Experimental and Clinical Psychopharmacology
2001, Vol. 9, No. 4, 418–424

1064-1297/01/$5.00 DOI: 10.1037//1064-1297.9.4.418

The Impact of Smoking Urges on Working Memory Performance

Carol J. Madden and Rolf A. Zwaan
Florida State University

The effect of smoking urges on cognitive performance is relatively short-lived (R. A. Zwaan, R. A. Stanfield, & C. M. Madden, 2000). The authors examined whether this results from the short-lived nature of the elicited urge itself or from practice effects on the cognitive task. Smokers listened to 1 of 2 imagery scripts (urge vs. neutral) and subsequently performed 2 cognitive tasks (math and language comprehension). Exposure to the urge script produced significantly less accurate performance at the onset of the 1st task than exposure to the neutral script, but there was no difference at the onset of the 2nd task. Thus, the quick disappearance of the urge effect seems to be due to the transient nature of the elicited urge itself rather than to practice effects.

Smoking urges are one of the main factors underlying addictive behavior in regular smokers and are also one of the central reasons for relapse in smokers who are trying to quit (U.S. Department of Health and Human Services, 1988). However, these addictive qualities are not the only negative aspect of urges. Smoking urges can also have a detrimental effect on smokers' ability to engage in everyday cognitive functions, such as understanding language. Smokers with an urge have been shown to perform less accurately on reading comprehension tasks than smokers without an urge (Zwaan, Stanfield, & Madden, 2000; Zwaan & Truitt, 1998). Cognitive processes such as comprehension are vital to everyday activities, and detrimental effects on these processes should be carefully considered. Although the detrimental effects of smoking urges on cognitive processes have been demonstrated, the nature and time course of these effects are currently not well understood. The present study is an attempt to bridge this gap.

Smoking urges, or *cravings*, can be defined as motivational states that enter conscious awareness, thus making a smoker aware of the goal to smoke a cigarette. It is a common misconception in today's society that smoking urges are elicited solely by nicotine deprivation. There is much evidence that urges are often elicited by smoking cues in the environment and can arise independently of nicotine deprivation (Drobes & Tiffany, 1997; Juliano & Brandon, 1998; Rohsenow, Childress, Monti, Niaura, & Abrams, 1991). These smoking cues can be such things as seeing a pack of cigarettes or watching someone smoke, smelling cigarette smoke in the air, listening to a story about smoking, holding a cigarette in one's hand, or imagining sentences about smoking. In the laboratory, these types of cues have been shown to elicit smoking urges in samples of smokers.

More important, the elicited urges have been shown to affect cognitive processing on a range of tasks, from simple tone reaction times (Baxter & Hinson, 2001; Cepeda-Benito & Tiffany, 1996; Sayette & Hufford, 1994) to reading comprehension accuracy (Zwaan et al., 2000; Zwaan & Truitt, 1998). Urge manipulations have also been shown to increase electroencephalographic (EEG) asymmetry, whereas subsequent cigarette smoking has been shown to reduce the EEG asymmetry (Zinser, Fiore, Davidson, & Baker, 1999).

These findings support a cognitive model of drug urges and drug use behavior developed by Tiffany (1990). Tiffany's model postulates that just like any other behavior, with sufficient practice drug use behaviors can become automatic (e.g., Baxter & Hinson, 2001; Logan, 1988; Shiffrin & Schneider, 1977), and are stored in long-term memory as *action schemas*. These are mental representations of the procedures for coordinating and carrying out the automatic drug-related behaviors. Like any mental representations, these schemas can be activated by cues in the environment such as those described above and, once activated, are difficult to interrupt.

According to Tiffany (1990), urges arise when the drug-use schemas are activated as automatic processes but cannot be implemented because of situational constraints. At this point, nonautomatic processes are activated in parallel with the automatic drug-use action schema. These are conscious processes that require resources from a limited working memory capacity. They attempt to inhibit the attention-demanding action schemas until the drug-use behavior can be implemented. However, given that working memory resources are limited, the nonautomatic response to the action schema depletes cognitive resources that might otherwise be used for cognitive tasks, such as studying for a test or giving a sales presentation. This is not a problem when the other cognitive tasks do not require a large portion

Carol J. Madden and Rolf A. Zwaan, Department of Psychology, Florida State University.

