



## Web-based Approach Bias Modification in smokers: A randomized-controlled study



Charlotte E. Wittekind<sup>a,\*</sup>, Daniel Lüdecke<sup>b</sup>, Barbara Cludius<sup>c</sup>

<sup>a</sup> LMU Munich, Department of Psychology, Clinical Psychology and Psychotherapy, Germany

<sup>b</sup> University Medical Center Hamburg-Eppendorf, Institute of Medical Sociology, Germany

<sup>c</sup> University Medical Center Hamburg-Eppendorf, Department of Psychiatry and Psychotherapy, Germany

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### ABSTRACT

Smoking is associated with automatic approach tendencies towards smoking-related stimuli. Therefore, it has been investigated whether training smoking individuals to consistently avoid smoking-related stimuli exerts positive effects on smoking behavior (Approach-Bias Modification [AppBM]). A web-based pilot study provided preliminary evidence for the effectiveness of AppBM in smokers; however, interpretability was constrained by several limitations. The aim of the present study was to replicate and extend previous findings. A web-based three group parallel (1:1:1) randomized-controlled study with adult smokers ( $N = 149$ ) was conducted (DRKS00011901). Upon completion of a baseline assessment, participants were randomized to either six sessions of AppBM or Sham training or a waitlist control group. In both trainings, participants were presented smoking-related and neutral pictures. While all smoking-related pictures were associated with pushing and all neutral pictures with pulling in AppBM training, the contingency was 50:50 in Sham training. Participants were re-assessed directly and six months after training. Primary outcome was daily cigarette consumption at follow-up. At follow-up, no significant group differences emerged, although AppBM training significantly reduced daily cigarette consumption directly after training. No consistent change of bias through AppBM training emerged. This study does not provide support for the long-term effectiveness of AppBM training as a stand-alone training in smoking.

*Pre-registration:* German Clinical Trials Register (DRKS00011901).

## 1. Introduction

### 1.1. Smoking: prevalence, health risks and treatment options

Although the prevalence of daily smoking has declined in the last decades, prevalence rates of approximately 6% (women) and 31% (men) are still high (Ng et al., 2014). Smoking is associated with severe negative health consequences and remains the major cause of preventable death (US Department of Health and Human Services, 2014). The majority of smokers is motivated to quit and has made at least one quit attempt within the last year (Centers for Disease Control and Prevention, 2017); however, only a minority of smokers uses smoking-cessation aids (Cokkinides, Ward, Jemal, & Thun, 2005; Shiffman, Brockwell, Pillitteri, & Gitchell, 2008) and unaided quit attempts achieve very low long-term prolonged abstinence rates of 3%–5% (Hughes, Keely, & Naud, 2004). But even if smokers use evidence-based smoking cessation interventions, such as counselling or nicotine

replacement therapy (Fiore et al., 2008), relapse rates are still high (Hartmann-Boyce, Chepkin, Ye, Bullen, & Lancaster, 2018; Mottillo et al., 2009). But why do so many smokers relapse despite the wish to stay abstinent and even after receiving evidence-based treatments? The lifelong risk of relapse can at least partly be explained by neurobiological processes (e.g., Everitt & Robbins, 2016; Koob & Volkow, 2016) and biased information processing (e.g., Stacy & Wiers, 2010), these explanations will be addressed in the following section.

### 1.2. Information processing in smoking

Regarding biased information processing, dual-process theories postulate the existence of two types of information processing that operate in a synergistic or antagonistic fashion (Deutsch & Strack, 2006; Wiers et al., 2007). One type of processing is fast, automatic and relies on associations in memory (impulsive system) while the other type is slow, deliberate and depends on cognitive capacities (reflective system,

\* Corresponding author. LMU Munich, Department of Psychology, Clinical Psychology and Psychotherapy, Leopoldstr. 13, 80802 Munich, Germany.

E-mail address: [charlotte.wittekind@lmu.de](mailto:charlotte.wittekind@lmu.de) (C.E. Wittekind).

Strack & Deutsch, 2004; for a critical discussion of dual-process theories see Keren & Schul, 2009). It is assumed that there is an imbalance between the two systems in favor of the impulsive system in addictive disorders. Repeated drug use such as smoking results in a sensitization of mesolimbic dopaminergic systems (Berridge & Robinson, 2016; Kalivas & Volkow, 2005; Koob & Volkow, 2016; Robinson & Berridge, 1993). As a consequence, smoking-related cues gain incentive salience and are processed preferentially which results in different information processing biases such as attentional biases (Bradley, Field, Mogg, & De Houwer, 2004; Cox, Fadardi, & Pothos, 2006; Mogg, Bradley, Field, & De Houwer, 2003; however, also see; Woud, Maas, Wiers, Becker, & Rinck, 2016) and automatic approach biases for smoking-related stimuli (Machulska, Zlomuzica, Adolph, Rinck, & Margraf, 2015; Wiers et al., 2013). Approach biases have been assessed by means of arm movements using the Approach-Avoidance Task (AAT, Rinck & Becker, 2007). The AAT rests upon the assumption that positive stimuli are related to faster arm flexion than extension and vice versa negative stimuli with faster arm extension than flexion (Chen & Bargh, 1999; Marsh, Ambady, & Kleck, 2005). During the task, pictures of varying content (e.g., smoking-related and smoking-unrelated) are presented on a computer screen and participants are instructed to either respond by pulling or pushing a joystick or computer mouse. Generally, the response direction depends on a non-affective dimension such as the format or color of the pictures. Thereby, it is assumed that the behavioral response is measured implicitly and not affected by response strategies (Rinck & Becker, 2007). Using an AAT with implicit instructions, automatic behavioral tendencies to approach smoking-related stimuli have been revealed (e.g., Machulska et al., 2015; Wiers et al., 2013).

