Working Memory in Nonsmokers and in Cigarette Smokers During Abstinence and Relative Satiety

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ABSTRACT (200 words)

Working memory impairments have been inconsistently linked to chronic smoking and to withdrawal. Withdrawal-related deficits in working memory could contribute to the difficulty of quitting smoking. To help clarify how smoking interacts with working memory, we studied 18 smokers and 16 demographically matched non-smokers using the N-Back Task. Testing was done in two test blocks on each of two days. In one session, smokers were tested after > 12 h abstinence (withdrawal session); in the other session, testing began ~1 h after smoking (satiety session). On both days, smokers consumed one cigarette between the two test blocks, and cigarette craving was assessed before each block. In the withdrawal session, smokers had significantly longer response latencies (in the 2-back condition) and tended to make more errors overall than non-smokers. In the satiety session, their performance did not differ significantly from that of non-smokers. A within-subject comparison of smokers' performance revealed significantly longer response latencies and more errors in the withdrawal session. Smoking one cigarette between test blocks of the withdrawal session did not significantly affect performance despite reduced craving. The between-session (withdrawal minus satiety) difference in craving, however, was significantly related to the corresponding difference in error rate. The findings indicate that working memory impairments accompany acute abstinence from smoking.

Key words: working memory, smoking cessation, nicotine dependence, nicotine withdrawal, cognition, craving

INTRODUCTION

Working memory is a cognitive function that is mediated by a system of limited capacity, and is implicated in a wide range of cognitive operations (Baddeley, 1996, Baddeley and Della Salla, 1996). In the simplest case of working memory, information is stored for a few seconds before decaying; in more complex applications, data can be retrieved, manipulated, and associated with other information (Goldman-Rakic, 1996). Human studies have suggested that chronic smoking, acute withdrawal, and acute smoking or nicotine administration can affect performance on tests of working memory, although the results have been inconsistent (Heishman et al., 2002, Heishman et al., 1993, Rezvani and Levin, 2001, Pritchard and Robinson, 1998).

Some research reports have suggested associations between impairments of cognitive function and smoking history. In one study, reaction time on the N-Back Task, a test of working memory, was shortest in never-smokers, intermediate in ex-smokers, and longest in smokers (Ernst at al., 2001). Another study found that smokers, even in satiety, performed more poorly than non-smokers on a recognition memory task in which lists of words were followed by a probe word (Spilich et al., 1992). These findings could be interpreted as evidence for a deleterious effect of cigarette smoking. In support of this interpretation, a large cohort study found that smokers, as compared to non-smokers, exhibited greater decline in performance between the ages of 43 and 53 on a word learning task (Richards et al., 2003). Other cohort studies, however, have not demonstrated significant effects of chronic smoking on cognitive decline, (Schinka et al., 2002, Carmelli et al., 1997).

Deleterious effects of acute withdrawal on working memory, and reversal of such effects by smoking or nicotine administration have also been observed. For example, within 4 h of initiating smoking abstinence, tobacco-dependent research subjects showed increased response latency and poorer accuracy on a digit recall task; their performance returned to baseline levels within 24 h of resuming smoking (Snyder et al., 1989). A similar effect was observed in smokers, whose performance during a serial recall of letters deteriorated after 12 h of deprivation and normalized after smoking a single cigarette (Blake and Smith, 1997). In another study, abstinent smokers and non-smokers performed a variant of the Sternberg Task, in which a set of items is presented for memorization shortly before the presentation of a single probe item (Grobe et al., 1998). Latency for responding to the probe presumably reflects the time needed to scan the items being held "on-line." Nicotine administration by nasal spray improved smokers' performance when distracting stimuli were presented (Grobe et al., 1998). A later study showed that smoking a nicotine-yielding cigarette but not a de-nicotinized cigarette shortened reaction times on a Sternberg task (Houlihan et al., 2001).

