



Begh, R., Smith, M., Ferguson, S. G., Shiffman, S., Munafò, M. R., & Aveyard, P. (2016). Association between smoking-related attentional bias and craving measured in the clinic and in the natural environment. *Psychology of Addictive Behaviors*, 30(8), 868-875. DOI: 10.1037/adb0000231

Peer reviewed version

Link to published version (if available):  
[10.1037/adb0000231](https://doi.org/10.1037/adb0000231)

[Link to publication record in Explore Bristol Research](#)  
PDF-document

This article may not exactly replicate the final version published in the APA journal. It is not the copy of record. This is the accepted author manuscript (AAM). The final published version (version of record) is available online via American Psychological Association at <http://www.apa.org/pubs/journals/adb/index.aspx>. Please refer to any applicable terms of use of the publisher.

## University of Bristol - Explore Bristol Research

### General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:  
<http://www.bristol.ac.uk/pure/about/ebr-terms.html>

**Association between smoking-related attentional bias and craving measured in the clinic and in the natural environment**

## **Objective**

Previous studies have investigated the association between attentional bias and craving in laboratories, but ecological momentary assessment (EMA) may provide ecologically valid data. This study examines whether clinic-measured attentional bias is associated with noticing smoking cues, attention to smoking, and craving assessed by EMA and whether EMA-assessed cues and attention to smoking are associated with craving.

## **Method**

Secondary analyses of clinical trial data involving 100 cigarette smokers attempting to quit assisted by behavioural support and nicotine patch treatment. Two weeks prior to quitting, participants completed attentional bias assessments on visual probe and Stroop tasks.

Participants carried personal digital assistants for seven weeks thereafter, which administered random assessments of smoking cues, attention towards smoking, and craving.

## **Results**

Participants completed 9271 random prompt assessments, averaging 3.3 prompts/day. There was no evidence that clinic-measured attentional bias was associated with cues seen (visual probe: OR=1.00, 95%CI=0.99, 1.01; Stroop: OR=1.00, 95%CI=0.99, 1.00), attention towards smoking (visual probe: OR=1.00, 95%CI=0.99, 1.02; Stroop: OR=1.00, 95%CI=0.99, 1.00), or craving (visual probe: OR=1.00, 95%CI=0.99, 1.02; Stroop: OR=1.00, 95% CI=0.99, 1.01). EMA responses to seeing a smoking cue (OR=1.94, 95%CI=1.74, 2.16) and attention towards smoking (OR=3.69, 95%CI=3.42, 3.98) were associated with craving. Internal reliability was higher for the Stroop ( $\alpha=0.75$ ) than visual probe task ( $\alpha=0.20$ ).

## **Conclusions**

In smokers attempting cessation, clinic measures of attentional bias do not predict noticing smoking cues, focus on smoking, or craving. However, there are associations between noticing smoking cues, attention towards smoking, and craving when assessed in the moment, suggesting that attentional bias may not be a stable trait.

**Keywords:** attentional bias, smoking cessation, craving, ecological momentary assessment.

## **Introduction**

The role of drug-related cognitive processes on substance use behaviour has been studied extensively across various drug addictions. Several theoretical models suggest that attentional bias—where drug users show excessive attention towards drug-related stimuli—may contribute to craving and relapse (Franken, 2003; Robinson & Berridge, 1993, 2001). In laboratory settings, attentional bias is commonly measured using the drug Stroop and visual probe tasks. In the drug Stroop task, participants are required to identify the colour of drug-related and neutral words or pictures (Cox, Fadardi, & Pothos, 2006). Slower responses to drug-related stimuli compared to neutral stimuli indicate a bias towards drug-related cues. In the visual probe task, participants are required to identify the shape of a probe (e.g. a circle or square) that appears in the former location of either a drug-related or neutral stimulus. Attentional bias is indexed by faster reaction times towards probes that appear in the location of drug-related stimuli than neutral stimuli. Using either task, drug users have generally shown an attentional bias towards drug-related stimuli (Bradley et al., 2004; Munafò et al., 2003).

