Psychopharmacology (2013) 229:187–197
DOI 10.1007/s00213-013-3098-5

ORIGINAL INVESTIGATION

Automatic approach bias towards smoking cues is present in smokers but not in ex-smokers

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Received: 6 November 2012 / Accepted: 27 March 2013 / Published online: 19 April 2013

Abstract
Rationale Drug-addicted individuals show automatic approach tendencies towards drug-related cues, i.e., an approach bias (ApB). Nevertheless, little is known about ApB in tobacco smokers and about the presence of ApB after smoking abstinence.
Objectives We investigated ApB to smoking cues in heavy tobacco smokers versus never-smokers and studied its relation to smoking characteristics and craving. Second, we compared ApBs of heavy smokers with biases of abstinent heavy smokers.
Method A group of current heavy smokers (n=24), ex-smokers who were abstinent for at least 5 years (n=20), and never-smokers (n=20) took part in the experiment. An indirect smoking approach avoidance task was performed, in which participants were required to respond to pictures of smoking and neutral cues by pulling (approach) or pushing (avoid) on a joystick, according to the content-irrelevant format of the picture (landscape or portrait). Craving scores were examined using the Questionnaire of Smoking Urges.
Results Heavy smokers showed an ApB for smoking cues compared to ex-smokers and never-smokers, which correlated positively to craving scores. There were no group differences in ApB scores for ex-smokers and never-smokers.
Conclusion These results suggest that ApBs for smoking cues are present in heavy smokers and decrease after long-term successful smoking cessation.

Keywords Addiction · Smoking · Smoking cessation · Implicit cognition · Approach bias · Approach avoidance task

Abbreviations

ApB	Approach bias
AAT	Approach avoidance task
QSU	Questionnaire of smoking urges

Introduction

A paradox in addictive behaviors is the continuation of drug use despite known long-term negative outcomes (Stacy and Wiers 2010). Most cigarette smokers strongly desire to quit, but few succeed, with 80 % of smokers relapsing within 1 year after their supposedly last cigarette (Hughes et al. 2008). Why some people are able to quit smoking successfully, whereas others are not and relapse, remains poorly understood. One important factor for relapse may be the degree to which smoking cues trigger a motivational reaction to smoke again, which happens largely outside

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conscious awareness (Ferguson and Shiffman 2009). This reaction is hypothesized to develop during the transition from voluntary to compulsive usage, due either to sensitization to drug cues (Robinson and Berridge 1993, 2003), habitual stimulus–response learning (Robbins and Everitt 1999; Tiffany 1990), or both (Mogg et al. 2005). Additionally, addiction has been described as a disorder of disrupted self-control over automatically triggered impulses to use (Baler and Volkow 2006). Together, as formulated by dual process models, both an overactive approach-oriented motivational system and a less sufficient regulatory control system may lead to compulsive continuation of a drug, without explicitly wanting this (Bechara 2005; Wiers et al. 2007).

Experimental evidence for motivational cue reactivity in addiction comes from research on automatic biases in several drug-dependent populations (see Stacy and Wiers 2010 for a review). In these studies, substance users show automatic selective attention to drug-related as compared to neutral cues (attentional bias) as well as the tendency to approach these cues faster rather than avoid them (approach bias, ApB), which is typically not seen in control groups. Attentional bias and ApB are measured by means of various computerized implicit reaction time (RT) tasks, in which participants' RT biases are assessed without explicitly asking participants. Such tasks are considered implicit or automatic if the instruction is indirect (i.e., participants are largely unaware of the task's outcome measures) or if the outcome measures meet at least one of a set of properties: being fast, goal-independent, or not directly controllable (De Houwer 2006; Stacy and Wiers 2010). Because of these criteria, implicit measures are less susceptible to social desirability than explicit measures and could measure automatic processes that lie outside of conscious awareness (De Houwer 2006). For example, Huijding and de Jong (2006) provided evidence that implicit measures better predict more automatic aspects of behavior, whereas explicit measures better estimate controlled behavior.

Over the last decade, a wealth of studies has focused on attentional biases in tobacco addiction. First, tobacco smokers have been shown to be slower in responding to smoking-related words compared to neutral words in a smoking Stroop task (Drobes et al. 2006; Munafo et al. 2003, 2005; Waters et al. 2003b), suggesting distraction by smoking cues. Moreover in pictorial visual cue tasks, smokers have shown to fixate longer on smoking cues compared to neutral cues (Bradley et al. 2008; Chanon et al. 2010; Mogg et al. 2003; Munafo et al. 2005; Waters et al. 2003a). However, only a few studies have concentrated on automatic action tendencies elicited by tobacco cues by studying the ApB. So far, five studies using the Stimulus–Response Compatibility (SRC) task have been reported, in which participants move a manikin towards (approach) and away from cues (avoidance) on a computer screen. At the start of each trial, the manikin is positioned either above or below the target stimulus. Approach/avoidance movements are to be made by moving the manikin downward or upward (or vice versa if the stimulus is below the target) with button presses (arrow pointing up/down). Smokers have been shown to move the manikin faster towards smoking cues than towards neutral cues and, hence, reveal a smoking ApB (Bradley et al. 2004, 2008; Mogg et al. 2003, 2005; Thewissen et al. 2007).