### 1.3. Approach-bias modification in smoking

If it is true that approach biases are important for the maintenance of smoking, their direct manipulation should affect the substance use behavior. Therefore, trainings aiming at directly modifying behavioral approach biases have been developed (Approach Bias Modification [AppBM], Wiers, Rinck, Kordts, Houben, & Strack, 2010), in which participants are instructed to consistently avoid smoking-related stimuli by pushing them away and to respond to smoking-unrelated stimuli with pulling. Generally, AppBM trainings are compared to a Sham training condition in which 50% of smoking-related and 50% of smoking-unrelated stimuli have to be pushed and pulled, respectively. Two studies administered AppBM as a stand-alone or low-threshold intervention and revealed positive effects on smoking behavior (Machulska, Zlomuzica, Rinck, Assion, & Margraf, 2016) and short-term abstinence (Baird et al., 2017). In contrast, studies in which AppBM was administered as an add-on to Cognitive Behavioral Therapy, Cognitive Behavioral Therapy + AppBM did not yield higher abstinence rates at the 3-month (Kong et al., 2015) and 6-month follow-up (Wittekind, Reibert et al., 2019) compared to Cognitive Behavioral Therapy + Sham.

### 1.4. The present study

The high number of smokers worldwide, the severe health consequences and the low utilization of available treatment options pose a significant challenge for the health care system. In this regard, web-based trainings hold the potential to reach people that would otherwise not seek or receive professional help. Additionally, effective web-based trainings can easily and widely be distributed and are very cost-effective. In order to investigate whether AppBM can effectively be delivered over the internet, we conducted a pilot study in smoking which provided preliminary evidence that AppBM was more effective in reducing cigarette consumption, tobacco dependence, and compulsive smoking behavior compared to a waitlist control group (WLC) (Wittekind, Feist, Schneider, Moritz, & Fritzsche, 2015). However, interpretability of

results is restrained by several limitations (e.g., no Sham training condition, no long-term follow-up, no assessment of behavioral tendencies pre and post training). Therefore, the first aim of the present study was to replicate findings of the pilot study (Wittekind et al., 2015). More importantly, we wanted to extend previous findings by (a) including three conditions, namely AppBM training, Sham training, and a WLC group, (b) assessing long-term effects with a 6-months follow-up, and (c) assessing behavioral tendencies at all time points. We hypothesized that AppBM would lead to a significantly greater reduction of daily cigarette consumption (primary outcome) as well as tobacco dependence and compulsive smoking behavior (secondary outcomes) compared to the Sham and the WLC group at the 6-month follow-up. Based on the findings of our pilot study (Wittekind et al., 2015), we also expected that AppBM would be superior compared to both control groups regarding daily cigarette consumption, tobacco dependence and compulsive smoking behavior at post-test (secondary outcomes). Following the rationale of Cognitive Bias Modification (Koster, Fox, & MacLeod, 2009), AppBM should reduce approach biases to smoking-related stimuli and this reduction should mediate effects of AppBM on smoking behavior (Wiers et al., 2010). Therefore, we expected that only AppBM would reduce implicit approach biases for smoking-related stimuli. Furthermore, we expected that the effect of training condition on the primary outcome would be mediated by a change in bias. Finally, it is conceivable that there is a dose-response relationship between frequency of training and reduction of smoking behavior, although this relationship has not been found in previous studies (Weil, Feist, Moritz, & Wittekind, 2017; Wiers et al., 2015). Therefore, it was again assessed whether more training was related to better clinical outcome (i.e., daily cigarette consumption, tobacco dependence).

## 2. Methods

### 2.1. Participants, recruitment, and setting

Participants were included if they were between 18 and 70 years of age, currently smoking, had sufficient knowledge of the German language, and provided informed consent. Participants were excluded if they reported a lifetime diagnosis of schizophrenia, bipolar disorder or acute suicidal tendencies. In that case, participants were automatically excluded during the web-based baseline assessment. Participants were recruited online by means of smoking-related internet forums (German speaking), Facebook, the homepage of the division of clinical psychology and psychotherapy of the LMU Munich, the homepage of the division of clinical neuropsychology of the University Medical Center Hamburg-Eppendorf, and PsyWeb (<https://psyweb.uni-muenster.de>). Furthermore, flyers were sent to self-help groups, smoking cessation facilities and health insurances. Additional recruitment strategies were the publication of press releases and advertisements at the campus and via newsletters of the LMU Munich. The study was conducted completely web-based from March 2016 to May 2017.

### 2.2. Measures

All assessments were conducted web-based using questback® ([www.unipark.de/www](http://www.unipark.de/www)). The diagnostic AATs were assessed using the online version of the experimental software Inquisit® (Version 4, [www.millisecond.com](http://www.millisecond.com)). An overview of all assessments and measures is provided in the Supplementary Material.

### 2.3. Assessment of smoking-related information

Tobacco dependence was assessed with the 6-item Fagerström Test for Nicotine Dependence (FTND) (Heatherton, Kozlowski, Frecker, & Fagerstrom, 1991) and with the Cigarette Dependence Scale-12 (CDS-12, Etter, Le Houezec, & Perneger, 2003), which covers the diagnostic criteria of the DSM-IV and the ICD-10. To assess compulsive smoking

behavior, the subscale *compulsive drive* of the Obsessive Compulsive Smoking Scale (OCSS, Hitsman et al., 2010) was administered. Cronbach's  $\alpha$  for these scales in this study were  $\alpha = 0.74$ ,  $\alpha = 0.86$ , and  $\alpha = 0.61$  respectively. Commitment to abstinence was assessed using the Thoughts about Abstinence Scale (TAAS, Hall, Havassy, & Wasserman, 1990) in which participants have to choose one of six abstinence goals (1 = total abstinence, never use again; 2 = total abstinence but realize a slip is possible; 3 = occasional use when urges strongly felt; 4 = temporary abstinence; 5 = controlled use; 6 = no goal). Subsequently, participants were asked to rate on three 10-point scales their (a) desire to quit, (b) expected success in quitting, and (c) expected difficulty of quitting.