These tasks have been used in several studies examining the prospective association between attentional bias and craving or relapse across a range of drugs. Attentional bias has been associated with an increased likelihood of relapse in smokers (Powell et al., 2010), alcohol users (Cox et al., 2002) and heroin users (Marissen et al., 2006), although negative findings have also been reported (Carpenter et al., 2012; Mitchell et al., 2013) as well as no associations at all (Field et al., 2013). Similarly, some theories suggest that attentional bias may be a cause or consequence of high levels of craving (Franken, 2003). In support of this, a meta-analysis revealed a positive, albeit weak association between the magnitude of attentional bias and the strength of craving across users of various substances (Field, Munafò,

& Franken, 2009). However, most investigations of attentional bias in drug users have been carried out in laboratory or clinical settings. This raises several issues on the validity of the context in which these behavioural measures are assessed, as it is unclear whether laboratory conditions accurately capture cognitive and motivational processes that occur in the natural environment. Considering that craving varies within individuals over time (Shiffman et al., 1997) and across different environmental contexts (Conklin, 2006), these measurement issues may impinge on the magnitude of associations reported with attentional bias.

Some of these methodological concerns can be addressed by assessing attentional bias in real-world settings. Ecological momentary assessment (EMA) involves collecting assessments of naturally occurring phenomena in real-time, typically relying on portable electronic devices (Shiffman, Stone, & Hufford, 2008). EMA methods have been successful in capturing temporal variations in factors associated with relapse, including changes in craving and negative affect (Shiffman et al., 1997; Shiffman & Waters, 2004). More recently, a systematic review of EMA studies revealed positive associations between craving and concurrent and prospective substance use (Serre et al., 2015). Although theoretical models generally assume that attentional bias is a stable characteristic in individuals (Cox et al., 2006; Field & Cox, 2008; Franken, 2003), some investigators argue that attentional bias may also fluctuate in the same way as craving when measured in the natural environment (Christiansen, Schoenmakers, & Field, 2015; Field, Marhe, & Franken, 2014). This is supported by studies that measure attentional bias in the field. For example, using a Stroop task on a hand-held device, heroin-dependent patients exhibited higher attentional bias during episodes of high temptation to use drugs compared to other times in the day (Waters, Marhe, & Franken, 2012). Another EMA study found that heroin-dependent patients with greater

Stroop bias and craving during temptation episodes were more likely to lapse than those who did not (Marhe et al., 2013).

Only one study to date has used EMA methods to examine the association between attentional bias and craving in treatment-seeking smokers (Waters et al., 2014). Using hand-held devices, the authors measured implicit attentional bias on a Stroop task and explicit attentional bias using a single-item scale for self-reported attention to smoking. Stroop bias scores were associated with participants' self-reported attention towards smoking cues and measurements of craving taken at the same time. However, assessing attentional bias repeatedly in the field with a Stroop task may be burdensome for participants. If attentional bias represents a stable characteristic, then it should be possible to relate a prior measure of attentional bias to attention to smoking cues and craving measured in the field.

Theoretically, attentional bias develops through classical conditioning processes and the repeated pairing of smoking-related stimuli with smoking (Robinson & Berridge, 2001). It should follow that exposure to smoking cues leads to increases in attentional bias. A person with higher attentional bias may perceive smoking cues in a situation where a person with no attentional bias may not and this could prompt craving (Franken, 2003). There is evidence from EMA research that exposure to substance-related cues is associated with concurrent craving (Fatseas et al., 2015). However, no previous study has assessed whether attentional bias is related to the detection of smoking cues in the natural environment.

We used data from a clinical trial designed primarily to examine the efficacy of attentional retraining in smokers attempting to quit (Begh et al., 2013; Begh et al., 2015). In our secondary analyses, we examined: 1) Whether attentional bias measured in clinic was

associated with noticing smoking cues in the environment (as theory would predict; Robinson & Berridge, 2001); 2) Whether attentional bias was associated with participants' self-reported attention towards smoking; 3) The assumption that attentional bias is associated with craving (Franken, 2003); 4) Whether noticing more smoking cues in the natural environment was associated with craving; and 5) The association between self-reported attention towards smoking and craving (as theory predicts that dwelling on smoking - prompted by noticing cues - gives rise to craving; Franken, 2003).