The incentive sensitization theory of addiction suggests a common underlying mechanism of attentional bias and ApB. All drugs release dopamine in the mesocorticolimbic system, a response that becomes sensitized after repeated drug use. Because of Pavlovian drug cue–reward associations, drug cues acquire incentive sensitization and consequently both grab the drug user's attention and elicit approach behavior (Robinson and Berridge 1993, 2003). Indeed, the strength of smoking attentional bias and ApB in smokers was positively correlated in two studies (Mogg et al. 2003, 2005), whereas this relation was not pursued in a third study measuring both automatic biases in a smoking and a never-smoking control group (Bradley et al. 2008). Despite the common mechanism of the phenomena, there are also differences. Probably the most important difference between the two biases is that, although the mechanism of attentional biases for cigarettes most likely lies in attentional capture (Chanon et al. 2010), the ApB is unique in that it embodies direct motor movements towards drug cues. While motor movements have to be compatible with individuals' own interpretation of actual approaching and avoiding (Watson et al. 2012), they are of particular interest as they might represent incentive sensitization to a drug. In animal models, sensitization is operationalized as locomotor activity in reaction to drugs or drug cues over the course of recurrent but intermittent drug supply (Mead and Stephens 1998), whereas in humans, such an operationalization has not yet been described. Given that smoking is a highly rewarding motor skill and smokers recently showed activation in action-related brain areas while watching smoking cues (Wagner et al. 2011), it is surprising that only little research on automatic action tendencies for smoking cues in cigarette smokers has been conducted.

In this study, smoking ApBs were studied with a recently developed approach avoidance task (AAT). Originally, in studying biases for fearful stimuli (Rinck and Becker 2007), the AAT has been successfully implemented to measure automatic approach avoidance action tendencies in addiction. The AAT has at least two benefits over the SRC. First, the participants' movements are accompanied with a visual zooming function: the pictures increase and decrease in size upon an approach movement (pulling a joystick) or an avoidance movement (pushing a joystick), respectively. In this way, the combination of pull/push movements with visual feedback during AAT better resembles the approach and avoid tendencies towards and away from oneself than the upward and downward movements on the SRC (Krieglmeyer and Deutsch 2010). Second, whereas in the SRC participants are explicitly instructed to move the manikin towards or away from drug-related or drug-unrelated stimuli in separate blocks, the AAT makes use of *irrelevant feature instruction*. Participants are asked to respond to a feature that is irrelevant to the task, namely the format instead of content of the stimuli. ApB is calculated by the RT difference between pushing and pulling cues (drug related or neutral). In this way, the AAT is relatively implicit in both outcome measure as well as instruction, which makes it less likely that participants are aware of the task and, hence, more likely to measure more automatic processes (De Houwer 2003). So far, ApBs measured with the AAT have been shown in heavy drinkers (Wiers et al. 2009), alcohol-dependent patients (Ernst et al. 2012; Wiers et al. 2011), heroin abusers (Zhou et al. 2012; though this study used a *relevant feature instruction*), and in cannabis users (Cousijn et al. 2011), whereby drug users pull faster than push cues of the abused drug compared to a nonaddicted control group. As yet, it remains unknown whether smokers reveal smoking ApBs on the AAT against a control group, which was the first goal of the present study.

Both the attentional and approach bias have been associated with motivational measures of drug use and clinical measures. For example, there is an accumulation of evidence that smokers' attentional bias and ApB for cigarettes correlate positively with craving scores (Mogg et al. 2003, 2005; Waters et al. 2003a; Watson et al. 2013) and predict relapse (Janes et al. 2010; Waters et al. 2003b) as well as smoking behavior (Waters and Feyerabend 2000). Moreover, manipulating automatic biases by bias modification training programs can, in turn, influence drug motivations and relapse. For example, Attwood et al. (2008) showed that increasing attentional biases in cigarette smokers led to more craving for tobacco, and modification of ApB for alcohol in alcohol-dependent patients resulted in decreased rates of relapse against placebo-training groups (Eberl et al. 2013; Wiers et al. 2011). These studies show that automatic biases may play a causal role in craving, drug taking, and relapse. Researching automatic tendencies is, thus, particularly valuable as they form a potential target for the treatment of smoking addiction.

