# Smoking and the course of anxiety and depression

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# CHAPTER 6

# Attentional Bias and Attentional Control across Information Processing Phases in Smokers and Non-Smokers: A Dot-Probe Study

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# Abstract

***Background.*** *Previous studies on attentional bias in smokers reported such bias in both the initial orienting and maintenance phases of attention, but findings are inconsistent. Attentional control may modulate the attention-capturing effects of distracting information. The aim of this study is to investigate attentional bias across phases of information processing and the role of attentional control in each of these phases.*

***Methods.*** *A dot-probe task with smoking-related and neutral pictures was tested in 24 smokers and 19 non-smokers. Stimulus-onset asynchronies (SOAs) were 100 ms, 500 ms, and 900 ms. Multivariate analyses were conducted to examine group differences in attentional bias. Correlations and linear regression analyses were performed, respectively, to examine the direction of the association between attentional bias and attentional control, and the moderation of attentional control on attentional bias.*

***Results.*** *Although smokers seemed to direct their attention preferentially to smoking-related pictures in all three SOA conditions, the effects were non-significant, except in the 900 ms SOA condition where the effect was statistically a trend. Attentional control did not moderate the effects, but a significant negative correlation was found between attentional control and attentional bias to smoking-related pictures presented for 100 ms in both smokers and non-smokers. Such negative correlation between attentional control and overall attentional bias was found only for smokers.*

***Conclusions.*** *Attentional bias to smoking-related stimuli seems to depend on the phase of information processing and on attentional control and these factors should be considered in future research of cognitive bias in smoking and addiction.*

# Introduction

Smoking is associated with a bias in the cognitive processing of smoking-related cues. The urge to smoke in smokers may be triggered by exposure to smoking-related sensory stimuli, such as an ashtray or a lit cigarette. These urges may be strengthened by a preferential allocation of attention to these cues[1, 2]. Such attentional bias to smoking-related stimuli has been widely investigated with the modified version of the Stroop task and the dot-probe task. In the modified Stroop task, participants are instructed to color-name smoking-related words and control words presented in different colors[3-6] or to make a motor response to the color of the word by using a button-press while ignoring the semantic content of the word[7-10]. Slower response to smoking-related words is assumed to indicate the inability to ignore the semantic content which slows down the color-naming. In the dot-probe task, a smoking-related picture and a non-smoking-related picture are presented simultaneously. After the offset of the pictures, a probe (usually an asterisk or a dot) appears immediately in the position of one of the pictures until the participant makes a response. Attentional bias towards smoking-related cues is inferred when the participant responds faster towards probes that replace the smoking-related picture. This has been demonstrated in a number of studies[1, 2, 11-16]. Studies using eye tracking have also shown that smokers shift their attention towards smoking-related cues and maintain their gaze for a longer duration on these cues as compared to non-smokers[17, 18].

Cue-target delay or stimulus onset asynchrony (SOA) may influence attentional bias to smoking-related cues. In order to examine biases in initial orienting and in maintenance of attention, studies have used short and long SOAs and obtained different results. For example, one study reported a bias in maintenance of attention: smokers showed a significantly greater attentional bias than non-smokers for smoking-related pictures presented at a stimulus duration of 2000 ms. However, no group differences were found at the stimulus exposure duration of 200 ms[15]. An eye-tracking study found that the gaze duration of smokers on smoking-related pictures was longer than that on the control pictures

suggesting a bias in the maintenance of attention on smoking-related cues[1]. Another study, however, reported bias in initial orienting of attention: active smokers showed a greater attentional bias toward smoking-related cues in short SOA of 200 ms but not in trials with a longer SOA of 550 ms[19]. One study found attentional bias both in initial orienting (stimuli presented for 200 ms) and in maintenance of attention (stimuli presented for 2000 ms)[20]. Individual differences in smoking behavior may moderate the effects and may explain some inconsistencies in the findings. For instance, a history of unsuccessful quit attempts influenced attentional bias to smoking-related stimuli, but not at longer stimulus presentations[2].