Other studies of smoking and/or nicotine manipulations on working memory have reported results contrasting with those above. For example, administration of nicotine gum (4 mg nicotine) did not reduce reaction time or improve accuracy on the N-Back Task in smokers who had abstained for 12 h(Ernst et al., 2001a). Further, in a study in which overnight-abstinent smokers consumed one cigarette with nicotine content manipulated, the amount of nicotine delivered was *inversely* correlated with working memory performance (Williams, 1980). In addition, deficits in spatial working memory were associated with the administration of nicotine nasal spray to abstinent smokers and non-smokers (Park et al., 2000). Summarizing the literature, Pritchard and Robinson

(1998) concluded that it "provide[s] no consistent evidence regarding the [acute] effects of smoking/ nicotine on [working memory] capacity" (pg71).

Complex social and physiological factors have been implicated in nicotine dependence. The effects of smoking and of withdrawal from smoking on cognition, may contribute to the maintenance and relapse of smoking behavior. The present study therefore aimed to further our knowledge of the interaction of cigarette smoking with working memory performance in human subjects. We employed a parametric version of the N-Back working memory task to assess: 1) whether there were differences in working-memory between non-smokers and smokers either in withdrawal or satiety, 2) whether 12 h abstinence resulted in working memory impairments among smokers, and 3) whether smoking one cigarette enhanced the working memory performance of smokers who had been abstaining for the previous 12 h. In secondary analyses, we assessed whether reported cigarette craving was associated with effects of abstinence and acute smoking on working memory performance.

METHODS

Recruitment/ Inclusion/Exclusion

Potential participants were recruited from flyers and newspaper ads. They were screened for eligibility during a telephone interview, which presented questions about their current use of medications, prior and current use of illicit drugs, medical and psychiatric condition, and current and previous cigarette usage. Individuals were excluded if they were younger than 18 or older than 50 years of age, or if they reported smoking marijuana more than once per week, drinking more than 10 alcoholic drinks per week, regularly using recreational drugs other than alcohol or marijuana, or taking medication for mood, sleep, or energy disturbance. Potential non-smoker participants who reported a lifetime history of smoking more than 5 cigarettes were excluded. Potential smoker participants were excluded if they reported smoking fewer than 15 or more than 40 cigarettes per day, or had not been smoking regularly for at least 2 years.

Of 1162 individuals who responded to flyers and newspaper ads, 166 both passed the telephone screen and provided informed consent to participate in the study. During the initial baseline visit, additional measures were obtained to assess eligibility. Expired carbon monoxide (CO) was taken as an objective measure of recent smoking (Micro Smokerlyzer II, Bedfont Scientific Instruments), with inclusion criteria of ≤ 7 ppm for the non-smoker group and ≥ 15 ppm for the smoker group.

The participants also completed questionnaires covering medical history, smoking history (including the Fagerström Test for Nicotine Dependence), childhood ADHD (Wender Utah Rating Scale; WURS) (Ward et al., 1993) and depressive symptoms (Beck Depression Inventory; BDI) (Beck and Beamesdorfer, 1974). A subject was excluded if he or she reported a debilitating medical condition, or had a score of ≥ 46 on the WURS or ≥ 10 on the BDI.

Twenty non-smokers and 26 smokers were deemed eligible for participation. Two smokers were disqualified because they were unable to abstain from smoking for > 12 h. Four non-smokers and six smokers were otherwise lost to attrition. The remaining 16 non-smokers and 18 smokers participated in the research reported here.

Procedures

Subsequent to baseline assessments, all participants were administered the N-Back Task four times – twice on each of two test sessions. Half of smokers abstained for > 12 h prior to their first but not their second test session, and the other half of the group abstained for > 12 h prior to their second but not their first test session. On the alternate sessions, smokers were allowed to smoke *ad libitum* before arriving in the laboratory. Because the N-Back Task was not administered until ~1 h after a smoker consumed his or her last cigarette on the day when *ad libitum* smoking was allowed, we refer to this condition throughout as "*relative* satiety." We use the label "withdrawal" to denote the >12 h abstinence condition. All smokers smoked one cigarette (their usual brands) in-between the two blocks of the N-Back Task administration on both test sessions.