Whether the causation also goes the other way around, if automatic biases are decreased when drug taking is ceased, remains an open question. There is evidence that immediate smoking abstinence increases reinforcing properties of smoking and attentional bias for smoking words (Waters and Feyerabend 2000), whereas after 2 weeks of cessation, smoking reinforcement (Lussier et al. 2005), craving, and withdrawal symptoms (Yoon et al. 2009) decline. Whether automatic biases likewise reduce after long-term drug abstinence is largely unknown. According to the incentive salience model of Robinson and Berridge (1993, 2003), sensitization to drugs is (semi-)permanent, which could imply that they serve a causal role in relapse. Dual process models of addiction also suggest that drug-seeking tendencies remain but emphasize that successfully refraining from a drug requires the ability and willingness to control these tendencies (Wiers et al. 2007). Various studies on smoking cessation techniques have used attentional bias (but not ApB) as an outcome measure, with conflicting results. On the one hand, smokers have been shown to be able to decrease motivational cue reactivity by cognitive strategies such as cognitive reappraisal (Littel and Franken 2011) and bias modification training (Attwood et al. 2008). Conversely, Pavlovian extinction training in which drug cues are presented to smokers but remain unreinforced have been shown to decrease craving but not attentional bias in smokers (Kamboj et al. 2012). Overall, these studies provide first evidence that it is possible to decrease automatic biases, although the mechanisms behind this are poorly understood and direct evidence for ApB is lacking.

Moreover, it is unknown whether smokers who have been abstinent for years still reveal automatic biases. Studies measuring automatic biases in former smokers are scarce and provide contradictory results. Munafo et al. (2003) found that ex-smokers, who had been abstinent for over 4 years, have diminished attentional bias for smoking cues, suggesting that biases can fade away. Nonetheless, other studies with a similar design did not find direct RT differences between ex-smokers and smokers (Munafo and Johnstone 2008; Munafo et al. 2005; Nestor et al. 2011). Interestingly, Nestor et al. found that smokers have increased mesolimbic brain activity while watching smoking cues compared to ex-smokers, whereas prefrontal areas were more active in ex-smokers. Since these brain areas are involved in reward and cognitive control, respectively, this suggests that cue reactivity decreases after cessation, parallel to increased cognitive control. To date, no studies have investigated approach tendencies after long-term smoking cessation, which was the second goal of this study.

Therefore, the aims of the present study were twofold: first, we examined whether heavy smokers would have an ApB for smoking cues, compared to a never-smoking control group and whether these scores related to self-reported craving. We expected smoking ApB to be larger in smokers than in controls and positively related to craving. Then, since the question remains whether ex-smokers who deliberately quit their heavy smoking still reveal an approach bias for cigarette cues, it was our second aim to compare ApBs in ex-smokers with never-smokers and heavy smokers. Although the literature on implicit or relatively automatic biases in ex-smokers provides conflicting results, we expected ApBs of ex-smokers to be smaller than of smokers and to be reduced after longer abstinence.

To diminish influencing variables other than abstinence between ex-smokers and smokers, the two groups were screened on smoking characteristics (duration of smoking >5 years, amount of cigarettes per day >15 cigarettes per day). We also assessed smoking attitudes (in ex-smokers in retrograde perspective, attitudes on when they were still smoking) to study potential motivational differences of such attitudes in smokers and ex-smokers. To inform the mechanism of ApB, we correlated ApB scores with smoking characteristics in smokers and ex-smokers. Previous studies showed a positive relation of attentional biases and smoking consumption (Waters and Feyerabend 2000) and of approach bias with cannabis addiction severity (Cousijn et al. 2011). Based on this, we hypothesized that the strength of approach bias was positively related to smoking in heavy smokers and ex-smokers. Furthermore, since addiction has been associated with increased impulsive personality traits (Everitt et al. 2008; Verdejo-Garcia and Perez-Garcia 2007), we compared the three groups on the Barrett Impulsiveness Scale (BIS). Impulsiveness is proposed to be related to reward sensitivity and lack of response inhibition in addiction (Dawe et al. 2004), but little is known about the relation between drug action tendencies and self-reported impulsiveness. To investigate whether current impulsiveness and self-control were related to the strengths of ApB, BIS subscales were correlated with ApB in each group. For smokers, we hypothesized the smoking ApB to be related with the BIS total score. In ex-smokers, we had particular interest in correlating ApB with the more cognitive subscales of BIS: *self-control impulsiveness*, and *cognitive instability impulsiveness*. We expected that ex-smokers who scored lower on these scales—reflecting higher levels of self-control and cognitive stability—would show a lower smoking ApB.

Methods

Participants

Twenty-four current cigarette smokers (mean age ± SD=35.54±10.35 years, 11 women), 20 ex-smokers (mean age ± SD=41.75±7.38 years, ten women), and 20 never-smokers (mean age ± SD=37.40±SD=10.04 years, nine women) were recruited via an online advertisement. Due to a programming failure, two ex-smokers were presented with 29 % of trials presented in the AAT but were nevertheless included into the study's analyses.[1] Groups were matched for age, gender, and years of education (all $p>0.09$, ns; see Table 1). Smokers were required to have smoked at least 15 cigarettes per day for a period of at least 5 years. Ex-smokers were considered eligible if they used to smoke more than15 cigarettes per day in their smoking period, were abstinent for a minimum of 5 years, and had not undergone nicotine replacement or other therapy to quit smoking. The never-smoking group never smoked more than two cigarettes over their lifetime.