## **Method**

### **Participants**

Participants were smokers recruited from general practices and stop smoking services in the UK via letters and personal referral from taking part in a trial (Begh et al., 2013; Begh et al., 2015). Inclusion criteria included: (a) aged 18 years or over; (b) smoked at least 10 cigarettes per day or had an exhaled carbon monoxide (CO) value of at least 10 parts per million (ppm); and (c) had normal or corrected-to-normal vision. Exclusion criteria were: (a) current use of smoking cessation medication; and (b) severe medical or psychiatric problems that would have compromised participation. Of the 137 participants that attended the baseline session, 122 participants took part in the EMA study. We excluded data from one participant who died shortly after enrolment. Data from 21 participants were removed during EMA data cleaning because they did not meet quality criteria (e.g. completed <50% of random prompts during study period). The remaining sample comprised 100 participants, where not all participants provided data for all aspects of the study (Figure 1).

### **Procedure**



The study received approval from the National Research Ethics Committee. Study procedures and measures are reported in detail elsewhere (Begh et al., 2013). Briefly, participants attended up to eight clinics. These included two pre-quit sessions (baseline and preparation), a quit day session and weekly sessions thereafter up until four-weeks post-quit and again at eight weeks post-quit.

At the baseline session, eligibility was checked, written consent obtained and demographic and smoking information were collected. Smoking status was assessed by expired-air carbon monoxide (ECO) (Bedfont Scientific Ltd, UK) and a quit date was agreed for two weeks' time. Trained stop smoking advisors provided weekly withdrawal-orientated behavioural support in clinics and a step down programme of 21mg/24-hour nicotine patches for 8-12 weeks.

## **Clinic Measures**

### ***Visual probe task***

Participants undertook a visual probe task during the baseline visit. Twelve picture pairs of smoking-related and neutral pictures were used in the assessment. These pictures have been applied in previous research (McClernon, Kozink, & Rose, 2008). The task comprised a total of 192 trials presented in two blocks. Eight practice trials with neutral picture pairs were presented before the first block of assessment trials. Each trial began with a fixation cross displayed in the centre of the computer screen for 500 ms, followed by presentation of a picture pair for 500 ms. A visual probe, either a circle or square, then appeared in the location of one of the pictures. Participants were required to identify the shape of the probe by pressing the corresponding keys on the keyboard as quickly as possible. Presentation of the picture pairs and probes were counterbalanced, i.e. each permutation of picture pair and probe

type was presented within each block. Thus, each type of probe appeared in the location of the smoking-related and neutral picture with equal frequency. Each block of trials was presented in a new random order for each participant, using EPrime version 2 (Psychology Software Tools Inc., Pittsburgh PA).

Reaction times (RTs) were derived from participants' responses to probes that replaced smoking-related pictures and neutral pictures. Incorrect responses were discarded, as were RTs that timed out after 2000 ms. An index of attentional bias was calculated by subtracting the median RTs for smoking-related pictures from the median RTs for neutral pictures. Positive scores reflected an attentional bias towards smoking cues.

### ***Pictorial drug Stroop task***

Participants completed the Stroop task following the visual probe task. Using the same stimuli as in the visual probe task assessment, 192 trials were presented in four blocks. Each block consisted of smoking-related or neutral pictures only. Eight practice trials were offered. Each trial began with a fixation cross presented in the centre of the computer screen followed by a picture outlined in red, blue, yellow, or green. Participants were required to indicate the colour of the border as quickly as possible by pressing the corresponding colour-labelled keys on the keyboard. The picture remained on the screen until a response was given; the trial timed out if no response was received within 2000 ms. Each block of trials was presented in a new random order for each participant.

A Stroop bias score for each participant was calculated by subtracting the median RTs for colour-naming neutral pictures from the median RTs for colour-naming smoking-related pictures. Positive scores indicated a bias towards smoking cues.

## **EMA Measures**

Participants were trained in using a handheld personal digital assistant (PDA; Samsung© i200) to collect information about smoking and quit experiences. The functionality and design of the EMA program mirrored that used in previous smoking studies (Schuz et al., 2013; Shiffman et al., 2002). A video demonstration was played during training, instructing participants to carry the PDA with them at all times for seven weeks, to monitor ad libitum smoking during the pre-quit period and respond to audible random prompts throughout their quit attempt. Random prompt assessments occurred up to five times per day, determined by participants' hours of wakefulness. Participants had one minute to respond to the sound of the prompt, otherwise it was recorded as a missed entry. Participants were also given an accompanying instruction booklet and a help-line number for technical support. Adherence to EMA monitoring was checked each week by the therapist using a computer program, which calculated the number of missed and completed reports and reported daily compliance to random prompts. At the eight-week post-quit visit, participants returned the PDA and were paid up to £150 if they had adhered to the EMA protocol.