This research was supported by National Institute on Drug Abuse Grant DA 11678. This article is based on a master's thesis submitted to Florida State University by Carol J. Madden, under the direction of Rolf A. Zwaan. We thank Anders Ericsson and Al Lang for helpful comments on earlier versions of this article.

Correspondence concerning this article should be addressed to Carol J. Madden, Department of Psychology, Florida State University, Tallahassee, Florida 32306-1270. Electronic mail may be sent to madden@psy.fsu.edu.

of working memory resources. However, when the cognitive demands for the other task are high, the conscious response to the action schemas might disrupt performance.

Zwaan and Truitt (1998) have demonstrated that smoking urges affect language comprehension. Regular smokers in whom an urge had been elicited showed performance deficits in answering comprehension questions relative to regular smokers who did not have an urge. More important, the deficit was largest on sentences that were more difficult. The urge manipulation (smoking vs. neutral imagery scripts) produced no differential effects on a similar group of nonsmokers. This finding is consistent with the conceptualization of smoking urges interfering with working memory to a greater extent when task demands are high.

A subsequent study (Zwaan et al., 2000) attempted to determine the time course of the urge effect over a 15-min comprehension task. In that study, three possible predictions were considered: (a) the urge effect could remain constant over time, (b) the urge effect could increase over time, or (c) the urge effect could decrease over time. Zwaan et al. found that the urge effect decreased over time, such that by the middle of the comprehension task, comprehension accuracy for the smokers with an urge was at the level of that for the smokers without an urge. The authors offered two possible explanations for the disappearance of the urge effect over time. First, it might be that the actual smoking urge dissipates over time. Alternatively, it is possible that the smoking urge effect dissipates over time, but the actual urge is present for the duration of the comprehension task. In other words, it is possible that the urge is still present but the task demands of the comprehension task and those of the response to the action schema do not compete for the limited working memory resources as time progresses.

The Present Study

The alternative explanations proposed by Zwaan et al. (2000) for the disappearance of the urge effect prompted the primary question of the present study. Has the urge actually dissipated over time, or is it simply its effect that has dissipated? In other words, is it possible that the urge is still present but the response to the action schema and the decreasing task demands of the comprehension task do not compete for the limited working memory resources as time progresses? The present study aims to uncover the answer to this puzzle by introducing a second task that uses different working memory processes once the urge effect disappears. If the urge effect reappears at the start of the second task, then the disappearance of the effect on the previous task may be attributed to decreased task demands over time rather than decay of the urge. At the start of the second task, the practice effects that were gained over the first task are no longer useful, and the task demands return to the initial increased level.

For the implementation of this idea, two tasks were used: a sentence comprehension task and a three-term addition task. These two tasks were chosen for several reasons. First, both tasks involve skills that people use regularly in everyday situations. Second, and more specific to our research questions, the processes used in the math task are sufficiently different from those in the sentence comprehension task, such that carryover of practice effects or strategy use from the comprehension task to the math task and vice versa would be minimal. This two-task design allows a test of the competing predictions that (a) the actual smoking urge dissipates over time or (b) the smoking urge effect dissipates over time, but the actual urge is present throughout the two tasks. If the urge effect has diminished solely because of decreasing task demands over time on each task, then the urge effect should reappear at the onset of the second task. This prediction would be statistically supported by a main effect of script across both time points of interest (first block of the first task and first block of the second task). Alternatively, the urge may dissipate over time. In this case, although task demands are increased at the onset of the second task, the urge is no longer present to interfere with the primary task, yielding no difference between groups at the onset of the second task. This prediction would be statistically supported by an interaction between script and task whereby there is a difference between the two script groups on the first block of the first task but not on the first block of the second task.