Participants were required to have normal vision, speak German fluently, be right-handed as confirmed by the Edinburgh handedness inventory (Oldfield 1971), and have no history of drug abuse or psychiatric illnesses according to DSM-IV criteria, as screened with the M.I.N.I. plus an International Neuropsychiatric Interview, German translation (Sheehan et al. 1998). Alcohol use was examined with the Alcohol Use Disorder Identification Test (AUDIT), and AUDIT scores above 8 were excluded (Saunders et al. 1993). Pack years were calculated by $\text{pack years} = \text{number of cigarettes/day} \times \text{years of smoking})/20$, with 20 being the size of a common pack of cigarettes. This measure integrates the duration of smoking with the number of cigarettes and leads to a standardized value for measuring smoking consumption over a period of time (e.g., Nestor et al. 2011). The study was approved by the Ethical Committee of the Charité, Universitätsmedizin Berlin.

Procedure

To increase craving, smokers were abstinent of tobacco smoking for at least 2 h prior to the experiment. After given informed consent, questionnaires were filled out on a computer, following AAT performance. After completing the task, participants were paid, debriefed, and thanked for their time and assistance.

Questionnaires

Tobacco dependence was assessed by means of the Fagerström test of nicotine dependence (FTND; Heatherton et al. 1991). Smokers filled out the questionnaire about their current use (mean score ± SD=5.08±1.18) and ex-smokers filled out the FTND with retrograde perspectives of their smoking period (mean score ± SD=4.00±1.41). Before the task, smokers and ex-smokers completed the brief Questionnaire of Smoking Urges (QSU brief; Cox et al. 2001), which distinguishes two subscales: *strong desire to smoke* and *relief from negative effects*. To measure impulsiveness, the Barratt Impulsiveness Scale, version 11 (Patton et al. 1995) was used, distinguishing the following six first-order factors: *attention*, *motor*, *self-control*, *cognitive complexity*, *perseverance*, and *cognitive instability impulsiveness*. Furthermore, participants completed the Beck Depression Inventory (BDI) to assess mood (Beck et al. 1996) as well as the Decision Balance Scale for smoking (DBS; Velicer et al. 1985) to measure motivational (pros) and

[1] Excluding these two ex-smokers from the analyses still results in a significant interaction effect of image type × group ($F(1, 59)=5.10$, $p=0.009$, $\eta^2=0.147$) on the 2 (image type)×3 (group) mixed ANOVA.

Table 1 Demographic and smoking characteristics of heavy smokers, ex-smokers, and never-smokers

	Heavy smokers, n=24, 11 females (42 %)		Ex-smokers, n=20, 10 females (50 %)		Never-smokers, n=20, 9 females (45 %)			p value
	Mean	SD	Mean	SD	Mean	SD		
Demographics							$F(2, 61)$	
Age (years)	35.54	10.35	41.75	7.38	37.40	10.04	2.44	0.096
Digit symbol score	211.58	31.67	208.90	35.38	220.90	28.59	0.79	0.461
Years of education	15.10	3.21	15.05	3.62	16.85	4.07	1.64	0.202
Alcohol use (AUDIT)	3.50	2.38	2.35	1.81	2.80	1.88	1.75	0.183
EHI	91.11[a]	19.79	86.60	23.17	77.81	26.49	2.01[b]	0.141
BDI	21.35[a]	12.19	21.20	14.81	19.75	12.94	0.09[b]	0.913
Smoking characteristics					$t(42)$			
Age start smoking (years)	16.04	2.05	15.20	1.70	–	–	1.46	0.152
Smoking duration (years)	18.98	9.13	14.40	6.88	–	–	1.85	0.072
Cigarettes per day	22.71	5.32	24.50	9.04	–	–	−0.82	0.419
Pack years	22.75	14.40	18.95	14.27	–	–	0.88	0.387
Abstinence (years)	–	–	11.23	5.82	–	–	–	–
FTND	5.08	1.18	4.00	1.41	–	–	2.78	0.008**
DBS pro smoking	18.63	6.34	17.15	10.94	–	–	0.53[c]	0.598
DBS con smoking	18.50	8.02	18.60	9.43	–	–	−0.04	0.970
Craving							$t(20)$	
QSU total score	24.81[d]	11.27	0.00[e]	0.00	–	–	10.09	0.000***
QSU strong desire to smoke	19.14[d]	7.78	0.00[e]	0.00	–	–	11.28	0.000***
QSU relief from negative effect	2.27[d]	2.25	0.00[e]	0.00	–	–	5.68	0.000***
BIS impulsiveness					$F(2, 61)$			
BIS attention	9.13	2.15	9.35	2.85	8.30	2.30	1.04	0.358
BIS motor	15.17	3.38	14.40	2.50	14.30	3.01	0.03	0.976
BIS self-control	13.13	2.44	13.05	3.17	12.15	3.07	0.74	0.483
BIS cognitive complexity	12.21	2.26	11.40	2.04	11.25	2.69	1.09	0.343
BIS perseverance	6.46	1.79	6.90	1.80	6.95	1.84	0.49	0.613
BIS cognitive instability	5.79	1.53	5.55	1.28	4.90	1.29	2.36	0.103
BIS total	60.54	9.16	60.75	8.66	57.37	10.84	0.78	0.463

SD standard deviation, *AUDIT* alcohol use disorder identification test, *EHI* Edinburgh Handedness Inventory, *BDI* Beck Depression Inventory, *FTND* Fagerström Test of Nicotine Dependence, *DBS* Decision Balance Scale, *QSU* Questionnaire of Smoking Urges, *BIS* Barrett Impulsiveness Scale

*p<0.05; **p<0.01; ***p<0.001

[a] n=23

[b] $F(2, 60)$

[c] Since assumption of homogeneity of variance is violated, the degrees of freedom are 29

[d] n=21

[e] n=17

cognitive aspects (cons) of smoking (again, in ex-smokers in retrograde perspective).