This attentional tendency may be involved in maintaining drug-seeking behavior and may also precipitate relapse after quitting. The incentive-sensitization theory[21] states that the mesotelencephalic dopamine reward system becomes sensitized by repeated use of addictive drugs, and in turn, gives these drugs and drug-related stimuli an incentive salience. This makes the perceptual and mental representation of these stimuli also highly salient and capable of capturing attention. With repeated drug use the act of drug-taking and drug-associated stimuli, gradually become more and more desirable, which evolves into obsessive craving and this is manifested behaviorally as compulsive drug-seeking and drug-taking.

In a related psychopharmacological model of attentional bias in drug-abusers[22] it is proposed that due to increased dopamine release, attentional bias to drug-related cues will first activate craving for the drug of abuse, and then attentional bias and craving begin to reciprocally modulate each other. This theory has gained some support in recent research[1, 23]. Franken's model further suggests that attentional bias may maintain the addictive behavior by enhancing the perception of drug-related cues in the environment, increasing drug-related cognitions for the cues and making it difficult to draw attention away from them. Finally, the attentional resources left for competitive cues are depleted because of the limited capacity of attention. Since this process is involuntary, it is difficult for the addict to apply attentional resources to prevent relapse[22]. To summarize, smoking is associated with enhanced processing of smoking-related

stimuli, and this processing may be affected by stimulus presentation-time. This processing is also assumed to be important in the maintenance of drug, and in the relapse to smoking after quitting.

Attentional control is the ability to use executive functioning to selectively keep focus on task-relevant stimuli and to hinder interference from distracting, task-irrelevant stimuli[24]. The efficiency of this inhibition function of attentional control may be reduced in high-anxious individuals, who as compared to low-anxious individuals, found it difficult to inhibit processing of task-irrelevant threatening stimuli on an anti-saccade task, thus having impaired inhibition[25]. This suggests that attentional control might help reducing anxiety by disengaging a person's attention from threat. The impaired attentional control in anxious individuals is conceptualized as the disruption of the balance between two attentional systems, the goal-driven and the stimulus-driven attentional systems[26]. Because of the increased activation of the stimulus-driven attentional system and decreased functionality of the goal-directed attentional system, anxious individuals process threat-related stimuli to a higher degree[27].

Individual variation in attentional control may determine the presence or absence of attentional threat bias. For example, individuals high in trait anxiety and low in attentional control showed enhanced processing of threat-related stimuli (probably because of the deficit in their voluntary attentional system) whereas those with high trait anxiety but better attentional control were able to disengage their attention from threat-related cues in a spatial-cueing task[28]. Similarly, individuals with high trait anxiety and poor attentional control had difficulty in ignoring task-irrelevant threat-related emotional pictorial stimuli[29]. In healthy volunteers low attentional control was associated with the distracting effect of task-irrelevant emotional cues[30]. In a dot-probe task, high posttraumatic stress symptoms were associated with threat-related attentional bias in trials with longer SOA (500 ms), suggesting difficulty in disengaging from threat stimuli. In trials with short SOAs (150 ms), however, attentional control moderated the relationship between the stress symptoms and threat bias; participants with high stress symptoms and high attentional control were able to disengage and shift their attention from the threat stimuli[31]. Consistently, in

children with good ability to regulate attention, threat-related bias was unrelated to anxiety symptoms. In this study, the SOA of 500 ms was used in a dot-probe task that used images of neutral, happy and angry facial expressions[32]. Similar attentional bias to threatening words in those with low attentional control has also been observed in studies using emotional Stroop task in individuals with general anxiety symptoms[33] and attachment anxiety[34]. In conclusion, individual differences in attentional control may influence the processing of task-irrelevant threatening stimuli.

The present study will extend this previous research of the association between attentional bias and attentional control by investigating the moderating role of attentional control on smoking-related attentional bias in smokers. This issue has not been addressed before. We will, first, replicate previous findings of attentional bias to smoking-related stimuli using three different stimulus presentation-times (SOAs), and then will examine whether attentional control moderates the association between smoking and smoking-related attentional bias.