## ***Smoking cues***

Attentional bias is defined as noticing and attending to smoking cues in the environment and asking participants to report on what they observe provides a direct and explicit measure of this. Participants reported by EMA whether they had noticed any smoking-related cues within the last hour of receiving a random prompt. The question, "Seen any of the following?" appeared with the following response options: cigarette, lighter or matches, cigarette packet, ashtray, cigarette on TV/film/ad, someone smoking, other smoking things and none of the above. Participants could endorse more than one item.

### ***Self-reported attention***

EMA self-reported attention items were derived from the Subjective Attentional Bias Questionnaire (SBQ; (Leventhal et al., 2007). Three items that were most relevant to the aims of this study were taken from the 8-item questionnaire to assess the extent to which participants felt that their attention was drawn to cigarettes and smoking cues in the last hour of receiving a random prompt: “Attention drawn to cigarettes?” “Stared at cigarettes/cigarette smoke” and “Had thoughts/images of smoking?” Responses to each item were made on a 1 (not at all) to 7 (extremely) scale. These responses were summed and averaged to give a score for self-reported attention towards smoking.

### ***Craving***

Participants were asked to recall the strength of their craving in the moments before the prompt had occurred, on a scale from 1 (not at all) to 7 (extremely) using EMA.

### ***Number of cigarettes smoked***

Participants logged every cigarette on the PDA after smoking. If they missed a cigarette entry during the day, they could enter the number of missed cigarettes in an evening report before going to sleep. Any smoking that occurred during the night could be entered in a morning report.

### ***Quit status***

The PDA administered a quit report if a cigarette had not been logged or entered as missed in a morning or evening report within 24 hours of the last cigarette entry. The PDA switched to quit mode if participants indicated that they had not smoked in the last 24 hours and any

further logged cigarettes were coded as lapses thereafter. Abstinence was verified at each clinic visit with a CO level <10 ppm (West et al., 2005).

### **Data management and analysis**

Data were excluded prior to analysis if quality criteria were not met, as is standard in other EMA studies (Schuz et al., 2013). Participants who completed <50% of random prompts overall during the study period were removed from the analysis, as were those who terminated EMA monitoring within the first study week (Figure 1). For visual probe and Stroop task data, participants with attentional bias scores greater than 3 SDs from the population mean were excluded. Cronbach's alpha was calculated as an index of internal reliability for both tasks.

### ***Statistical models***

Multilevel mixed-effects logistic or ordinal logistic models (STATA 13) were used for the analyses, to allow for clustering of the random prompt data by subject. We used a random subject-specific intercept in all models. A quit variable (yes/no) was also included as a random effect in all models. An unstructured covariance matrix structure was specified for random effects. Gender, age, day and post-quit lapses were included as fixed effects in all models. Day (days since baseline clinic visit) was subdivided into two variables (days since baseline clinic if not quit and days since quitting) to allow different associations with the dependent variable, before and after quitting. Continuous linear and quadratic terms were included for each day variable. For all models statistical significance of the parameter estimates were assessed with a Wald test. Details of specific models described below.

### ***Clinic attentional bias and its association with noticing smoking cues***

We used both the visual probe and Stroop clinic measures to assess whether either was associated with seeing at least one smoking cue and, among those who saw at least one cue, the number of cues seen in the past hour, assessed by EMA.

#### ***Clinic attentional bias and its association with self-reported attention***

We used both the visual probe and Stroop clinic measures to assess whether either was associated with self-reported attention assessed by EMA.

#### ***Clinic attentional bias and its association with craving***

We used both the visual probe and Stroop clinic measures to assess whether either was associated with craving assessed by EMA.

#### ***EMA measures of noticing cues and its association with craving***

Attentional bias theory predicts that noticing more cues in the environment produces craving. We examined this by a model in which we associated the craving score with the number of cues noticed in the past hour on EMA random prompt assessments.