Method

Participants

Sixty-four undergraduate students participated in this study as part of a course requirement in an introductory psychology class at Florida State University. All participants were smokers and were smoking at least 10 cigarettes a day (by self-report) at the time of the study. Zwaan and colleagues (Zwaan et al., 2000; Zwaan & Truitt, 1998) have twice shown that the script manipulation (urge vs. neutral) has no effect on the urge ratings or task performance of nonsmokers under the same conditions while performing this type of task. Furthermore, Zwaan and colleagues have not found differences in overall performance levels between smokers and nonsmokers (as a function of smoking) at the outset of similar tasks. Even if such differences were to appear in the present design, they would not be relevant to the central question. Therefore, it was considered unnecessary to include yet another control sample of nonsmokers in the present study. The proportion of men to women was equally distributed across conditions. Although Zwaan et al. (2000) did not find differential effects of urge on the basis of sex, there is clinical research suggesting that women may be more sensitive to nonnicotine related aspects of smoking than are men (see Perkins, 1996), perhaps making them more susceptible to smoking urge cues such as the scripts used here. Therefore, sex was controlled for in assigning participants to conditions. All participants gave breath samples that yielded carbon monoxide (CO) levels greater than 10 ppm. Nonsmokers typically produce levels ranging from 3 to 8 ppm, light to moderate smokers produce levels ranging from 10 to 25 ppm, and moderate to heavy smokers produce levels from 25 to 50 ppm.

Materials

Shortened versions of Salthouse and Babcock's (1990) listening span and computation span tasks were used to assess participants' general comprehension and computational skill and capacity. The listening span task is a variation on Daneman and Carpenter's

(1980) reading span task, a standard predictor of comprehension performance designed to tap the combined storage and processing capacities of working memory. This particular span task was chosen because it was accompanied by a computation span task, given that both comprehension and computational assessments were necessary in the present design. The computation span task was a variation of the listening span task in that sentences were replaced by equations. Both span tests were presented auditorily over a tape player while participants followed along and made responses in test booklets.

Two imagery scripts, which were developed by Maude-Griffin and Tiffany (1996) and previously used by Zwaan and colleagues (Zwaan et al., 2000; Zwaan & Truitt, 1998), were used in the experimental procedure. The following script was designed to elicit an urge in the smokers:

> You're sitting in a restaurant and you've just finished a satisfying meal. As you drink your last cup of coffee, you lean back in your chair and think about how great you feel. You decided to go without smoking today and feel OK. As you close your eyes and draw in a deep breath, you inhale the unmistakable smell of cigarette smoke. You open your eyes and turn to see that the couple at the table next to you has just lit up cigarettes to have with their after-dinner coffee. As you watch them talking, laughing, and enjoying their cigarettes, you realize that a cigarette would be pleasant right now. What a perfect way to end this meal. As you drink some more coffee and fidget with your spoon, you think of how a cigarette would feel between your fingers.

The neutral script matched the urge script in positive affective valence (see Maude-Griffin & Tiffany, 1996, for details) and second-person delivery, but was unrelated to smoking. It described someone relaxing and enjoying a view through a window.

The two experimental tasks consisted of 32 sentences slightly modified from King and Just (1991) as well as 32 three-term addition problems. Both tasks afforded the same style of presentation, the same format of a verification decision, and the same time frame as the sentence comprehension task. Because a given item on the comprehension and addition tasks took approximately the same time regardless of which task came first, all participants began the second task at about the same time. These two tasks were designed and pilot tested such that they yielded similar accuracy percentages and trial/reaction times.

All sentences in the comprehension task conformed to an identical object-relative syntactic structure, which made the sentences difficult for readers to comprehend (e.g., "The salesman that the accountant visited donated generously to the church collection."). These sentences were used in the present study because they had previously been shown to exhibit the urge effect under very similar conditions (Zwaan et al., 2000; Zwaan & Truitt, 1998). The 32 sentences were divided into four blocks of eight. Each sentence was followed by a question, asking whether one of the two agents performed one of the two actions (e.g., "Did the salesman donate to the church collection?"). Thus, each sentence yielded four possible question constructions, two correct and two incorrect. The four question constructions were balanced across blocks. Each sentence appeared on the screen for 4 s, and when it disappeared, the question was displayed. If participants did not respond by pressing the YES or the NO key within 4 s, a warning message appeared telling the participants that they were too slow and to respond more quickly on subsequent trials. Because the structure of the sentences was identical for all items and the questions conformed to a limited set of constructions, the task was ideal for practice effects and strategy development. Participants could quickly learn that they were required only to map the two agents to their respective actions, and they could concentrate exclusively on that task. In fact, it was possible to gather all of the necessary information by reading only part of each sentence.