During each block of testing, smokers were evaluated for cigarette craving using three scales: 1) a 10-item Likert Urge To Smoke scale (UTS) (Jarvik et al., 2000), 2) a 7-item Likert craving subscale that is part of a 25-item Shiffman-Jarvik multi-factor withdrawal scale, and 3) a 4-item visual analog craving scale (Schuh and Stitzer Index). Scores on the three craving scales were highly correlated (r's ranged from .79 to .88). To limit the number of statistical comparisons, we used only the UTS scores as our index of craving. We chose the UTS since it had the highest internal consistency of any of the 3 craving measures obtained (α=.86).

Before each testing session, measurement of expired CO provided a quick verification of compliance with abstinence as required (see above). Moreover, to diminish the effect of increased performance variance due to the effect of practice, subjects were given pre-experimental task training. The training consisted of 2-min blocks of each condition (0-, 1-, 2-, and 3-back), which participants had to perform until attaining a level of at least 60% accuracy without variation of more than 10% on two consecutive blocks of the same condition. All testing sessions took place in the afternoon (between 14:00 h and 17:00 h).

Parametric N-back Task

The working memory N-back task consisted of randomly presented, 42-sec blocks of 0-back, 1-back, 2-back, and 3-back conditions, and 18-sec periods of rest separating the blocks from one another. Each type of block (0-back, 1-back, 2-back, and 3-back) was repeated twice during the course of 8 min of testing, and consisted of a sequence of letters of the alphabet presented in a pseudorandom order one at a time. Each letter appeared for a duration of 400 ms with an inter-stimulus interval (ISI) of 2000 ms. At the onset of the 0-back block condition, participants, saw the instruction "Find X" and were required to press one key ("yes key") when the letter "X" appeared, and a second key ("no key") when any other letter appeared. At the onset of the 1-back block, participants saw the instruction "Find 1-back" and were required to press the "yes key" when the letter presented was identical to the one immediately preceding it, and the "no key" whenever any other letter appeared. The same procedure was followed for the 2- and 3-back conditions, except that during the 2-back, the target letter was the letter that was displayed two letters prior, and during the 3-back the target letter was that presented 3 letters prior. Each block contained 21 stimuli: 7 targets and 14 non-targets.

Data Analysis

Analyses were conducted to address three primary questions: 1) Are there differences in working memory between nonsmokers and smokers, either in withdrawal or relative satiety? 2) Does > 12 h abstinence from smoking produce impairments in working memory? and 3) Does smoking one cigarette enhance the working memory performance of smokers who had abstained > 12 h? Each of these questions was addressed by repeated measure Analyses of Variance (ANOVA). To compare the performance of nonsmokers and smokers (question 1) one set of repeated measure ANOVAs was conducted that included non-smokers and smokers only in relative satiety (first block of testing in both cases), with "group" included as a between subject independent variable. A second set of repeated measure ANOVAs was conducted that included only the performance of smokers in withdrawal (Block 1 of withdrawal session), again with "group" included as a between subject independent variable. To assess whether smoking withdrawal resulted in working memory impairments (question 2), a set of ANOVAs looked at the Block 1 (pre-cigarette) N-Back performance of smokers in both sessions, with condition (withdrawal Vs relative satiety) included as a within subject variable.

The question of whether smoking one cigarette would enhance working memory among smokers in withdrawal (question 3) required a more complicated approach given that pre- versus post-cigarette performance was necessarily confounded with test administration order. That is, pre-cigarette testing always preceded post-cigarette testing. In order to address this confound, repeated measure ANOVAs were conducted that included performance of test blocks 1 and 2 for both smokers (withdrawal session only) and nonsmokers. Test block was included as a within subject independent variable and group was included as a between subject variable. We reasoned that if smokers changed across blocks in a way that differed significantly from non-smokers, the difference could plausibly (though not definitively) be attributed to the effect of their having smoked between blocks, rather than as an effect of repetition. As such, we looked to the interaction between group and block for statistical evidence of an effect of smoking one cigarette.