Experimental task

A zoom version of the AAT was developed to measure implicit ApB. The paradigm required participants to push or pull a joystick (Logitech Attack TM 3) in response to the format of the cue (landscape or portrait) in which 50 % of the cues contained a smoking picture cue and 50 % contained a neutral picture cue (see Fig. 1 for a smoking avoidance trial). A picture format to response assignment was counterbalanced, with half of the participants pulling the joystick for landscape and pushing it for portrait cues, and vice versa. Participants had to respond to a picture within 3 s. Pulling and pushing the joystick increased and

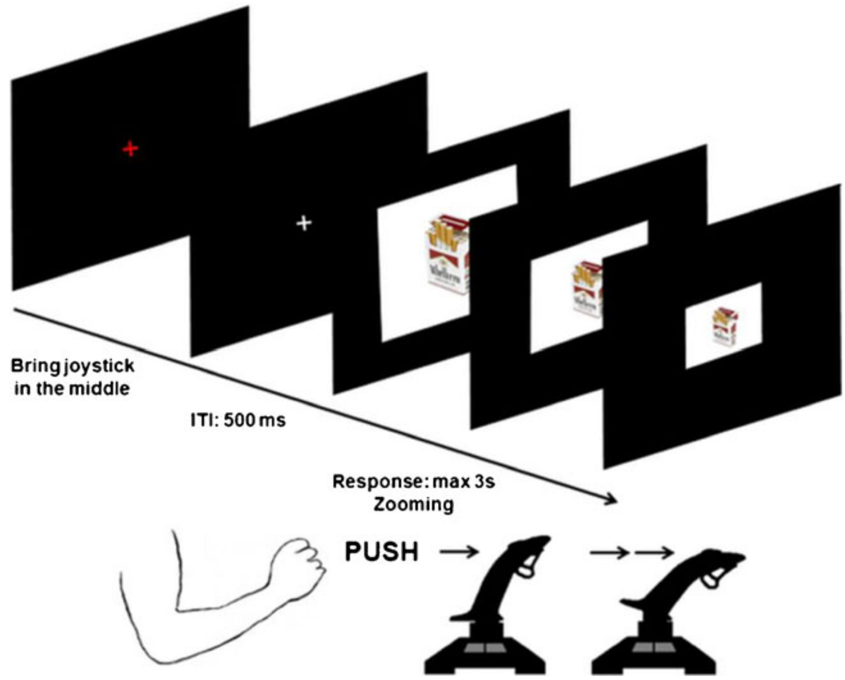

Fig. 1 Example of an avoidance trial of a smoking cue in the approach avoidance task, in which the cue zooms out

decreased the size of the cue, respectively. After 20 practice trials, 112 test trials were presented in three blocks, in which the distribution of stimulus content and image format was equal. There were 46 smoke-related cues and 46 color- and shape-matched neutral cues appearing pseudorandomly over the experiment, maximally allowing three cues with similar content or format in a row. Smoking cues consisted of individuals smoking cigarettes and close-ups of cigarettes or cigarette packs. The majority of cues were used in previous studies (e.g., Janes et al. 2010), whereas others were collected specifically for this experiment. Neutral cues were individuals holding matched items (such as pens or chop sticks) in their hands as well as close-ups of these items. Cues were presented against a black background and did not differ in luminance ($t(91)=1.29$, $p>0.05$), analyzed with an adapted script of the MATLAB SHINE Toolbox (Willenbockel et al. 2010). The experiment was run on a computer with a 17-in. LCD monitor, 60 Hz of refresh rate, and a resolution of 1,440×900 pixels. Stimulus presentation and the recording of response time were accomplished using MATLAB (r2010a; MathWorks Company) and Psychtoolbox v3 (Brainard 1997).