In this experiment, the pictures were presented in three SOAs, that is, 100 ms, 500 ms, and 900 ms to examine whether smokers have attentional bias to smoking-related pictures in initial orienting and / or in the maintenance of attention. Previously, attentional bias in smokers to such pictures in a visual probe task has been investigated using long stimulus exposure durations such as 500 ms or 2000 ms[2, 16, 20] which may not provide an indication of attentional bias in initial orienting. Our study uses much shorter stimulus duration of 100 ms which is likely to reflect initial orientation in attention. The two longer SOAs, that is, 500 ms and 900 ms may reflect maintenance of attention on smoking-related cues. We hypothesized that smokers would show an attentional bias in initial orienting and in maintenance of attention to smoking-related cues; that is, attentional bias would be evident in all three SOAs in smokers. We also hypothesized that attentional control would moderate the association of attentional bias to smoking-related cues, such that smokers with low attentional control would have greater bias to smoking-related stimuli as compared to those with high attentional control.

# Methods

## Participants

Participants were Leiden University students who were recruited through advertisements and they participated in the study in exchange for a partial fulfillment of course credits or a small financial compensation. Inclusion criteria were an age between 18 and 35 years, right-handedness, normal or corrected-to-normal vision, fluency in Dutch or English, and no current or lifetime history of any psychiatric or neurological disorder. Smokers had to smoke at least 10 cigarettes per day for more than 1 year. Selection criteria for non-smokers were never having experimented with smoking.

## Materials

### *Visual dot-probe task*

To program a dot-probe task, we used the same stimuli as were used in Bradley et al.[2]. The stimuli consisted of 16 colored smoking-related pictures (e.g., a woman smoking a cigarette, an ashtray with a cigarette next to it) paired with a photograph of a similar matching scene that did not include any cigarette-related content (e.g., a woman applying lipstick, a bowl with a pen next to it). Additional eight picture-pairs unrelated to smoking were used for practice trials. The task consisted of two blocks: a practice block and an experimental block. The practice block included 16 trials; if the participant consecutively made 8 correct responses they were directed to the experimental block which consisted of 288 trials (of which 96 were filler trials). Each trial started with a black central fixation cross on a white background for 500 ms. It was followed by an inter-stimulus interval of 500 ms, after which a picture-pair was presented. Then, a probe in the form of either "one dot" or "two dots" appeared in the position of one of the pictures. Participants were instructed to press as fast and as accurate as possible the upward arrow key on the computer keyboard if they saw the one-dot probe, and the downward arrow key if they saw the two-dot probe. There were three presentation-times (SOAs) for the picture-pair (100 ms,

500 ms, 900 ms). Congruency (probe occurring in the location of the smoke-related or the non-smoking related picture), probe type (one or two dots), probe position (left or right), and SOA were fully counterbalanced. Picture-pairs were chosen randomly. The inter-trial interval varied randomly between 400 ms and 1000 ms. Unlike in the study by Bradley et al.[2] the trials with different short and long SOAs occurred in a random order in blocks of 48 trials. After each block there was a break that lasted 40 seconds. Intermixing short and long SOA trials randomly in a block would reduce the likeliness that participants form temporal expectations for the target stimuli[19]. Half of the smoking-related pictures were congruent with the location of the probe, whereas the other half were not. Additionally, in half of the trials the probe was presented in the left side of the screen and in the other half on the right side. The task took overall about 15 minutes to complete.

### *Attentional Control Scale*

The attentional control scale (ACS) is a 20-item self-report questionnaire[28]. It assesses the ability to focus attention and resist unintentional shifting to irrelevant or distracting information (e.g., my concentration is good even if there is music in the room around me), to shift attention while avoiding unintentional focusing on irrelevant information (e.g., it is easy for me to read or write while I'm also talking on the phone), and to flexibly control thought (e.g., I can become interested in a new topic very quickly when I need to). All items are scored on a 4-point Likert scale from '1' (almost never) to '4' (almost always) with higher scores indicating better attentional control. Some items are reversed scored.

### *Positive and Negative Affect Schedule*

The positive and negative affect schedule (PANAS) is a self-report questionnaire. It consists of 20 items, 10 assessing participant's positive affect (PA) and the other 10, negative affect (NA). It is rated on a 5-point scale (0 = not at all, 4 = extremely). PA represents the extent to which an individual experiences pleasurable engagement with the environment. Examples of emotions indicative of high PA are excitement, determination, and alertness. NA

shows the extent to which an individual shows subjective distress and unpleasurable engagement. Thus, emotions such as irritability, distress, and hostility manifest high NA[35]. The reliability and validity of PANAS have been found to be adequate in previous research[36].