In all analyses outlined above, N-Back condition (1-, 2-, and 3-back) was used as a within subject variable, and the analyses were conducted separately for both errors and reaction times (RTs). Also, since we were interested in identifying effects on working memory performance in particular, we followed up significant results with analyses that additionally included 0-back performance (a non-working memory control condition) as a covariate. Finally, secondary correlational analyses were conducted to assess whether any effects observed in working memory performance were associated with self-reports of cigarette craving. Specifically, difference scores were computed, by subject, for performance measures in the conditions of interest (e.g., % errors in the withdrawal session minus % errors in the satiety session) as well as for subjective ratings of craving in the conditions of interest (e.g., craving in withdrawal session minus craving in the satiety session). Pearson's correlation coefficient was then computed for the two difference scores.

RESULTS

Subjects

Demographic information for the 18 smokers and 16 non-smokers are presented in Table 1. Smokers and non-smokers did not significantly differ in age, race, gender, years of education, or BDI score. Smokers did have significantly higher WURS scores, suggesting a significantly higher incidence of childhood ADHD in the group. The smokers reported a current cigarette consumption of 19.8 ± 6.2(mean ± SD) cigarettes per day and a smoking history of 14.8. ± 8.9 years. Their severity of nicotine dependence, as assessed by Fagerström scores (range 0-10), was moderate for the smokers in the present sample (4.78 ± 1.67).

N-Back Performance

Non-Smokers Versus Smokers

Figure 1a presents the RT and error rates for non-smokers and smokers in relative satiety. Based on the 1-, 2-, and 3-back conditions, smokers in relative satiety did not significantly differ from non-smokers in either RT ($F(1,32)=.55$, $p=.46$) or error rate ($F(1,32)=1.36$, $p=.25$). Figure 1b presents the RT and error rates for non-smokers and smokers in withdrawal. As suggested by the figure, a significant interaction was observed between N-Back level and group as predictors of reaction time ($F(2,64)=3.68$, $p=.03$). Follow-up t-tests at each of the levels indicated that smokers were significantly slower than non-smokers on the 2-Back ($t(32)=2.73$, $p=.01$), but not at the other N-Back conditions (p's > .3). The group difference at the 2-Back remained significant in an Analysis of Covariance (ANCOVA) that included 0-Back RT as a covariate to control for non-memory related deficits in performance ($F(1,31)=7.8$, $p=.01$). An analysis of error rates, indicated that smokers in withdrawal also were less accurate than non-smokers ($F(1,32)=4.13$, $p=.05$). When error-rates on the 0-back were included as a covariate to control for non-memory related deficits in performance, the difference between groups in error-rates was no longer significant ($F(1,31)=2.6$, $p=.12$).

The effects of withdrawal on N-back performance

In order to assess the effects of withdrawal on working memory, Block 1 performance of smokers on the N-Back Task (i.e., performance prior to within-session smoking) was compared between the withdrawal and relative satiety conditions. A main effect of condition was observed with smokers performing more slowly in the withdrawal session as compared to relative satiety ($F(1,17)=5.10$, $p=.04$). Correspondingly, smokers made significantly more errors in the withdrawal condition compared to relative satiety

(F(1,17)=5.03, p=.04). To control for non-memory related effects of the manipulation, 0-back performance was included as a covariate in re-analyses of both RT's and errors. The difference in reaction time performance across condition remained significant (F(1,16)=4.92, p=.04), as did difference in error rate (F(1,16)=5.63, p=.03; see Figure 2).

The effects of one cigarette on performance in withdrawal

As within session smoking always took place between the first and second blocks of the N-Back Task, we looked to the interaction between test block and group (using only the withdrawal session for smokers) for possible statistical evidence of an effect that could be attributed to within session smoking. We present the data relevant to this analysis of interaction graphically by plotting the difference scores of Block 1 minus Block 2 for both smokers in withdrawal, and for non-smokers (Figure 3). The subjects generally showed improved performance in the second block (positive numbers on Figure 3). A repeated measure ANOVA of reaction times across N-Back levels revealed no group by block interaction (F(2,64)=1.59, p=.22). In a similar analysis of error rate, again no interaction was observed between group and test block (F(2,64)=1.20, p=.31).