The 32 addition problems were also divided into four blocks of eight problems, and these addition problems conformed to an identical structure. Each problem consisted of three terms: a two-digit term, a one-digit term greater than five, and another two-digit term. The problems were presented for 4.5 s. After the problem disappeared, an answer appeared just below where the problem had been and the participant had to press a YES or a NO key to indicate whether the answer was correct. If participants did not respond within 3.5 s after the answer appeared, a warning was displayed at the bottom of the screen telling the participants they were too slow and to respond more quickly on subsequent trials.

The answer could have been 1 of 3 constructions: the actual correct sum, 10 greater than the correct sum, or 10 less than the correct sum. The sum was correct on half of the items, and the three-answer constructions were balanced across blocks. The uniformity of the incorrect answers lent itself to strategy development, in that participants could recognize that the error always resided in the tens column and could concentrate on that column of addition, taking into account the possible carry from the ones column. Also, participants could adopt an estimation strategy because the degree of error (10) was relatively large on an incorrect answer. Feedback was not provided to participants in order to minimize negative affect, which might increase urge to smoke in both groups of participants (see Brandon, Wetter, & Baker, 1996; Maude-Griffin & Tiffany, 1996; Payne, Schare, Levis, & Colletti, 1991; Tiffany & Drobes, 1990).

Procedure

The experimental procedure was very similar to that of Zwaan and Truitt (1998) and Zwaan et al. (2000). Participants completed the trial either 1 or 2 at a time in 1-h sessions. To control as much as possible for time of day, and because smokers are less likely to have urges in the morning, all participants were tested between 1:00 p.m. and 6:00 p.m. On arrival at the laboratory, participants verified that they smoked at least 10 cigarettes in a day and signed a consent form. Next, participants provided a breath sample to be analyzed for CO level. The sample was immediately analyzed using an Interscan 1000 series portable CO analyzer, model 1146 (Chatsworth, CA). CO levels have been shown to correlate very highly with self-report measures of smoking (Becona & Vazquez, 1998). Participants producing CO levels less than 10 ppm were assigned to a separate experiment (not smoking related) run in the laboratory.

Participants were then asked to step outside the laboratory and smoke one of their own cigarettes. This was included in the procedure as an assurance that all participants were equated on time since their last cigarette, thus controlling for the biological effects of deprivation on smoking urges. Although nicotine levels vary for different brands of cigarettes, each smoker should intake that level of nicotine to which he or she is accustomed. Although Maude-Griffin and Tiffany (1996) found that levels of deprivation (6 and 24 h) did not differentially affect urges elicited by the scripts used here, others have shown that deprivation can augment the effects of smoking cues (Payne, Smith, Sturges, & Holleran, 1996). After smoking, participants completed a listening span task and a computation span task (Salthouse & Babcock, 1990). Order on these tasks was counterbalanced across participants, and both tasks together took approximately 20–25 min. On completion of the span tasks, participants listened to either the smoking urge script or the neutral script over headphones.

After hearing one of the scripts, participants were familiarized with the YES and NO keys, which were actually the period and X keys on the keyboard covered by specially marked labels. Next, instructions for whichever task that participant was to complete first (addition or sentence comprehension) appeared on the screen. After completion of 32 trials on the first task, instructions for the second task appeared on the screen and the participant completed the 32 trials on the second task. The computer recorded the accuracy and latencies of the participants' responses.

After completing both computer tasks, the participants filled out a computer questionnaire about relevant smoking-related habits. Participants were asked how many cigarettes they smoked a day, how long they had been smoking 10 or more cigarettes a day, and how long after waking until they smoked their first cigarette of the day. Kozlowski, Director, and Harford (1981) have shown this to be a useful index of smoking addiction. Participants were then asked to retrospectively rate their urge to smoke on a 7-point scale. This retrospective rating was taken for five time points throughout the duration of the experiment: at the time participants returned to the laboratory immediately after having smoked a cigarette; at the end of the span tasks; after participants heard the script over the headphones; at the end of the first computerized task, and at the end of the second computerized task. Urge ratings were taken retrospectively to minimize the likelihood of eliciting smoking urges during the experiment. If taken during the experiment, the reference to smoking urges might have acted as a smoking cue, thus triggering a smoking urge in both groups and disabling the script manipulation. Finally, participants were debriefed and dismissed. The entire experiment lasted approximately 50 min. All participants were tested using the Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993). The experiment was run on a Macintosh Quadra (Cupertino, CA).