Statistical analyses

Responses that were missed or incorrect and RTs shorter than 300 ms or longer than three standard deviations (SDs) above the mean were discarded based on each participant's performance. RTs were measured from the onset of stimulus presentation until the joystick reached a maximum (push) or minimum (pull) position. Median RTs were used to calculate individual ApB scores, since they are less sensitive to outliers than mean scores (Cousijn et al. 2011; Rinck and Becker 2007; Wiers et al. 2009, 2010). For each participant, we calculated four RT scores for pulling and pushing smoking and neutral stimuli. Of these, ApB scores were calculated by subtracting median scores of pushing and pulling RTs (RTpush − RTpull) for each of the two stimulus types separately (see, e.g., Cousijn et al. 2011). Positive ApB scores indicate an approach bias (i.e., tendency to pull faster than push an image), whereas negative ApB scores indicate an avoidance bias (i.e., faster push than pull). Normal distributions of the four summary variables (smoking push, smoking pull, neutral push, and neutral pull) were tested with the Kolmogorov–Smirnov test. To test whether overall median RTs and error rates differed over smoking status, two separate one-way ANOVAs were performed with either overall median RTs or error rates as within-subject factor and group as between-subject factor. Moreover, a 2 (response type)×2 (image type)×3 (group) mixed ANOVA was performed to test whether the response type had an effect on ApB scores over groups.

To test for main effects of movement, a 2×3 mixed-factor ANOVA was performed, with movement (RTs push/RTs pull) as within-subject factor and group (smokers/ex-smokers/never-smokers) as between-subject factor. Then, since ApB scores were our variables of interest, a 2×3 mixed-factor ANOVA on ApB scores was used, with image type (smoking/ neutral) as within-subject factor and group (smokers/ex-smokers/never-smokers) as between-subject factor. Post hoc group comparisons on ApB scores were performed with two-way two-sample t tests. Because of specific hypotheses for smoking ApB scores being larger in smokers than in never-smokers and ex-smokers, one-way two-sample t tests were used for these two contrasts. Correlations between ApB scores, smoking characteristics, nicotine dependence, craving scores, and impulsivity scores were performed by means of bivariate Pearson's correlations.

Results

Sample characteristics

The groups did not differ in age, gender, alcohol usage, intelligence, years of education, or BDI scores (see Table 1 for demographic and smoking-related characteristics). Smokers and ex-smokers did not differ in the amount of cigarettes smoked per day, smoking duration, pack years, nor in motivational aspects of smoking on the DBS. However, there was a significant difference in FTND, with smokers being more tobacco-dependent than ex-smokers used to be ($t(42)=-2.78$, $p=0.008$), which may be a bias of the retrospective nature of the report in ex-smokers. Moreover, there were no group differences on BIS impulsiveness scores (see Table 1).

Approach bias scores in smokers, ex-smokers, and never-smokers

Group comparison

Homogeneity of variance assumption was not violated for any of the variables ($p>0.01$, see Table 1). Task difficulty was low, and exclusion of errors and trial outliers left 95.8 % of trials for further analyses. All variables were distributed normally ($p>0.25$). Results of the AAT for the three groups are demonstrated in Fig. 2. Both median RTs ($F(2, 61)=0.14$, $p=0.87$, ns) and mean error rates ($F(2, 61)=0.20$, $p=0.82$, ns) did not differ between groups. Moreover, there was no effect of response type on approach biases over the three groups: neither the response type × image type ($F(1, 58)=0.04$, $p=0.84$, ns) nor the response type × image type × group ($F(1, 58)=1.53$, $p=0.23$, ns) revealed a significant interaction effect. The 2×3 mixed-factor ANOVA on median RTs showed a main effect of movement ($F(1, 61)=5.47$, $p=0.023$, $\eta^2=0.082$), with pulling cues being faster (M ± SE=887.61±20.45 ms) than pushing cues (M ± SE=906.99±21.33 ms).

For ApB scores, the 2 (image type)×3 (group) mixed ANOVA revealed an interaction effect of image type × group ($F(1, 61)=3.67$, $p=0.031$, $\eta^2=0.107$). There were no significant main effects. In line with our hypothesis, smokers had stronger smoking ApB scores than never-smokers ($t(42)=1.74$, $p=0.044$; smokers: M ± SE=45.90±18.82 ms; never-smokers: M ± SE=2.83±14.82 ms), whereas ApB scores for neutral cues did not differ between the groups ($t(42)=0.28$, $p=0.78$, ns). Moreover, smokers had higher smoking ApBs than ex-smokers ($t(42)=1.72$, $p=0.047$; smokers: M ± SE=45.90±18.82 ms; ex-smokers: M ± SE=1.13±17.33 ms), but there was no difference in neutral bias scores ($t(42)=-1.11$, $p=0.27$). Neither smoking ApB scores were different between ex-smokers and never-smokers ($t(38)=0.75$, $p=0.94$, ns; ex-smokers: M ± SE=1.13±17.33 ms; never-smokers: M ± SE=2.83±14.82 ms) nor were neutral ApB scores ($t(38)=1.45$, $p=0.16$, ns; ex-smokers: M ± SE=42.78±17.64 ms; never-smokers: M ± SE=8.52±70.54 ms).