#### 2.4. Assessment of behavioral tendencies: Approach-Avoidance Task

To assess behavioral tendencies for smoking-related stimuli, an AAT with implicit instructions was administered at all assessments. Ten smoking-related and nine smoking-unrelated pictures<sup>1</sup> with either a blue or a yellow frame were presented in randomized order in the middle of the screen. Smoking-related pictures were taken from the picture set provided by Stippekohl et al. (2010) and the pilot study (Wittekind et al., 2015), smoking-unrelated pictures were taken from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1997) and the pilot study (Wittekind et al., 2015). Depending on the color of the frame, participants had to push or pull the pictures using the computer mouse (see Fig. 2). Each picture was presented twice, with a blue and yellow frame, such that half of the pictures had to be pushed and half to be pulled. By random assignment, one subgroup of participants was instructed to push blue and to pull yellow framed pictures ( $n = 72$ ), whereas the other subgroup should do the opposite ( $n = 77$ ). In total, 80 assessment trials were recorded (2 frame color [blue, yellow]  $\times$  2 picture type [smoking, neutral]  $\times$  2 repetitions  $\times$  10 pictures). Participants were asked to rate their current urge to smoke on a scale ranging from 0 to 100 before and after conducting the diagnostic AAT.

#### 2.5. Training conditions

In the two training conditions 10 smoking-related and 10 smoking-unrelated pictures, which had not been used in the diagnostic AAT, were presented. In the AppBM training condition smoking-related pictures were always framed with the color that was associated with pushing and smoking-unrelated pictures in the color that was associated with pulling. In the Sham training condition, half of the smoking-related and half of the smoking-unrelated pictures were associated with pushing, half with pulling (i.e., same contingency as diagnostic AAT). The set-up was similar to the diagnostic AAT, except that participants performed 160 training trials.<sup>2</sup> The total duration of each training session was approximately 5min. Participants were instructed to use the training as often as possible for four weeks. Use of training was tracked and in case participants had not trained for one week, we sent them a short reminder. The subjective evaluation of the training is provided in the Supplementary Material.

#### 2.6. Power calculation

Based on the findings of the pilot study, an effect of  $f = 0.175$  and an attrition rate of 40% was assumed for the sample size calculation of

<sup>1</sup> Mistakenly, nine instead of 10 smoking-unrelated pictures were presented (i.e., one neutral picture was presented twice).

<sup>2</sup> If the picture was moved in the wrong direction, an error message was presented and contrary to the diagnostic AAT, the picture only disappeared when the mouse was finally moved in the correct direction. Thereby, it was ensured that smoking-related pictures were always avoided during AppBM.

the primary outcome (number of cigarettes at the 6-month follow-up). Using G\*Power (Faul, Erdfelder, Lang, & Buchner, 2007), an  $\alpha$  of 0.05 and a  $\beta$  of 0.90 suggested a total sample size of 88 participants for the  $2 \times 2$  interaction effect. The drop out of 40% was added such that at least 147 participants had to be included. Data collection was terminated after the 151st participant had completed the baseline assessment.

