.10)	3.53 (2.99)	4.01 (3.02)	2.04 (2.56)	9.09 **	9.70 **	2.31 *
Posttask QSU factor 2 (0–10)	6.35 (3.04)	3.52 (2.92)	4.26 (3.17)	2.26 (2.83)	7.89 **	9.30 **	2.22 *
Change in QSU factor 2 (0–10)	–0.067 (0.60)	–0.011 (1.17)	0.24 (0.88)	0.21 (1.05)	–2.50 *	–0.12	–0.34
Pretask NA (1–5)	1.82 (0.70)	1.57 (0.54)	1.62 (0.57)	1.63 (0.54)	1.62	2.67 **	3.13 **
Posttask NA (1–5)	1.76 (0.66)	1.51 (0.48)	1.60 (0.60)	1.56 (0.50)	0.99	3.04 **	2.49 *
Change in NA (1–5)	–0.065 (0.26)	–0.051 (0.28)	–0.015 (0.33)	–0.067 (0.18)	–0.47	0.51	–1.13
Pretask PA (1–5)	2.97 (0.79)	2.87 (0.77)	2.96 (0.86)	2.96 (0.82)	–1.50	0.84	0.93
Posttask PA (1–5)	3.04 (0.82)	2.92 (0.76)	2.93 (0.86)	3.00 (0.87)	–0.12	0.15	1.78
Change in PA (1–5)	0.080 (0.35)	0.053 (0.32)	–0.032 (0.32)	0.046 (0.28)	1.56	–0.70	1.49
OE (1–11)	7.21 (2.81)	5.85 (2.98)	6.14 (2.95)	4.76 (2.84)	5.24 **	5.31 **	0.48

Note. Mean (SD) of subjective measures (ns = 69, 72, 71, 69 for the AB-NS, AB-S, NON-NS, NON-S conditions). z1, z2 = z values for parameter estimates (PEs) for main effect of pre-session Abstinence, within-session Smoking respectively in GEE analyses; z3 = z value for PE for pre-session Abstinence by within-session Smoking interaction. Significant effects are bolded.

QSU = Questionnaire for Smoking Urges; PANAS = Positive and Negative Affect Scale; OE = Outcome Expectancies.

* p < .05.

** p < .01.

Table 3
Associations Between Predictor Variables and the Smoking Stroop Effect

Predictor variable	Parameter estimate predictor variable (SE)	
Change in HR	-2.72	(1.75)
+ Abstinence, Smoking	-3.05	(1.77)
Change in ZY	11.3 **	(3.31)
+ Abstinence, Smoking	11.5 **	(3.30)
Change in CO	0.70	(2.93)
+ Abstinence, Smoking	1.10	(3.02)
Change in SC	-15.8	(72.5)
+ Abstinence, Smoking	-21.8	(72.8)
Posttask QSU-Factor 1	3.92 **	(1.37)
+ Abstinence, Smoking	3.63 *	(1.59)
Posttask QSU-Factor 2	4.13 **	(1.43)
+ Abstinence, Smoking	3.88 *	(1.66)
Posttask NA	8.95	(10.5)
+ Abstinence, Smoking	6.98	(10.5)
Posttask PA	3.77	(6.92)
+ Abstinence, Smoking	3.60	(6.86)
OE	4.48 **	(1.53)
+ Abstinence, Smoking	4.12 *	(1.61)

Note. Associations between predictor variables and the smoking Stroop effect, using GEE analyses. Data shown are parameter estimates (SE) of predictor variables from models containing Session (parameter estimate of Session not shown) and the predictor variable (tested individually). The lower row shows parameter estimates (SE) of predictor variables from models including presession Abstinence and within-session Smoking (parameter estimates of presession Abstinence, within-session Smoking not shown). Significant parameter estimates are bolded.

BPM = Beats per minute; ZY = Zygomaticus major activity; CO = Corrugator supercilii activity; SC = skin conductance reactivity; QSU = Questionnaire for Smoking Urges; PANAS = Positive and Negative Affect Scale; OE = Outcome Expectancies.

*
p < .05.

**
p < .01.