Subjective craving and performance

Among smokers, the mean UTS item scores (1-7) in the withdrawal visit were 5.6 $\pm$ 1.2 and 2.9 $\pm$ 1.6 before and after smoking, respectively; in the relative satiety visit, these scores were 3.8 $\pm$ 1.5 and 2.9 $\pm$ 1.5 before and after smoking, respectively. In a repeated measure ANOVA, significant main effects were observed for the effect of session (F(1,17)=13.5, p=.002), indicating that abstinence of > 12 h produced more withdrawal than abstinence for ~ 1 h. In addition, there was a significant effect of within session smoking (F(1,17) = 39.3, p<.001). A significant interaction was also observed between session and block (F(1,17)=13.5, p=.002) as a result of the greater reduction in

UTS scores after smoking during the withdrawal session than during the relative satiety session. The subscales of the Shiffman-Jarvik Nicotine Withdrawal Symptom Scale are presented for each condition in Table 2.

As exploratory analyses, we assessed the relation between the changes in subjective craving of smokers across conditions and the changes in N-Back performance across the same conditions. Since no reliable effect of within session smoking on performance was observed, we limited this comparison to the withdrawal vs. satiety difference scores. The correlation between individual differences in craving (withdrawal minus relative satiety sessions) and differences in RT across the same conditions (withdrawal minus relative satiety sessions) was $r(18)=.25$, $p=.32$; for the corresponding analysis of error rate, the relation was $r(18)=.50$, $p=.04$.

Missing data

Although empirical analyses (described below) indicated no substantial effect on the potential to derive statistical inferences from the present data, responses made within 400 msec of the stimulus presentation were not recorded because of a programming error. On average, no response was recorded on 34.0% $\pm$ 18.9% of the trials. The proportion of trials without a response recorded (because the subject responded either during the 400-ms. stimulus presentation or not at all) did not differ significantly across groups (36.5% + 16.6% for non-smokers and 31.8% + 20.9% for smokers; $t(32)=.72$, $p=.47$.)

The effects of data truncation

Since all analyses were conducted on mean scores across different conditions (rather than on individual trials) understanding the effects of the missing data amounts to understanding the relationship between the resulting conditional means and the means that would have been observed in the absence of the truncation. We conducted a small separate study to examine this question directly. Data were collected from eight subjects (three who were part of the main study and five who were not; four of whom were smokers, and four of whom were nonsmokers). Subjects completed the same N-Back task (administered identically) except with the programming error corrected. The intact data from these eight subjects formed one data set. A second set of data was then formed from these data by eliminating all responses made within the first 400 msec (simulating the truncation error in the study). We then were able to empirically assess the relationship between the conditional means in the absence and presence of the truncation.

The correlation between the data sets was high for both reaction times and error rates, with the conditional means of the truncated data accounting for nearly 95% of the variance in the conditional means of the intact data on each measure. Curve fitting indicated that the truncated RT data were fit as well to the original data by a linear transformation as by higher order transformations. This comparison is of interest since a linear transformation entails no effect on statistical analyses. A similar analysis suggested that missing data had little effect on mean accuracy scores. Even when accuracy scores for subjects were separated by condition and included as independent observations, a paired t-test indicated no systematic difference between accuracy rates on the intact data and those on the truncated data ($t(31)=.47$, $p=.64$).

DISCUSSION

This study provides evidence for a specific working memory deficit associated with acute withdrawal in a sample of smokers with only moderate severity of nicotine dependence (Fagerström scores 4.78 $\pm$ 1.67). Smokers after > 12 h abstinence, but not in relative satiety, performed more poorly on the N-Back Task than did control subjects. They responded more slowly in the 2-back condition, and tended towards overall longer reaction times. More directly, working memory performance by smokers was significantly slower and more prone to errors when the subjects had abstained > 12 h as compared to when they were in relative satiety. These effects of withdrawal retained statistical significance when we controlled for non-working memory performance variability using the 0-Back condition. Despite some inconsistency of literature, as discussed in the introduction, these data support the conclusion that abrupt initiation of smoking abstinence leads to deterioration of working memory. This deficit, in turn, may contribute to the maintenance of smoking behavior.