#### 2.7. Design and procedure

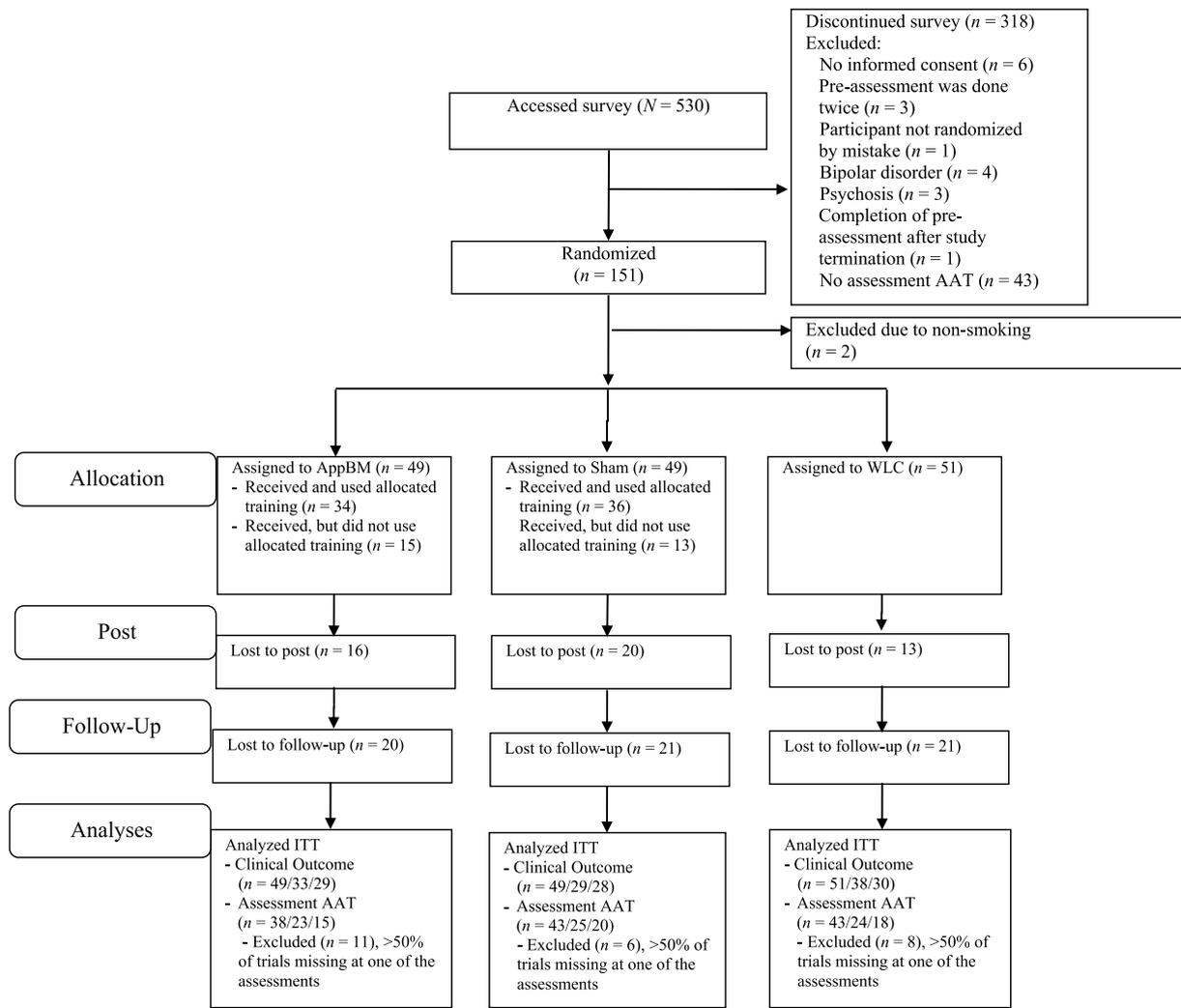
We conducted a web-based randomized controlled parallel-group trial (RCT). After completing both the baseline assessment and the diagnostic AAT (t0), participants were randomly allocated to one of the three conditions with a 1:1:1 allocation ratio. Participants who indicated that they did not smoke at pre assessment ( $n = 2$ ) were excluded from analyses after randomization (see Fig. 1). No important changes (e.g., changes of eligibility criteria, randomization ratio, duration of follow-up period, see Moher et al., 2010) were carried out after trial commencement. The random sequence was computer-generated by the first author using the program [www.randomizer.org](http://www.randomizer.org). Randomization of participants was conducted by the first author, so allocation was not concealed. After randomization, an email was sent to participants containing information whether they were assigned to a training condition or the WLC. Therefore, participants of the training conditions were blinded, but this was not possible for the WLC group. After the randomization email, participants of the WLC group were only contacted at the post- and follow-up assessment. To increase motivation to complete the assessments, they were informed at baseline that they would receive the training as well as additional material at follow-up. All participants were sent an email inviting them to complete the post-assessment and the FU-assessment. Participants were reimbursed for completing post- and follow-up assessment, with 10€ for each assessment. The study was registered at the German Clinical Trials Register (DRKS00011901) and approved by the Ethics Committee of the German Psychological Society (SM\_042013).

#### 2.8. Data reduction and reliability

Reaction times (RT) of the first mouse movement (initial RT) were analysed in the present study. For analyses, only RT data of correct trials were used. Trials were classified as incorrect when participants moved the mouse into the wrong direction or changed directions throughout the trial. Additionally, RTs faster than 100 ms or slower than 2.5 standard deviations above the group mean were excluded. If more than 50% of the trials were excluded at one of the assessments (pre, post, FU), RT data of that specific participant was not considered for analyses (see Fig. 1). After excluding these participants, the average number of missing trials was 13% at baseline, 11% at post-assessment, and 2% at follow-up with no significant differences between groups, all  $ps > .20$ . For each trial type and AAT effects, internal consistencies (Cronbach's alpha) were calculated (see Table 5). Internal consistencies for RTs of each category can mostly be considered excellent. Internal consistencies for AAT effects were substantially lower.

#### 2.9. Strategy of data analysis

Data were analysed using the IBM Statistical Package for Social Sciences (SPSS, version 24) and R Language for Statistical Computing (R Core Team, 2018). To assess baseline difference, independent one-way analyses of variances (ANOVA) were used for continuous and chi-square tests for categorical variables. We applied linear mixed effect models (lme4 package in R, Bates, Maechler, Bolker, & Walker, 2015) with repeated measure design to test the main hypotheses. These models include all available data and are not affected by randomly missing data, so missing data was not imputed (Gueorguieva & Krystal, 2004). For smoking-related dependent variables, Time (0 = baseline;



**Fig. 1.** Flow of participants. The numbers refer to the sample sizes at the pre-, post-, and follow-up assessments. AppBM = Approach-Bias Modification, AAT = Approach-Avoidance Task.



**Fig. 2.** Set-up of the diagnostic AAT. Participants were presented 20 practice trials, which were followed by 80 assessment trials. Each trial began with the presentation of a red fixation cross located in the middle of the screen. In order to start the trial, participants had to click on the fixation cross. Depending on the color of the frame, the picture had to be pushed or pulled. Pushing led to a decrease, pulling to an increase in picture size (i.e., blue is as-

sociated with pulling in the given example). This zoom function was included to reinforce the visual impression of approach and avoidance (Rinck & Becker, 2007). Finally, the picture disappeared as soon as the mouse cursor reached the upper or lower edge of the screen. If the mouse was moved in the wrong direction, an error message was presented, which, however, could be ignored by participants.