## Procedure

Participants who responded to the advertisement were first screened by telephone or email for eligibility to participate in the study. On arrival, participants were given brief verbal instructions on all of the tasks that they would be participating in, after which they signed a written informed consent. It was followed by a standardized protocol that included detailed instructions on how to do the tasks. In about 35-minute testing session participants were required to complete two computerized tasks and to fill in a number of questionnaires. They were taken to a quiet, well-lit experimenter chamber and seated 40-45 cm from the computer screen to complete a visual probe task and to fill in the ACS. The tasks were designed in e-prime (v.2) and were presented on a 17-inch CRT monitor. After completing the computerized tasks, participants filled in a number of questionnaires that were used to collect their demographic data, smoking behavior, and baseline mood. Participants received either monetary rewards or course credits for their participation.

This study was approved by the Ethics Committee of the Institute of Psychology at Leiden University and was carried out in compliance with the Helsinki Declaration.

## Data Reduction and Statistical Analyses

Data with erroneous responses (2.5 %) and reaction times (RTs) of the filler trials were discarded (33 %). Outliers were removed by, first, excluding from the analyses all RTs less than 200 ms and greater than 2000 ms (0.2 %). Then, RTs more than 3 standard deviations (SDs) above or below each participant's mean were excluded (1.2 %). Smokers and non-smokers were significantly different in number of errors and outliers ($ps < 0.001$) with smokers

having greater number of errors and outliers. However, there were no differences in the errors on congruent and incongruent trials ($p > 0.05$) and on trial type.

After data cleaning, preliminary analyses were conducted to ensure no violation of the assumptions of univariate and multivariate tests. Participants' characteristics were evaluated by independent-samples t-test and chi-square test for independence. Cohen's d was used as a measure of effect size for significant associations. For each participant, mean RT was calculated for both the congruent and the incongruent trials in all three SOA conditions. Attentional bias score was then calculated for each participant by subtracting the congruent trials from the incongruent ones, and these bias scores were calculated separately for each SOA condition. A positive value, thus, reflects faster RTs when the probe replaces smoking-related stimuli. Overall attentional bias was calculated for each participant by averaging their bias scores representing the three SOAs. We will use the following abbreviations: AB100ms, AB500ms, AB900ms, and overall AB. A multivariate analysis of variance (MANOVA) was run on the bias scores to examine the difference between smokers and non-smokers in attentional bias to smoking-related pictures presented at three different durations. To examine group differences in overall attentional bias, an independent-samples t-test was run. The relationship between attentional bias and attentional control was further explored using Pearson product-moment correlation coefficient. These analyses were followed by running separate correlations for smokers and non-smokers. Finally, we conducted separate hierarchical linear regressions for overall AB and then separately for AB100ms, AB500ms, and AB900ms, in order to examine the moderation of attentional control on attentional bias and smoking. For each regression analysis, the dependent variable was the attentional bias score, the predictor was smoking status, and the moderator was the score on the ACS. The moderator was centered to the mean to reduce multicollinearity[37]. The first model of linear regression included smoking status. The second model added attentional control, and the third model included the product variable representing the interaction between smoking status and attentional control. For two participants (a smoker and a non-smoker) the z-score of the mean attentional bias index on some

stimulus exposure conditions and on overall AB was above 3. Thus, we first ran the analyses without these outlying cases, and then repeated all the analyses in the whole sample [a]. All analyses used an alpha level of .05. Analyses were run in PASW (V. 17.0) for windows.

# Results

Forty-three students (19 non-smokers, 24 smokers; age-range: 18-35 years; Mean = 22.5 years, SD = 4.0) participated in the experiment. Table 1 shows that smokers and non-smokers were not different significantly on demographic and clinical variables and attentional control (*p*s > 0.05).