In anticipation of a deleterious effect of abstinence from smoking on performance of the N-Back Task, we tested whether smoking could reverse a potential deficit. Although a previous study found no effect of nicotine gum on performance in abstinent smokers (Ernst et al., 2001), we reasoned that cigarette smoking might still be effective, as components of the smoking experience, other than nicotine *per se*, influence behavior. In this regard, nicotine patches and gum do not reduce craving as well as smoking a cigarette (Fiore et al., 1994, Schneider and Jarvik, 1984). While these modes of nicotine delivery do not produce analogous blood levels of nicotine (Schneider and Jarvik, 1984)or peak (bolus) delivery to the brain (Benowitz et al., 1990) experienced smokers report that even IV-nicotine, which more closely mimics the pharmacokinetics of smoking, produces less relaxation and less satisfaction, and is less able to reduce craving than smoking (Westman et al., 1996). In fact, human subjects generally respond similarly to smoking a regular and de-nicotinized cigarette, consistently preferring the cigarette that delivered secondary reinforcers alone to IV nicotine (Westman et al., 1996).

Thus, secondary reinforcers can have a substantial role in the effects of smoking. Smoking one cigarette did reduce reaction time in the 2-back condition, but post-smoking error rate scores tended to be higher on this condition. Therefore, we cannot interpret the one positive finding to be an effect to improve working memory; and there is thus no reliable indication that acute smoking of one cigarette was sufficient to improve performance on the N-back task.

This lack of effect could reflect the insufficiency of one cigarette to restore nicotine levels adequately. It is also possible that a positive effect may require sustained activation of nicotinic acetylcholine receptors over some time or production of a neuromodulatory product. Notably, in the study by Snyder and colleagues (1989), a return to baseline performance on a digit recall task was observed within 4-8 h but not 1 h of reinitiating smoking following deprivation for 10 days. It is therefore possible that in contrast to the relatively well documented, immediate effect of nicotine to improve sustained and selective attention in abstinent smokers (Pritchard and Robinson, 1998), the normalization of working memory function may require more time.

The negative finding of acute smoking on the N-back performance is, nevertheless, in conflict with one study in which smoking a single cigarette was sufficient to restore function of the articulatory loop of working memory (Blake and Smith, 1997), and with another study that reported shortened reaction times after one cigarette on a Sternberg task (Houlihan et al., 2001). These contradictory results may reflect differences in the cognitive tests used, and the fact that working memory consists of various sub-components, such as storage and manipulation of information and rehearsal of performance (e.g., Baddeley, 1996). These subcomponents have been distinguished form one another neuroanatomically (Awh et al., 1996, Baker et al., 1996, McCarthy et al., 1996, Cohen et al., 1997) and thus may also respond differently to smoking manipulations. It is also possible, particularly given that the effect of the smoking manipulation could only be assessed via an interaction with group, that the lack of effect was a Type 2 error.

Our findings are consistent with those of Ernst et al. (2001), who reported longer reaction times among smokers than non-smokers on the N-Back Task. In that study, all subjects performed the N-back task after chewing either nicotine gum or placebo gum. In both conditions, the smokers were tested after overnight abstinence from smoking (> 12 h). When we compared non-smokers and smokers abstinent for > 12 h, we observed a similar group difference. While thus consistent, the present data do, however, suggest that acute abstinence among smokers rather than a trait-like effect produced (or at least contributed to) the group difference between smokers and non-smokers.

The present results were mixed with respect to the hypothesized relationship between subjective craving and the effects of smoking manipulations on working memory. On the negative side, within session smoking did not produce a statistically significant effect on performance, even as it effectively reduced subjective craving to the level reported in the satiety condition. These observations suggest dissociation between the factors underlying subjective craving, and the neural substrates underlying withdrawal-based working memory deficits. On the positive side, however, a significant correlation was observed between decrease in craving by individual smokers in satiety relative to withdrawal and the corresponding decrease in error rate. Although larger sample sizes are required for definitive statements, these data taken together suggest that overlapping but not identical factors contribute to cigarette craving and working memory impairments during withdrawal.