1 = post-test; 2 = follow-up), and Group (0 = WLC; 1 = Sham; 2 = AppBM) and their cross-level interaction Group x Time were entered as predictors in the models. To test our hypothesis that AppBM training would lead to a reduction of approach biases across time, AAT effects were predicted by Picture Type (smoking-related, smoking-unrelated), Time, Group (WLC, Sham, AppBM), and the interaction Group x Time x Picture Type. To investigate whether there was a dose-response relationship between frequency of training and clinical outcome (daily cigarette consumption, tobacco dependence), correlations (Spearman's rho) were calculated within the AppBM group. Intention-to-treat (ITT) analyses were conducted considering all participants who

completed the baseline survey and met inclusion criteria were used.<sup>3</sup>

### 3. Results

Sociodemographic and clinical information are summarized in Table 1. At baseline groups did not differ on any of the assessed

<sup>3</sup>Results of the per-protocol analyses including all participants who completed the pre-, post-, and follow-up assessment and used the training at least once are provided in the Supplementary Material.

**Table 1**  
Sociodemographic, smoking-related, and psychopathological information for the intention-to-treat-sample: means (SD) and frequencies.

Variable/time	AppBM (n = 49)	Sham (n = 49)	WLC (n = 51)	Statistics
Age (in years)	40.41 (13.87)	40.51 (13.48)	40.45 (13.46)	$F(2, 146) < 1, p = .999$
School education (years of school)	12.22 (1.25)	11.98 (1.45)	11.63 (1.54)	$F(2, 96.79) = 2.27, p = .109$
Gender (m/f)	17/32	21/28	21/30	$\chi(2) < 1, p = .683$
Cigarettes per day	16.94 (8.92)	15.82 (7.65)	16.86 (8.60)	$F(2, 146) < 1, p = .761$
Tobacco dependence (FTND) <sup>a</sup>	4.20 (2.53)	4.08 (2.63)	4.37 (2.90)	$F(2, 146) < 1, p = .863$
Tobacco dependence (CDS-12)	44.41 (7.76)	45.14 (7.08)	45.59 (8.22)	$F(2, 146) < 1, p = .743$
Compulsive drive (OCSS)	8.48 (2.47)	8.41 (2.27)	8.22 (2.34)	$F(2, 146) < 1, p = .837$
Smoking duration (in years)	21.87 (11.99)	21.84 (12.65)	21.73 (13.16)	$F(2, 146) < 1, p = .998$
Prior quit attempts (once/twice/three times/ > 3/none)	8/10/6/18/7	9/8/4/20/8	11/11/10/15/4	$\chi(6) = 5.76, p = .674$
TAAS abstinence goal <sup>b</sup>	2.73 (1.64)	2.20 (1.06)	2.20 (1.23)	$F(2, 94.63) = 2.08, p = .130$
TAAS desire to quit	7.71 (2.57)	8.02 (2.10)	8.02 (1.93)	$F(2, 146) < 1, p = .731$
TAAS expected success in quitting	5.24 (2.60)	5.49 (2.17)	5.67 (2.22)	$F(2, 146) < 1, p = .664$
TAAS expected difficulty of quitting	8.29 (1.53)	8.27 (1.60)	8.25 (1.47)	$F(2, 146) < 1, p = .995$
Motivation to quit <sup>c</sup>	2.43 (1.10)	2.33 (0.77)	2.18 (0.84)	$F(2, 95.38) < 1, p = .410$
Motivation to use training <sup>c</sup>	2.33 (0.90)	2.16 (0.92)	2.10 (0.92)	$F(2, 146) < 1, p = .441$
Conviction that training is helpful <sup>d</sup>	3.06 (0.92)	2.78 (0.82)	3.04 (0.98)	$F(2, 146) = 1.50, p = .227$
Psychiatric disorders (yes/no) <sup>e</sup>	17/32	20/29	16/35	$\chi(2) < 1, p = .607$
Application of other cessation strategies (yes/no) <sup>f</sup>	8/21	5/23	12/18	$\chi(2) = 3.50, p = .174$
Frequency of training	3.65 (4.61) range 1–18	5.03 (5.47) range 1–25	NA	$t(68) =  1.14 , p = .259$

Note. AppBM = Approach-Bias Modification; WLC = waitlist control group.

<sup>a</sup> Fagerström Test for Nicotine Dependence (0–2 = low dependence; 3–4 = low to moderate dependence; 5 = moderate dependence; 6–7 = moderate to high dependence; 8–10 = high dependence).

<sup>b</sup> Thoughts about AbstinenceScale (1 = total abstinence, never use again, 2 = total abstinence but realize a slip is possible, 3 = occasional use when urges strongly felt, 4 = temporary abstinence, 5 = controlled use, 6 = no goal).

<sup>c</sup> 1 = very motivated, 2 = rather motivated, 3 = partly motivated, 4 = little motivated, 5 = not motivated at all.

<sup>d</sup> 1 = very convinced, 2 = rather convinced, 3 = partly convinced, 4 = little convinced, 5 = not convinced at all. <sup>e</sup> from post to follow-up.

<sup>e</sup> During the baseline assessment, participants were asked whether they suffered from one of the following diagnoses (Substance Use Disorder; Depression; Anxiety Disorder; Obsessive Compulsive Disorder; Eating Disorder, Posttraumatic Stress Disorder; bipolar disorder and schizophrenia [both of the latter led to an automatic exclusion]; any other psychiatric disorder. Answers were combined to presence vs. absence of any psychiatric disorder).

<sup>f</sup> From post to follow-up.

variables. From those participants who indicated to suffer from a psychiatric disorder, 28 (53%) had a depressive disorder, six an anxiety disorder (11%), and 10 (19%) had both a depressive and an anxiety disorder, with no differences between conditions,  $\chi(6) = 6.65, p = .355$ .