Results

Descriptives

The following means (and standard deviations) for the demographic and individual difference data were collapsed across condition because there were no differences found between the urge and no-urge groups: CO level as measured in parts per million in exhaled breath samples at the start of the experiment, 17.4 (7.3); computation span score (sum of trials correctly answered and recalled), 86.7 (10.4); listening span score (sum of trials correctly answered and recalled), 87.8 (7.9); average number of cigarettes smoked per day, 15.5 (6.2); number of years participants had been smoking, 2.9 (2.7); number of minutes after waking until participants smoked their first cigarette of the day, 54.4 (71.8); number of men out of the total, 28/62. Analyses of these data indicated that the pseudorandomly assigned groups (controlled only for sex) were comparable in terms of smoking history and verbal and math abilities (all ts < 1). Also, the CO levels indicated that the groups did not differ in terms of how much they had recently smoked ($t < 1$). Overall, the CO levels indicated that the participants were generally light to moderate smokers.

Manipulation Check

The t tests for all five retrospective urge ratings show that the only time during the experiment when the urge and neutral script groups diverged was immediately after hearing the scripts. Participants who heard the script about smoking provided significantly higher retrospective urge ratings than participants who heard the neutral script, $t(59) = 2.57, p < .05$. This demonstrated the validity of the urge script manipulation in effectively eliciting smoking urges. Mean urge ratings (and standard deviations) by urge condition for the five time points were as follows: Urge 1.7 (1.2), 3.5 (1.8), 4.4 (1.9), 3.6 (1.9), and 4.2 (2.1); no urge 1.5 (.7), 3.5 (1.9), 3.1 (2.0), 3.8 (1.8), and 4.3 (2.0).

Comprehension Accuracy

The main goal of this study was to examine the effect of script over time, by comparing the two groups at the two critical time points (first block of the first task and first block of the second task). The specific alternative hypotheses predicted either a main effect of script across the two time points or an interaction involving time and script. This interaction would arise from a difference at the onset of the first task, but not at the second. To test for this main effect and interaction, a 2 (script: smoking urge or neutral) × 2 (time: first block of the first task or first block of the second task) × 2 (order: math first or reading comprehension first) analysis of variance (ANOVA) was performed. Script and order were manipulated between subjects, whereas time was a within-subject factor.

Two participants were removed from the statistical analysis because of multiple response times under the cutoff (400 ms for math and 500 ms for reading), indicating that they were guessing rapidly rather than performing the cognitive tasks. Also, one of the reading comprehension items was removed from the analysis because of unintentional semantic cues favoring the incorrect response (both groups scored below 20% accuracy on this item). The accuracy score results are displayed in Figures 1 (collapsed across tasks), 2, and 3 (showing individual tasks).

The ANOVA produced a significant interaction between script and time, $F(1, 58) = 5.17, p < .05$, indicating that the smokers who heard the urge script performed less accurately than those who heard the neutral script, but only at the onset of the first task. There was no statistical difference between groups at the onset of the second task, indicating that although concurrent task demands were once again high, the urge had dissipated enough that no measurable interference remained at that time. Follow-up analyses confirmed this notion, yielding a significant difference between the two script groups at the onset of the first task, $t(60) = 3.12, p < .05$, but no difference at the onset of the second task ($t < 1$). In Figure 1, an initial effect of urge can be seen on the first block of the first task, but this difference disappears quickly, as it is statistically gone in the first block of the second task.

Follow-up analyses for the individual tasks showed similar results. At the onset of the math task when it occurred first, the group that heard the urge script performed less