Although responses made in less than 400 msec were not recorded, an eight subject study conducted to assess the effect of the missing data suggested the error had minimal impact on the statistical inferences made. Reaction time and error rates in the presence and absence of the truncation were highly correlated (r=.97). Of course there is no guarantee that the effect of the data loss in the study data set is similar to that observed in this simulation. However, particularly with respect to the observed effect of withdrawal on reaction times, it is difficult to envision a scenario in which the data truncation would effectively create, or even enhance a true difference across conditions. That said, a resulting spurious difference is not impossible, and so this remains a limitation of the present study.

The observed effect of acute withdrawal from smoking on working memory is particularly intriguing with respect to neuroimaging studies underway in our lab. Using functional magnetic resonance imaging to assess neural activation in a smaller sample of smokers and non-smokers, as they performed the N-Back task (London et al., 2003), we found smokers in withdrawal had greater task-related activity in dorsolateral prefrontal and parietal cortices than non-smokers. These preliminary brain-imaging findings support the notion of a withdrawal-associated impairment of working memory and add to the present behavioral data by suggesting an inefficiency of the cerebral response to working memory challenge.

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Table 1. Characteristics of Participants

	Non-smokers (n = 16)	Smokers (n = 18)
Age (years)	30.6 ± 8.4	35.5 ± 10.9
% Female	37.5%	27.7%
Years of Education	14.6 ± 1.5	13.8 ± 1.9
Race		
Caucasian (non-Hispanic)	68.8%	72.2%
Hispanic	0%	0%
African American	18.8%	22.2%
Other	12.5%	5.6%
Beck Depression Inventory	4.94 ± 4.2	4.59 ± 5.8
Wender Utah Rating Scale*	10.3 ± 4.6	18.8 ± 6.7

* Group difference significant with α=.05.

Table 2. Shiffman-Jarvik Withdrawal Subscales

	Relative Satiety Session		Withdrawal Session	
	Pre-Cigarette	Post Cigarette	Pre-Cigarette	Post-Cigarette
Craving *ƒ	4.53 + 1.20	4.13 + 1.08	5.66 + 1.14	4.17 + 1.06
Psychological Symptoms *	2.79 + .80	2.85 + .54	3.69 + 1.03	3.04 + .82
Physical Symptoms *	1.83 + 1.01	1.65 + .73	2.33 + 1.26	1.82 + 1.07
Sedation	2.06 + 1.09	2.56 + 1.43	2.53 + 1.12	2.95 + 1.71
Anxiety	4.28 + .77	4.44 + .95	4.61 + .99	4.57 + 1.32

Summary of Shiffman-Jarvik Withdrawal subscales.

* p<.05 for difference between pre-cigarette relative satiety session and pre-cigarette withdrawal session.

ƒ p<.05 for difference between pre-cigarette withdrawal session and post-cigarette withdrawal session

Figure Legends

Figure 1a. N-Back performance of smokers (in the satiety session) and non-smokers. Lines indicate mean RT's and bars indicate mean errors, both ± 1 SE, and both at each N-Back level. No significant group differences were observed.

Figure 1b. N-Back performance of smokers (in the withdrawal session) and non-smokers. Lines indicate mean RT's and bars indicate mean errors, both ± 1 SE, and both at each N-Back level. RT's of smokers in the withdrawal session were larger than those of non-smokers in the 2-Back; smokers in this session tended to make more errors overall than non-smokers ($p=.05$).

Figure 2. N-Back performance of smokers in withdrawal and satiety sessions. Lines indicate mean RT's and bars indicate mean errors, both ± 1 SE, and both at each N-Back level. In the withdrawal session, smokers responded more slowly and tended to make more errors compared with the satiety session (p's<.05)

Figure 3. Difference scores for N-back performance of smokers and non-smokers: Block 2 – Block 1 (Smokers smoked between blocks). Lines indicate mean RT's and bars indicate mean errors, both ± 1 SE, and both at each N-back level. The only significant difference was greater improvement (block 2 vs. block 1) in RT for the smokers than the non-smokers in the 2-back condition. Difference scores on error rates in the 2-back condition were in the direction of greater improvement for the non-smokers than the smokers.