### 3.1. Completion rate

The rate of participants who completed all assessments was 54% (AppBM: 57%; Sham: 47%; WLC: 57%) and did not differ between groups,  $\chi(2) = 1.34, p = .512$ . Completer and non-completer (i.e., at least one assessment missing) did not differ as to age, gender, education (years of school), most smoking-related variables, the motivation to use the training, and the conviction that the training would be helpful (all  $ps > .07$ ). However, completers had a less restrictive abstinence goal compared to non-completers (i.e., lower commitment to achieve permanent abstinence, as assessed with the item “abstinence goal” of the TAAS, see Measures),  $t(144.72) = |2.52|, p = .013$  (completers:  $M = 2.63, SD = 1.48$ ; non-completers:  $M = 2.09, SD = 1.12$ ) and a lower desire to quit,  $t(143.41) = |2.05|, p = .042$  (item #2 of the TAAS; completers:  $M = 7.59, SD = 2.46$ ; non-completers:  $M = 8.30, SD = 1.80$ ). Additionally, completers were less motivated compared to non-completers,  $t(147) = |2.05|, p = .042$  (completers:  $M = 2.45, SD = 0.91$ ; non-completers:  $M = 2.14, SD = 0.90$ ).

### 3.2. Intention-to-treat analyses: clinical outcome

#### 3.2.1. Long-term effects

Mean scores at post and follow-up are provided in Table 2. Results of the main analyses are summarized in Table 3. Our primary hypothesis that AppBM training would lead to a stronger reduction of daily

cigarette consumption compared to the control groups at follow-up was not confirmed. Unexpectedly, all groups showed a significant reduction of daily cigarette consumption from pre to follow-up. Regarding tobacco dependence, we found no evidence in our data that AppBM training was associated with a stronger reduction of tobacco dependence compared to the WLC. Thus, we could not confirm our second hypothesis. For the subscale compulsive drive of the OCSS, the Sham group showed a stronger reduction of compulsive drive compared to the WLC whereas no differences between the AppBM and the WLC emerged.

#### 3.2.2. Short-term effects

Regarding short-term effects, the AppBM group showed a stronger reduction of daily cigarette consumption compared to the WLC. One sample t-tests indicated that the reduction was significantly different from zero in the AppBM,  $t(32) = |2.89|, p = .007$ , but not in the WLC group,  $t(37) < 1, p = .709$ . Regarding tobacco dependence, as assessed with the FTND, the interaction Group x Time was not significant for the AppBM group; for the CDS-12 non-significant trends emerged for the Time x Group interactions. The AppBM group showed a stronger, but non-significant reduction of compulsive smoking behavior compared to the WLC.<sup>4</sup>

<sup>4</sup> Analyses regarding short- and long-term effects were repeated with severity of tobacco dependence as an additional predictor (low/moderate/light according to the FTND). However, none of the interactions containing the predictor severity was significant, all  $ps > .096$ .

**Table 2**  
Post and follow-up scores for smoking-related information for the intention-to-treat sample: means (SD).

Variable/time	Cigarettes per day		FTND		CDS-12		OCSS (compulsive drive)	
	Post	FU	Post	FU	Post	FU	Post	FU
<b>ITT</b>								
AppBM <sup>a</sup>	15.55 (8.59)	15.38 (10.21)	3.76 (2.62)	3.79 (2.82)	42.52 (8.25)	40.55 (11.32)	7.42 (2.08)	7.21 (2.94)
Sham <sup>b</sup>	15.00 (7.03)	14.43 (9.29)	3.63 (2.37)	3.71 (2.58)	43.21 (8.50)	41.71 (11.81)	7.79 (2.55)	7.18 (3.27)
WLC <sup>c</sup>	16.32 (8.52)	15.33 (8.40)	3.92 (2.62)	4.37 (2.97)	45.08 (6.81)	42.67 (9.56)	7.76 (2.17)	7.77 (2.99)

FTND = Fagerström Test for Nicotine Dependence (0–2 = very low, 3–4 = low; 5 = medium, 6–7 = severe, 8–10 = very severe); CDS-12 = Cigarette Dependence Scale-12 (12 = low dependence up to 60 = high dependence); OCSS = Obsessive Compulsive Smoking Scale.

- <sup>a</sup> Sample sizes of the AppBM group at post,  $n = 33$ , and at follow-up,  $n = 29$ .
- <sup>b</sup> Sample sizes of the Sham group at post,  $n = 29$  ( $n = 30$  for the FTND), and at follow-up,  $n = 28$ .
- <sup>c</sup> Sample sizes of the WLC group at post,  $n = 38$ , and at follow-up,  $n = 30$ .

3.3. AAT effects: changes across time

AAT effects for each group are provided in Table 4. Contrary to expectations, the interaction Group x Time x Picture Type was neither significant at post-test ( $\beta = 28.22$ , 95% CI [-15.30–71.74],  $p = .204$ ) nor at follow-up ( $\beta = -13.06$ , 95% CI [-62.32–36.20],  $p = .603$ ). As AppBM did not consistently change bias scores and no significant group differences regarding our primary outcome (daily cigarette consumption) emerged at follow-up, we refrained from performing mediation analyses.

3.4. Training data: frequency of use and effects on urge to smoke

The majority of participants used the training (AppBM group:  $n = 34$  [69%]; Sham group:  $n = 36$  [73%]). The number of training sessions varied greatly in both groups with no significant differences between groups (see Table 1). No dose-relationship was found as training frequency was not related to any of the clinical outcomes at post-test: daily cigarette consumption,  $r = .060$ ,  $p = .761$ ; tobacco dependence (FTND),  $r = 0.075$ ,  $p = .704$ , and CDS-12,  $r = 0.195$ ,  $p = .319$ ; compulsive drive,  $r = -0.070$ ,  $p = .723$ ; and follow-up: daily cigarette consumption,  $r = 0.164$ ,  $p = .455$ ; tobacco dependence (FTND),  $r = 0.286$ ,  $p = .186$ , and CDS-12,  $r = 0.199$ ,  $p = .362$ ; compulsive drive,  $r = -0.085$ ,  $p = .699$ .