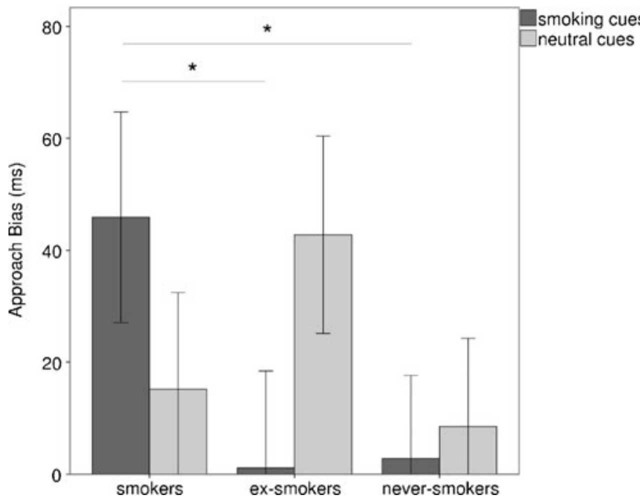

Fig. 2 Mean ApB score for smoking and neutral cues in smokers, ex-smokers, and never-smokers. Positive scores show faster tendencies to approach than avoid cues. Smoking ApB was larger in smokers compared to never-smokers and ex-smokers (both, $p<0.05$). Smokers' ApB for smoking cues and ex-smokers' ApB for neutral cues were larger than 0 (both, $p<0.05$)

Correlations

Smoking ApB and neutral ApB were correlated positively over all groups ($R=0.344$, $p=0.005$). Three participants in the smoking group did not fill out the QSU questionnaire, which left 21 smokers for craving analyses. As hypothesized, smokers' ApB scores for smoking cues correlated positively with total QSU craving scores ($R=0.56$, $p=0.008$). The correlation was particularly apparent for the subscore QSU *strong desire to smoke* ($R=0.50$, $p=0.022$), but not with subscore QSU relief from negative effect ($R=0.37$, $p=0.10$). Ex-smokers' ApB scores for smoking cues, although not deviant from 0 but with large variance (M ± SD=1.13±77.48, range −182.5 to 156 ms), correlated positively with smoking duration ($R=0.55$, $p=0.012$), with pack years ($R=0.55$, $p=0.013$), and the amount of cigarettes smoked per day by trend ($R=0.44$, $p=0.053$), but not with duration of abstinence ($R=0.11$, $p=0.635$). None of the groups showed a correlation between smoking bias and the FTND score ($p>0.16$), nor with BIS scores ($p>0.17$).

Since ex-smokers and controls did not report to crave cigarettes at all (i.e., all QSU scores were 0), we did not conduct correlations with this measure for these groups. In ex-smokers, BIS scores of *cognitive instability impulsivity*, measuring thought insertion and occurrence of running thoughts, correlated negatively with neutral ApB scores (R=−.53, p=0.016), with higher ApB scores correlating with lower *cognitive instability impulsiveness*. None of the correlations with other factors of BIS were significant (p>0.10).

Discussion

In this study, automatic action tendencies towards smoking cues were studied in smokers, ex-smokers and a never-smoking control group, as measured with the AAT (Cousijn et al. 2011; Rinck and Becker 2007; Wiers et al. 2009, 2010, 2011; Zhou et al. 2012). Compared to never-smokers and ex-smokers, smokers revealed an approach bias towards smoking-related images, which, as predicted, correlated with smokers' QSU craving scores.

The first result suggests that, for smokers, smoking cues are not only attention grabbing as has been shown in previous attentional bias paradigms (Mogg et al. 2003; Waters et al. 2003a), but are also eliciting automatic action towards them. This study has been the first to use the AAT for examining approach tendencies for smoking cues in a heavy-smoking group versus a never-smoking control group. Approach tendencies assessed with the AAT have been described in other addictions—in alcohol-dependent patients (Ernst et al. 2012; Wiers et al. 2011), heroin abusers (Zhou et al. 2012), and in cannabis users (Cousijn et al. 2011)—suggesting a common underlying pathway for approaching drug cues in addiction. Moreover, it has previously been shown that cigarette smokers exposed to smoking cues demonstrated increased activation in limbic brain areas (Nestor et al. 2011) as well as in action-related brain areas (Wagner et al. 2011). These findings support the hypothesis that mesolimbic neuroadaptations underlie the automatic approach bias for drug cues, as proposed by the incentive salience theory of addiction (Robinson and Berridge 1993, 2003). The positive correlations of smoking approach tendencies with explicit craving scores in smokers are also in accordance with the incentive salience theory that suggests that sensitization and craving are related. Nonetheless, this correlation has not been described in previous ApB literature on the AAT in addicted populations, neither in alcohol-dependent (Wiers et al. 2011) and heroin-dependent patients (Zhou et al. 2012) nor in heavy cannabis users (Cousijn et al. 2011). A possible explanation for this is that the time in between drug taking is generally shorter in smokers compared to other drug users. This may lead to higher levels of craving after a short period of time. Moreover, the alcohol- and heroin-dependent patients in previous studies were in treatment programs and already abstinent of the drug for several months, which may have influenced explicit craving ratings.