***Table 1. Participants' characteristics***

| | **Non-smokers** | | **Smokers** | | ***p*** |
|---|---|---|---|---|---|
| | N = 19 | | N = 24 | | |
| Age (Mean, SD) | 21.5 | 4.0 | 22.9 | 4.6 | ns |
| Gender, female (N, %) | 14 | 74 | 16 | 67 | ns |
| Education (N, %) | | | | | ns |
| -basic | 13 | 68,4 | 15 | 62.5 | |
| -intermediate | 5 | 26,3 | 9 | 37,5 | |
| -high | 1 | 5.3 | 0 | 0 | |
| PANAS-PA† (Mean, SD) | 31.4 | 7.9 | 31.0 | 6.2 | ns |
| PANAS-NA† (Mean, SD) | 14.0 | 4.1 | 14.2 | 4.0 | ns |
| ACS† (Mean, SD) | 54.9 | 9.2 | 53.3 | 7.3 | ns |

*$p < 0.05$
†PA: scores on the positive affect sub-scale of the PANAS; NA: scores on the negative affect sub-scale of the PANAS; ACS: Attentional control scale
††ns: non-significant

## Group Differences in Attentional Bias to Smoking-Related Pictures

MANOVA showed a trend of smoking status on attentional bias in the 900 ms SOA condition ($F_{(1, 39)} = 3.1$; $p = 0.08$; partial $\eta^2 = 0.07$) while a non-significant effect on the 500 ms ($p = 0.1$) and 100 ms ($p = 0.2$) SOA conditions. However, the pattern of the association between smoking status and attentional bias was similar for all three SOAs. In the 900 ms SOA condition, smokers had

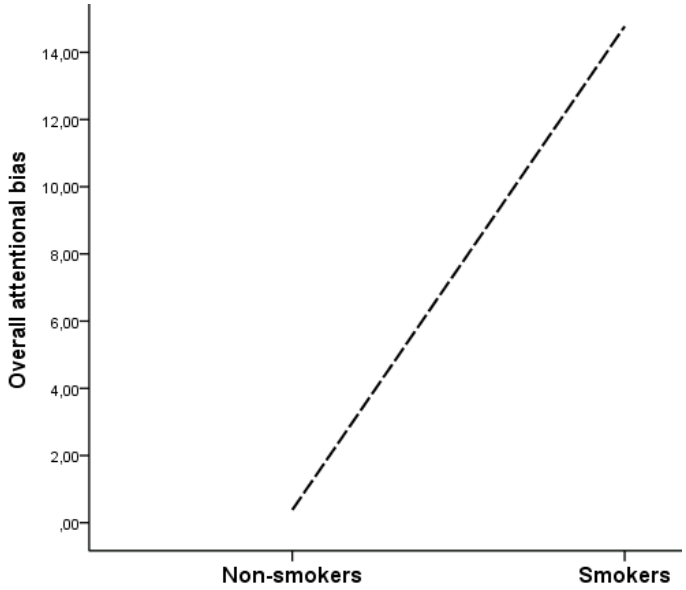


***Figure 1a. Attentional bias to smoking-related stimuli in smokers and non-smokers***

larger bias score (M =17.0; SD = 30.7) for the smoking-related pictures than non-smokers (M =1.6; SD = 23.7). A significant group difference was found for overall AB ($t_{(39)} = -2.4$; $p = 0.02$; Cohen's d = -0.8) with smokers having larger bias score (M = 14.8; SD = 18.3) than non-smokers (M = 0.4; SD = 19.7). See figure 1a.

## The Relationship Between Attentional Control and Attentional Bias

Pearson product-moment correlation indicated that attentional control was significantly but negatively correlated with AB100 ms (r = -0.46; *N* = 40; *p* = 0.003) and with the overall AB (r = -0.31; *N* = 40; *p* (two-tailed) = 0.054). There was no correlation of attentional control with AB500ms and AB900ms (*p*s > 0.05). Separate correlations for smokers and non-smokers revealed that in