4. Discussion

The aim of the present study was to test the effectiveness of a web-based AppBM in smoking. To this end, current smokers were recruited online and either randomized to AppBM training, Sham training or a waitlist control group. Training effects were assessed directly after the training phase of four weeks and at a 6-month follow-up.

**Table 3**  
Results of the linear mixed effects model for clinical outcome for the intention-to-treat-sample.

Fixed parts	Cigarettes per day			FTND			CDS-12			OCSS (compulsive drive)		
	B	CI <sup>a</sup>	p	B	CI	p	B	CI	p	B	CI	p
<b>ITT<sup>b</sup></b>												
Intercept	16.86	14.55–19.17	< .001	4.37	3.63–5.11	< .001	45.59	43.47–47.70	< .001	8.22	7.57–8.86	< .001
Time (t1)	0.10	-1.02–1.22	.862	-0.18	-0.59–0.22	.378	0.15	-1.33–1.63	.841	-0.35	-0.86–0.15	.172
Time (t2)	-2.02	-3.90–-0.13	.036	0.07	-0.53–0.66	.829	-1.94	-4.87–1.00	.197	-0.24	-1.13–0.64	.591
Sham x t1	-1.00	-2.69–0.70	.250	-0.07	-0.67–0.53	.819	-2.06	-4.29–0.18	.071	-0.28	-1.04–0.48	.470
AppBM x t1	-1.99	-3.63–-0.34	.018	-0.23	-0.82–0.36	.452	-2.11	-4.27–0.06	.057	-0.68	-1.42–0.06	.071
Sham x t2	-0.29	-3.01–2.42	.832	-0.52	-1.37–0.32	.225	-2.09	-6.32–2.15	.334	-1.12	-2.39–0.16	.086
AppBM x t2	0.28	-2.41–2.97	.838	-0.43	-1.28–0.41	.317	-1.79	-5.99–2.41	.403	-0.96	-2.22–0.30	.136

Note. <sup>a</sup> 95% confidence interval. <sup>b</sup> AppBM group:  $n = 49/33/29$ ; Sham group:  $n = 49/29/28$ ; WLC:  $n = 51/38/30$ . FTND = Fagerström Test for Nicotine Dependence (0–2 = very low, 3–4 = low; 5 = medium, 6–7 = severe, 8–10 = very severe); CDS-12 = Cigarette Dependence Scale-12 (12 = low dependence up to 60 = high dependence); OCSS = Obsessive Compulsive Smoking Scale; t1 = post-assessment; t2 = follow-up.

**Table 4**  
AAT effects for each combination of Picture Type, Response Direction, and Group for the intention-to-treat sample: means (SD).

Picture Type	Response Direction	AppBM <sup>a</sup>			Sham			WLC		
		Pre	Post	FU	Pre	Post	FU	Pre	Post	FU
Smoking	Push	522.17 (103.74)	534.26 (105.67)	497.80 (70.66)	512.395 (85.7924)	488.640 (75.3222)	503.13 (70.67)	528.71 (111.30)	518.75 (72.36)	531.69 (98.903)
	Pull	521.82 (103.72)	544.89 (97.38)	514.33 (74.48)	513.128 (90.2071)	490.760 (80.5978)	495.30 (60.61)	525.49 (103.58)	525.46 (84.67)	522.83 (92.69)
	<b>AAT effect</b>	<b>0.36 (51.04)</b>	<b>-10.63 (39.29)</b>	<b>-16.53 (50.25)</b>	<b>-0.73 (49.28)</b>	<b>-2.12 (38.69)</b>	<b>7.83 (49.58)</b>	<b>3.22 (47.02)</b>	<b>-6.71 (61.02)</b>	<b>8.86 (26.28)</b>
Neutral	Push	522.37 (97.39)	529.48 (106.68)	517.73 (87.65)	517.442 (79.70)	502.88 (91.37)	502.50 (71.52)	517.50 (95.49)	519.7 (65.79)	532.06 (103.42)
	Pull	528.32 (99.89)	556.09 (107.91)	520.13 (87.41)	517.91 (83.17)	507.14 (85.28)	504.40 (60.34)	527.21 (99.09)	521.50 (71.06)	528.75 (95.05)
	<b>AAT effect</b>	<b>-5.95 (38.75)</b>	<b>-26.61 (55.53)</b>	<b>-2.40 (60.82)</b>	<b>-.47 (40.039)</b>	<b>-4.26 (40.36)</b>	<b>-1.90 (28.40)</b>	<b>-9.7 (71.20)</b>	<b>-1.73 (47.86)</b>	<b>3.31 (38.95)</b>

Note: <sup>a</sup> sample sizes for the ITT sample are (pre/post/follow-up): AppBM: 38/23/15; Sham: 43/25/20; WLC: 43/24/18.

**Table 5**  
Internal Consistencies (Cronbach's  $\alpha$ ) for Each Combination of Response Direction and Stimulus Type Used in the AAT.