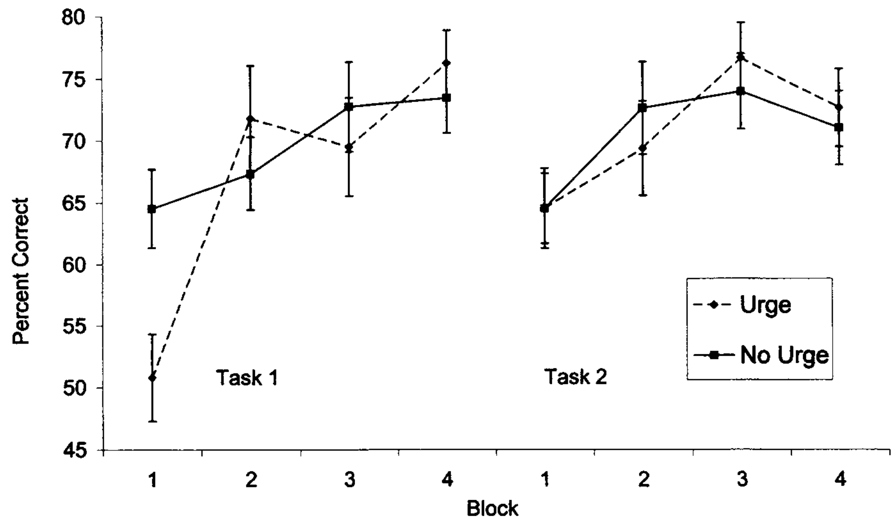

Figure 1. The accuracy data over all four blocks of both tasks, collapsed across reading and math.

accurately than the group that heard the neutral script, $t(28) = 2.37, p < .05$. However, when math occurred as the second task, the two groups did not differ ($t < 1$). Likewise, when reading was the first task, the first block showed a significant difference between the two groups, $t(30) = 2.04$, $p < .05$, but not when the reading task occurred second ($t < 1$). Figures 2 and 3 depict the initial effect of urge on the first block of the first task for both math and reading. However, this difference is statistically gone in the first block of the second task for both math and reading. All follow-up tests used the mean square error term from the overall ANOVA.

Discussion

The present study examined whether the transient effect of a smoking urge results from the short-lived nature of the elicited urge itself or whether the effect dissipates in the presence of an ongoing urge due to practice effects on the dependent task. Working memory resources have been shown to be recruited away from cognitive tasks by elicited smoking urges. However, this can occur only as long as working memory demands of the cognitive tasks are large enough to require the resources that the smoking urge uses. In the present design, this condition was met at the onset of each novel task, when practice effects were not yet observed. However, effects of smoking urges were observed at the onset of the initial task only. When the task was switched to determine whether the urge effect would reappear in the absence of practice effects, no group differences were observed. This interaction extends previous findings in demonstrating that the quick disappearance of the smoking urge effect seems to result

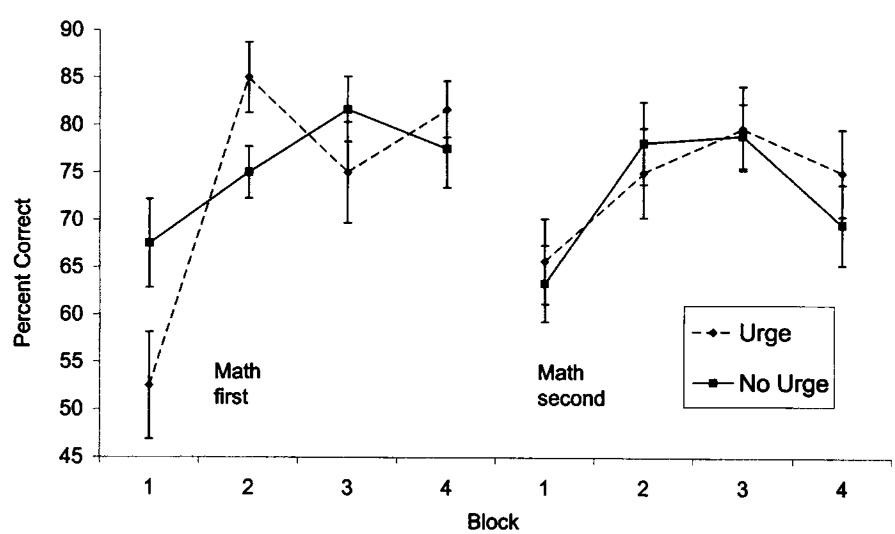

Figure 2. The accuracy data over the four blocks of the math task when it occurred both first and second.