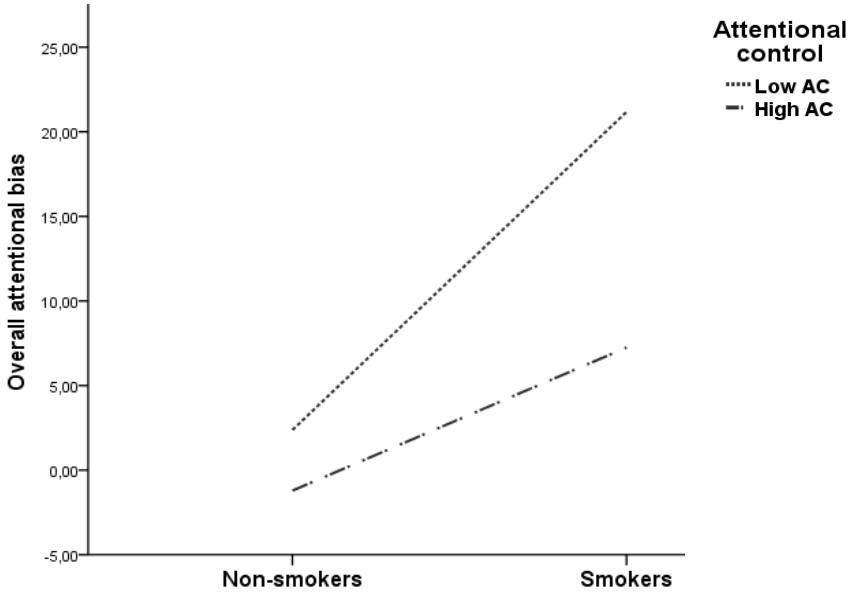


***Figure 1b. Smoking-related attentional bias in smokers and non-smokers with high and low attentional control***

smokers attentional control was negatively correlated with AB100ms (r = -0.42; *N* = 22; *p* (two-tailed) = 0.054) and with overall AB (r = -0.42; *N* = 22; *p* (two-tailed) < 0.051). In non-smokers, attentional control was negatively correlated with AB100ms (r = -0.46; *N* = 18; *p* (two-tailed) = 0.053). Other correlations of attentional control with AB500ms and AB900ms were non-significant in both groups (*p*s > 0.05). Figure 1b shows the mean overall attentional bias scores for the smoking groups with low and high attentional control. As can be seen that

smokers with low attentional control have high attentional bias to smoking-related pictures than those with high attentional control, and smokers have high overall attentional bias than non-smokers.

Table 2 shows the results of linear regression models. Regression analysis with AB100ms as the dependent variable showed that the first model with smoking status as predictor explained no significant variance in attentional bias ($p > 0.05$). In the second model when we added attentional control, 27.8 % of significant overall variance was explained in the dependent variable ($R^2$ change = 0.26; $p = 0.001$). The third model that added the interaction term of smoking status and attentional control, did not account for a significant variance in AB100ms ($p > 0.05$). Regression analyses with AB500ms and AB900ms were non-significant ($ps > 0.05$). Regression analysis with overall AB as the dependent variable showed that the first model with smoking status explained 13.0 % of significant variance in overall AB ($p < 0.05$). The second model with attentional control explained an additional 7.0 % of the variance in the outcome variable, showing a trend ($R^2 = 20.0$; $p = 0.08$). The final model with the interaction term was non-significant ($p > 0.1$) [b].