Time	Response Direction	Stimulus Type	Cronbach's $\alpha$
Pre	Pull	Smoking	$\alpha = .90$
Pre	Pull	Neutral	$\alpha = .91$
Pre	Push	Smoking	$\alpha = .93$
Pre	Push	Neutral	$\alpha = .91$
Pre	Push – Pull	Smoking	$\alpha = .39$
Pre	Push – Pull	Neutral	$\alpha = .22$
Post	Pull	Smoking	$\alpha = .91$
Post	Pull	Neutral	$\alpha = .92$
Post	Push	Smoking	$\alpha = .91$
Post	Push	Neutral	$\alpha = .92$
Post	Push – Pull	Smoking	$\alpha = .47$
Post	Push – Pull	Neutral	$\alpha = .44$
FU	Pull	Smoking	$\alpha = .87$
FU	Pull	Neutral	$\alpha = .86$
FU	Push	Smoking	$\alpha = .88$
FU	Push	Neutral	$\alpha = .93$
FU	Push – Pull	Smoking	$\alpha = .34$
FU	Push – Pull	Neutral	$\alpha = .50$

Note: Push – Pull = internal consistencies were calculated using difference scores (push – pull) for each stimulus within each category.

behavior are mediated by a change in bias (Grafton et al., 2017; MacLeod & Clarke, 2015); however, none of the smoking studies has found a significant mediation effect (Kong et al., 2015; Machulska et al., 2016; Wittekind, Reibert et al., 2019). The absence of a mediation effect might explain why AppBM was not superior to Sham in improving long-term clinical outcome in two studies (Kong et al., 2015; Wittekind, Reibert et al., 2019). However, it also raises the question whether behavioral approach biases are an important maintenance factor of smoking behavior as proposed by different theoretical accounts (Berridge & Robinson, 2016; Deutsch & Strack, 2006). In order to be able to test the theoretical assumptions, it is essential to reliably assess the proposed mechanisms of change. However, most implicit paradigms are plagued by low reliability (e.g., Lebel & Paunonen, 2011) and internal consistencies for AAT effects in the present study were unsatisfactory. As a consequence, it remains unresolved whether AppBM did not change behavioral tendencies or whether we were merely not able to assess any changes in bias reliably. It is imperative for future research not only to assess and report psychometric properties of implicit measures (Parson, Kruijt, & Fox, 2018), but also to develop more reliable experimental tasks. Alternatively, it is conceivable that effects of AppBM are mediated by different processes, for example, improvements in executive functioning (Heeren, Mogoşe, McNally, Schmitz, & Philippot, 2015; McNally, Enock, Tsai, & Tousian, 2013). If the latter were true, it might explain why Sham trainings performed surprisingly

well in studies conducted in other populations (R. W. Wiers et al., 2015; Wittekind, Bierbrodt, et al., 2019). It is important for future research to systematically investigate the working mechanisms of AppBM by also assessing cognitive processes other than behavioral tendencies such as executive functioning. However, as both control groups (i.e., Sham, WLC) improved from post to follow-up in the present study, training of another process seems an unlikely explanation. Rather, assessment reactivity (McCambridge & Day, 2008; Walters, Vader, Harris, & Jouriles, 2009) and motivation to change might explain why participants of the control groups reduced their smoking behavior at follow-up. Alternatively, the usage of other smoking cessation techniques seems a plausible explanation; however, when participants who indicated that they used alternative strategies were excluded from analyses, the pattern of results remained unchanged rendering this explanation unlikely.

#### 4.1. Limitations

Although the study holds several strengths, interpretation of findings is comprised by several limitations. First, dropout was high, only 54% of participants completed all assessment. Even though the attrition rate is high, it is comparable to previous web-based CBM studies conducted in samples with substance use (Elfeddali, de Vries, Bolman, Pronk, & Wiers, 2016; Wiers et al., 2015). In the present study, 60% of potential participants discontinued the baseline assessment which demonstrates how difficult it is to recruit the target population. Additionally, roughly one-third of participants who were randomized never used the training (see Fig. 1) and of those who used the training, a substantial proportion did not complete the assessments lowering statistical power. The high attrition rate and the low frequency of usage could be an indicator of low motivation and low acceptability of the training. Furthermore, quality of data could not be checked as no data integrity questions were included in the surveys though the rather good reliability of most questionnaires in the present study can be taken as indirect evidence for the quality of questionnaire data. In contrast, in the analyses of AAT data 25 out of 149 participants (17%) were excluded due to an excessive number of missing trials at one of the assessments and this proportion was substantially higher compared to previous studies (Machulska et al., 2015, 2016). For the remaining sample the number of missing trials was rather high which might indicate that the web-based assessment was related to a lack of motivation or concentration. However, the average number of missing trials was comparable to a study in which the mouse AAT was administered in person in a sample of smokers (Wittekind, Reibert et al., 2019). Another limitation refers to the reliance on self-report measures; however, this was unavoidable as the study was completely web-based. As a consequence, we were neither able to include biochemical verification procedures nor could we reliably assess psychiatric disorders. Additionally, we did not

obtain ratings for the pictorial stimuli used for training and assessment. Therefore, we do not know whether pictures were relevant and attractive for participants. As smoking-relevant cues might differ across individuals, training effects might be increased by using personalized stimuli.

#### 4.2. Conclusions

This study tested the effectiveness of web-based AppBM (compared to Sham and waitlist) on smoking behavior and tobacco dependence. Positive short-term effects as to smoking behavior were found in the AppBM group; however, reductions were rather small. No significant group differences emerged at the 6-month follow-up. Additionally, AppBM did not consistently change smoking-related biases and the reliability of the AAT was rather low. Therefore, future studies are needed to enhance the reliability and effectiveness of the AAT as an assessment and training tool. Furthermore, the combination of cognitive-behavioral interventions and AppBM training might produce larger and clinically relevant effects.

#### Declaration of interest

None.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.brat.2018.12.003>.

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