Despite the positive relation of ApB to craving in smokers, we did not find the hypothesized correlation with smoking characteristics (e.g., cigarettes per day and pack years). A reason for this may be that only heavy smokers who smoked more than 15 cigarettes per day participated in the study, hence reaching a ceiling effect in dependency. Conversely, smoking ApBs in ex-smokers did not correlate with craving (none of the ex-smokers reported to crave at all) but positively with pack years and smoking duration. In other words, ex-smokers who smoked more and longer in their past still demonstrated relatively strong approach tendencies for smoking. Given these results, it is possible that incentive salience to cues is present in most active users but decreases over abstinence. This suggests that further research clarifying the relationships between smoking cessation, ApBs, and craving could reveal interesting results. Importantly, although these first findings on smokers' ApB are supporting the incentive salience theory of addiction and make it likely that ApB is the result of Pavlovian conditioning, the study design does not rule out that other mechanisms also play a role in ApB. It could be that approach tendencies in drug abusers represent habitual responses to drug cues, or goal-directed behavior in which the approach tendencies were to be controlled by the expectancy of the rewarding outcome of the drug (Watson et al. 2012). Future studies are necessary to provide more insight into the mechanism of the ApB to drug cues.

The second result also confirmed our hypothesis: ex-smokers were expected to reveal a diminished approach bias for smoking cues, which was shown. Ex-smokers' smoking ApBs were significantly smaller than smoking ApBs of current smokers. Although the present study was the first to study ApBs in ex-smokers, the results are in line with a previous study on attentional bias (Munafo et al. 2003), that likewise revealed no difference in smoking cue vigilance between ex-smokers and never-smokers on a visual probe task. Still, other studies did not find a behavioral effect of diminished attentional bias in ex-smokers (Munafo and Johnstone 2008; Munafo et al. 2005; Nestor et al. 2011). Nevertheless, the results suggest that if mesolimbic neuroadaptations indeed underlie the ApB in current smokers, these neuroadaptations are not permanent but can reverse after cessation. In this way, our findings do not confirm Robinson and Berridge's prediction that neuroadaptations and senzitization are stable over abstinence. Further, the incentive salience theory also predicts craving and sensitization to be related (Robinson and Berridge 1993). In our study, none of the ex-smokers reported craving. It could, therefore, be that automatic biases decrease over abstinence as a result of decreased craving or decreased rewarding effects of drugs. Or, ex-smokers found strategies to diminish their approach behavior to smoking cues, as suggested by dual process models of addiction (e.g., Wiers et al. 2007). The groups did not differ in self-reported motivation to smoke (ex-smokers filled out these motivations in retrospect, on when they were still smoking) and, although hypothesized, neither in BIS impulsiveness scores. Smoker status as well as the absence of smoking ApB could, hence, not be explained by (previous) drug motivations or impulsiveness personality traits.

Some limitations of the study have to be considered. First, smokers and ex-smokers differed not only in their smoking status but also in their FTND scores, i.e., tobacco dependency scores. FTND scores were lower in ex-smokers compared to smokers, despite equal scores for smoking duration and number of cigarettes smoked. Since ex-smokers filled out the FTND questionnaire retrospectively, one explanation for the group difference in tobacco dependency is that memories of tobacco dependence were recollected less well. Moreover, if there was a true difference in addiction severity, it could not explain a double dissociation between smokers and ex-smokers. If the group difference was driven by the confounding factor severity only, one would expect the ex-smokers to show an intermediate effect between smokers and never-smokers rather than an effect double in size. A second limitation is that, besides excluding participants who sought treatment, ex-smokers were not asked about the way in which they quit their smoking behavior. To inform the approach bias in ex-smokers, future studies should ask ex-smokers whether they experienced withdrawal feelings, substitution behavior, or weight gain. Third, explicit ratings of valence of arousal for the stimuli were not assessed, which could have been interesting to correlate with bias scores as well as craving scores. It is expected that arousal for smoking cues is high in smokers, but that ex-smokers do not explicitly rate neutral cues as arousing. Last, in previous studies on automatic biases in smoking, bias scores have been shown to be higher in light smokers than in heavier smokers (Hogarth et al. 2003; Waters et al. 2003a). In these studies, bias scores turned out to be absent in individuals smoking more than 20 cigarettes per day. In our design, however, we only included heavy smokers. It is therefore possible that approach bias scores could be higher in smokers when lighter smokers were also included.

In summary, the study provides evidence for approach motor tendencies for smoking cues in smokers, but not in ex-smokers. ApB scores in smokers might be a relevant objective measure for motivational aspects of drug dependence. Since ApBs were shown to be a predictor for continuation of drug use in cannabis smokers (Cousijn et al. 2011) and retraining approach biases in bias modification training programs lead to lower relapse rates and improved treatment outcomes in alcohol-dependent patients (Eberl et al. 2013; Wiers et al. 2011), ApBs could be of clinical value in drug addiction. Individualized therapies could be developed for smokers who wish to quit. For example, when ApBs are high, therapies could specifically target cue reactivity and automatic processes and motivate smokers to perform cognitive training aimed at this purpose (Wiers et al. 2013).

Acknowledgments The study was supported by a grant from the German Federal Ministry of Education and Research: NGFN: 01GS08159 (Gallinat). The authors thank Georgina Torbet, Noah Gabriel Martin, and James Harwood for proofreading.

Conflict of interest None

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