| *Table 2. Predictors of attentional bias* | | | | | |
|---|---|---|---|---|---|
| | **R2** | **R2 Change** | **B** | **SE** | **β** |
| **Overall attentional bias** | | | | | |
| **Model 1** | .13 | .13* | | | |
| Smoking status | | | 14.4 | 6.0 | .36* |
| **Model 2** | .20 | .07 | | | |
| Smoking status | | | 13.0 | 5.9 | .33* |
| Attentional control | | | -0.7 | 0.4 | -.27 |
| **Model 3** | .22 | .02 | | | |
| Smoking status | | | 13.0 | 5.9 | .33* |
| Attentional control | | | -0.3 | 0.5 | -.14 |
| Interaction of smoking status and attentional control | | | -0.7 | 0.8 | -.18 |
| **Attentional bias (100 ms)** | | | | | |
| **Model 1** | .02 | .02 | | | |
| Smoking status | | | 8.7 | 10.7 | .13 |
| **Model 2** | .28 | .26*** | | | |
| Smoking status | | | 5.2 | 9.4 | .08 |
| Attentional control | | | -2.2 | 0.6 | -.51*** |
| **Model 3** | .29 | .01 | | | |
| Smoking status | | | 5.2 | 9.4 | .08 |
| Attentional control | | | -2.6 | 0.8 | -.61** |
| Interaction of smoking status and attentional control | | | 0.9 | 1.2 | .15 |
| **Attentional bias (500 ms)** | | | | | |
| **Model 1** | .01 | .01 | | | |
| Smoking status | | | 7.3 | 11.3 | .10 |
| **Model 2** | .05 | .04 | | | |
| Smoking status | | | 6.1 | 11.3 | .09 |
| Attentional control | | | -0.9 | 0.7 | -.21 |
| **Model 3** | .06 | .002 | | | |
| Smoking status | | | 6.1 | 11.4 | .09 |
| Attentional control | | | -0.7 | 0.9 | -.17 |
| Interaction of smoking status and attentional control | | | -0.4 | 1.4 | -.06 |
| **Attentional bias (900 ms)** | | | | | |
| **Model 1** | .07 | .07 | | | |
| Smoking status | | | 15.4 | 8.9 | .27 |
| **Model 2** | .07 | 0 | | | |
| Smoking status | | | 15.4 | 9.1 | .27 |
| Attentional control | | | -0.002 | 0.6 | -.001 |
| **Model 3** | .08 | .01 | | | |
| Smoking status | | | 15.4 | 9.2 | .27 |
| Attentional control | | | 0.3 | 0.8 | .09 |
| Interaction of smoking status and attentional control | | | -0.7 | 1.2 | -.13 |
| *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ | | | | | |

# Discussion

We investigated attentional bias to smoking-related pictures in smokers and non-smokers. The pictures were presented for 100 ms, 500 ms, and 900 ms. We also examined the moderating role of attentional control on attentional bias to smoking-related pictures in the groups.

The main findings of the study were that smokers had higher *overall* attentional bias score than non-smokers. No significant group differences were observed when pictures were presented for 500 ms and 100 ms, whereas the difference between smokers and non-smokers in attentional bias was a trend when pictures were presented for a longer stimulus duration of 900 ms. These findings, though showing a trend, are suggestive of a bias in the maintenance of attention, but not in initial orienting. We did not find a moderation or interaction of attentional control on attentional bias to these stimuli. However, we did find a strong, negative correlation of attentional control with attentional bias to smoking-related stimuli presented for 100 ms and with the overall attentional bias score. Smokers with low attentional control have high overall attentional bias and attentional bias to smoking-related pictures presented for 100 ms. This suggests that the effect of attentional control on attentional bias is more prominent when stimuli are presented briefly. Such negative correlation, though, was also found for non-smokers when stimuli were presented for 100 ms. Thus, the data indicate that in individuals with low ability to regulate attention, *involuntary* attentional capture by smoking-related cues is increased. Later in the discussion, we would mention a possible reason of attentional bias in non-smokers for smoking-related pictures presented at a duration of 100ms.

Our research is in agreement with the attentional maintenance or disengagement model because it suggests that smokers have difficulty to disengage their attention from smoking-related picture once fixated on it. Several studies investigating smoking-related attentional bias have found evidence for a bias in maintenance of attention but not in initial orienting[1, 15]. Bias in maintenance of attention has also been reported in studies in alcoholics

and other drug users. For example, in heavy social drinkers, attentional bias for alcohol-related cues displayed for 200 ms was not evident, however, it was apparent at longer stimulus durations of 500 ms and 2000 ms[23]. However, few studies found evidence of attentional bias, both, in initial orienting and in the sustained attention[2, 20]. This discrepancy in findings may be due to smokers made quit attempts in those studies[2, 16].