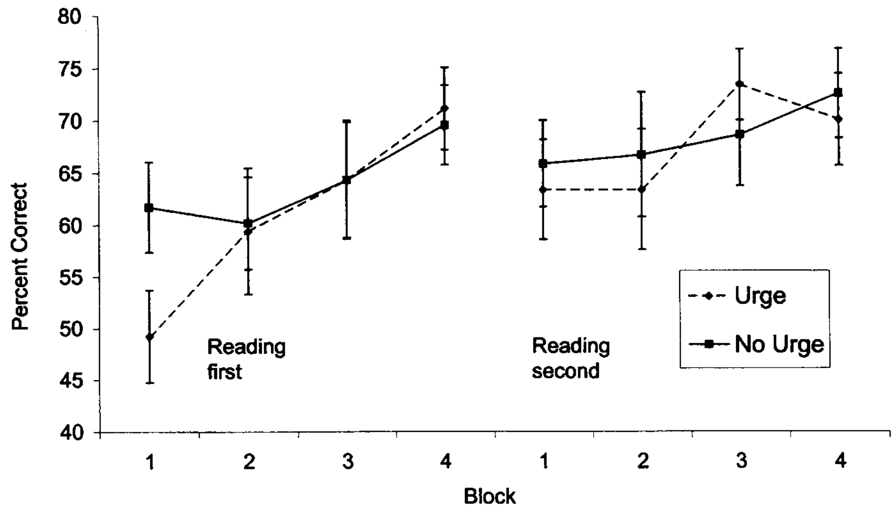

Figure 3. The accuracy data over the four blocks of the reading task when it occurred both first and second.

from the transient nature of the elicited urge itself and not from reduced working memory demands of the dependent task over time.

The results support the hypothesis that smoking urges dissipate over time. Regardless of whether practice on a given task leads to more automatic cognitive processing, the urge is recruiting fewer working memory resources as it dissipates over time. By the time the novel task is introduced, the urge must be attenuated to the point that it does not interfere with working memory performance on the new task. As is depicted in all three graphs, both groups of participants improve with practice over time on each task. However, the participants with a smoking urge start out with a deficit and improve at a greater rate over the course of the first task. The significant interaction between script and time indicates that there is a significant initial effect of urge on accuracy scores, which disappears even in the absence of practice effects (the onset of a novel task). There is no urge effect on the first block of the second task when task demands are high again, and strategies from the first task are not useful. The pattern of accuracy scores for the reading task resembles that obtained by Zwaan et al. (2000), in which reading was the sole task. Also, the pattern of math accuracy scores extends the previous finding of Zwaan et al. to a new domain of cognitive function, namely mental arithmetic.

The results of the present study provide further support for the general hypothesis that drug urges interfere with cognitive processes. The findings are consistent with Tiffany's (1990) cognitive model of drug urges and drug-use behavior, from which this hypothesis is derived. According to this model, the urge script used in the present study activated an action schema for smoking-related behaviors in regular smokers. These smokers were unable to smoke at the time of schema activation and had to suppress the schema, which interfered with their ability to perform the math and reading tasks used in the experiment. However, these smokers were able to quickly manage their smoking urge and improve their performance to the level of those who heard the neutral script.

In summary, it seems that the presence of a smoking urge affected accuracy at the beginning of the experiment but then dissipated over time regardless of task novelty. At the onset of the second task, the urge was no longer measurable with the present method. The findings presented here are consistent with previous studies in which smoking cues have been shown to elicit urges and affect performance on a range of tasks (Cepeda-Benito & Tiffany, 1996; Sayette & Hufford, 1994; Zwaan & Truitt, 1998; Zwaan et al., 2000). These results also extend the current body of research to include mental arithmetic among those tasks that are susceptible to interference from smoking urges.

Findings such as these are valuable to a relatively new and growing field. In a recent edited volume on models of working memory, Miyake and Shah (1999) pointed out that this area of research is still in its infancy. Specifically, they claimed that the nature and extent of the influence on working memory associated with brain pathology, drug, and emotional factors has not yet been well specified (Miyake & Shah, 1999, pp. 469–470). In their review of the current state of the field, Miyake and Shah called for a more systematic documentation of the working memory effects for these capacity-modulating factors, as well as a greater accountability for these factors in models of working memory. The present study attempted to address this issue by providing a systematic investigation of the impact of smoking urges on working memory performance. It has become evident that urges and cravings have a significant effect on working memory, and further empirical exploration is clearly warranted in this domain.

References

Baxter, B. W., & Hinson, R. E. (2001). Is smoking automatic? Demands of smoking behavior on attentional resources. *Journal of Abnormal Psychology, 110*, 59–66.

Becona, E., & Vazquez, F. L. (1998). Self-reported smoking and measurement of expired air carbon monoxide in a clinical treatment. *Psychological Reports, 83*, 316–318.

Brandon, T. H., Wetter, D. W., & Baker, T. B. (1996). Affect, expectancies, urges, and smoking: Do they conform to models of drug motivation and relapse? *Experimental and Clinical Psychopharmacology, 4*, 29–36.

Cepeda-Benito, A., & Tiffany, S. T. (1996). The use of a dual-task procedure for the assessment of cognitive effort associated with cigarette craving. *Psychopharmacology, 127*, 155–163.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). Psyscope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments and Computers, 25*, 257–271.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 415–466.

Drobes, D. J., & Tiffany, S. T. (1997). Induction of smoking urge through imaginal and in vivo procedures: Physiological and self-report manifestations. *Journal of Abnormal Psychology, 106*, 15–25.

Juliano, L. M., & Brandon, T. H. (1998). Reactivity to instructed smoking availability and environmental cues: Evidence with urge and reaction time. *Experimental and Clinical Psychopharmacology, 6*, 45–53.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*, 580–602.

Kozlowski, L. T., Director, J., & Harford, M. A. (1981). Tobacco dependence, restraint, and time of day to the first cigarette of the day. *Addictive Behaviors, 6*, 307–312.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95*, 492–527.

Maude-Griffin, P. M., & Tiffany, S. T. (1996). Production of smoking urges through imagery: The impact of affect and smoking abstinence. *Experimental and Clinical Psychopharmacology, 4*, 198–208.

Miyake, A., & Shah, P. (Eds.) (1999). *Models of working memory: Mechanisms of active maintenance and executive control.* New York: Cambridge University Press.

Payne, T. J., Schare, M. L., Levis, D. J., & Colletti, G. (1991). Exposure to smoking-relevant cues: Effects on desire to smoke and topographical components of smoking behavior. *Addictive Behaviors, 16*, 467–479.

Payne, T. J., Smith, P. O., Sturges, L. V., & Holleran, S. A. (1996). Reactivity to smoking cues: Mediating roles of nicotine dependence and duration of deprivation. *Addictive Behaviors, 21*, 139–154.

Perkins, K. A. (1996). Gender differences in nicotine reinforcement as determinants of tobacco smoking. *Experimental and Clinical Psychopharmacology, 4*, 166–177.

Rohsenow, D. J., Childress, A. R., Monti, P. M., Niaura, R. S., & Abrams, D. B. (1991). Cue reactivity in addictive behaviors: Theoretical and treatment implications. *International Journal of the Addictions, 25*, 957–993.

Salthouse, T. A., & Babcock, R. L. (1990). *Computation span and listening span tasks.* Unpublished manuscript, Georgia Institute of Technology, Atlanta.

Sayette, M. A., & Hufford, M. R. (1994). Effects of cue exposure and deprivation on cognitive resources in smokers. *Journal of Abnormal Psychology, 103*, 812–818.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 1313–1326.

Tiffany, S. T. (1990). A cognitive model of drug urges and drug-use behavior: Role of automatic and nonautomatic processes. *Psychological Review, 97*, 147–168.

Tiffany, S. T., & Drobes, D. J. (1990). Imagery and smoking urges: The manipulation of affective content. *Addictive Behaviors, 15*, 531–539.

U.S. Department of Health and Human Services. (1988). *The health consequences of smoking: Nicotine addiction: A report of the Surgeon General* (DHHS Publication No. CDC 88–8406). Washington, DC: U.S. Government Printing Office.

Zinser, M. C., Fiore, M. C., Davidson, R. J., & Baker, T. B. (1999). Manipulating smoking motivation impact on an electrophysiological index of approach motivation. *Journal of Abnormal Psychology, 108*, 240–254.

Zwaan, R. A., Stanfield, R. A., & Madden, C. M. (2000). How persistent is the effect of smoking urges on cognitive performance? *Experimental and Clinical Psychopharmacology, 8*, 518–523.

Zwaan, R. A., & Truitt, T. P. (1998). Smoking urges affect language processing. *Experimental and Clinical Psychopharmacology, 6*, 325–330.

Received November 21, 2000
Revision received April 23, 2001
Accepted April 27, 2001 ■