The negative correlation between attentional control and attentional bias to smoking-related pictures presented for 100 ms indicates that the present results are also consistent with research showing initial orienting in attention to smoking-related cues[19] but only in smokers with low attentional control. Such association, however, was found for non-smokers as well. One explanation of these results could be that a bias to smoking-related stimuli presented for 100 ms may have been induced in non-smokers at the time of screening (when they were asked questions about their smoking behavior, which may have made smoking-related stimuli more salient), but only in those with low attentional control. This statement can be supported by a study showing that when non-smokers were aware of the presence of smoking-related stimuli in the experiment, they displayed the same attentional bias as the smokers, but not when they were unaware[38].

The neurobiological mechanisms underlying smoking-related attentional bias are largely unknown. The incentive salience that smoking and smoking-related stimuli have acquired by repeated nicotine use makes the dopamine reward system sensitized, which, in turn, makes these stimuli highly salient and capable of capturing attention, leading to drug-seeking and drug maintenance with repeated exposure to the drug[21]. It has been shown that attenuating dopamine levels in smokers by acute tyrosine and phenylalanine depletion, was associated with the reduction of attentional bias overtime to smoking-related words[39, 40]. Moreover, the reduction of dopamine levels by $D_2/D_3$ dopamine antagonist haloperidol reduced the enhanced brain activation associated with attentional bias to smoking-related pictures, leading to no-difference in brain activation between smokers and non-smokers[41]. Similarly, the increase in attentional bias and the activation of associated brain areas was

associated with the administration of dopamine $D_2/D_3$ receptor agonist pramipexole dihydrochloride in high compulsive stimulant-dependent individuals[42]. At a speculative level, these studies can be extended by investigating group differences in the reduction or increase of attentional bias and related brain activation as a result of decreasing or increasing dopamine levels by administering dopamine antagonist/ agonist in smokers with low and high attentional control. Further, nicotine deprived smokers show greater processing bias[43], thus it would be helpful to experimentally manipulate craving to examine the effect of attentional control on the processing of these cues when there is an increased urge to smoke. Moreover, using eye tracking or event-related potential measures, the present research can be replicated and extended to investigate, for example, in more detail whether individual differences in attentional control modulate attentional bias in initial orienting to smoking-related cues or in maintenance of attention on these cues. The incentive-habit theories of addiction that are supported by studies showing that low levels of nicotine dependence have been associated with high attentional bias for smoking-related cues[18] can be further investigated taking into account individual differences in attentional control.

Our study suggests that there may be differences among smokers in their attentional processing of smoking-related cues, in their vulnerability to smoking, and their risk of relapse after quitting, and these may be mediated by their ability to control attention. Thus, the present results may have implications for understanding the mechanisms by which smokers relapse to smoking after quitting.

These results may be evaluated in light of the following limitations. Firstly, nicotine deprivation was not manipulated, so urge to smoke may not be very high in many participants which may have polluted the results because variables such as recency of smoking may vary across smokers. Secondly, we recruited participants who smoked 10 or more cigarettes per day, thus, not controlling for variation in smoking behavior between light and heavy smokers. Despite these limitations, this study is important because it investigates smoking-related attentional bias while taking into account attentional control.

This issue has not been addressed before. Another merit of the study is that we were able to assess participants' mood, given that smoking is closely associated with negative mood[44] which may have an effect on attentional control[45].

To summarize, regardless of their attentional control, the present study indicates that smokers seemed to direct their attention to smoking-related pictures when presented under conditions where multiple shifts in attention were possible. However, when the stimulus presentation-time was short, smokers showed reflexive and automatic attention to smoking-related stimuli only when they had low attentional control. (Similar association between initial orienting in attention and attentional control in non-smokers may be due to their awareness of the presence of smoking-related stimuli in the experiment). However, this later finding has been shown only by correlation, and the univariate and multivariate analyses and regression models did not show any interaction or moderation between attentional control and attentional bias.

This study may have important implications for smoking cessation. For example, attentional bias modification (ABM) may be most suitable for smokers low in attentional control and may reduce attentional bias for smoking-related stimuli thus resulting in alleviating craving in addicted smokers; however, a single training session of ABM may not produce desired effects[13]. Moreover, individuals with low ability to regulate attention may have hypervigilance to smoking-related cues, and may represent a risk group for smoking relapse. Following attention training that aimed at strengthening attentional control, smokers with more pronounced bias and poor attentional control may more likely achieve abstinence and less likely relapse.

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