#### ***EMA measures of self-reported attention and its association with craving***

Attentional bias theory predicts that attention towards smoking gives rise to craving. We tested this by examining the association of the self-reported attention score with craving assessed by EMA.

We analysed the data separately for the pre-quit and post-quit day data and found no substantial differences in the pattern of results. We also analysed the data after quit day only for the first week of the quit attempt but this gave very similar results. We therefore report the

results for all periods combined. Participants were randomised to attentional retraining or sham training so we carried out separate analyses with treatment arm. This produced largely the same results; therefore these are not reported.

## **Results**

### **Demographics and smoking characteristics at baseline**

The 100 participants were on average 44 (SD=13) years old, smoked 21 (SD=9) cigarettes per day and were moderately dependent with an FTND score of 5.5 (SD=2.3). The mean visual probe task bias score was 3 ms (SD=28) and mean Stroop bias score was 1 ms (SD=52). One sample t-tests revealed that neither bias score was significantly different from zero (visual probe:  $t[96]=1.05$ ,  $p=0.30$ ; Stroop:  $t[97]=0.10$ ,  $p=0.92$ ).

### **EMA compliance**

In total the 100 participants responded to 9271 random prompt assessments during the study period averaging 3.3 (SD=0.7) prompts per day. Of the 100 participants, 88 abstained from smoking for at least 24 hours at some point. They completed 32 days of EMA monitoring on average (mean 12 days pre-quit, 20 days post-quit) where at least one random prompt was issued. Overall daily compliance to random prompts was 82%.

### **Internal reliability**

Cronbach's alpha coefficients were 0.20 for the visual probe task and 0.75 for the Stroop task, with the latter reaching the minimum standard ( $>0.70$ ) for acceptable internal reliability (Kline, 1999).

### **Association between clinic attentional bias and noticing smoking cues**

Of 9271 random prompts completed, participants reported seeing at least one smoking cue in 3935 (42.4%) assessments. Within the 3935 assessments where at least one smoking cue was seen, the mean number of smoking cues seen was 2.5 (SD=1.5)

There was no evidence of an association between visual probe or Stroop assessments of attentional bias and the number of cues seen, or having seen at least one cue ( $p>0.66$ ; Table 1).

### **Association between clinic attentional bias and self-reported attention**

Of 3935 assessments where at least one smoking cue was seen, participants completed 3905 assessments of attention towards smoking. Within these 3905, the mean score for self-reported attention was 3.2 (SD=1.5) on a scale of 1-7.

There was no evidence of an association between visual probe or Stroop assessments of attentional bias and self-reported attention to smoking ( $p>0.37$ ; Table 1).

### **Association between clinic measures of attentional bias and craving**

Ordinal logistic regression analyses indicated that attentional bias RT scores on the visual probe and Stroop task were not associated with repeated measures of craving at each random prompt: visual probe task (OR=1.00, 95% CI=0.99, 1.02), Stroop task (OR=1.00, 95% CI=0.99, 1.01).

### **Association between EMA measures of noticing smoking cues and craving**

Within random prompt assessments, seeing at least one smoking cue was positively associated with craving (OR=1.94, 95% CI= 1.74, 2.16; Table 2). There were positive associations with



craving for individual items, including seeing a cigarette, lighter or matches, a cigarette packet, an ashtray and someone else smoking ( $p < 0.0001$ ; Table S1) but not for seeing a cigarette on TV/film/ad and other smoking things ( $p > 0.36$ ). For assessments where at least one smoking cue was seen, the number of cues seen was positively associated with craving (OR per one more cue seen=1.10, 95% CI=1.03, 1.17).

### **Association between EMA measures of self-reported attention and craving**

There was evidence of an association between self-reported attention to smoking and craving (OR per one unit higher self-reported attention=3.69, 95% CI=3.42, 3.98).

### **Discussion**

This study investigated whether reaction time measures of attentional bias administered in a clinic prior to quitting smoking were associated with noticing smoking cues seen in the environment, self-reported attention to smoking, and craving all assessed using EMA measures. The study also examined whether noticing smoking cues and self-reported attention to smoking was associated with craving when all were assessed using EMA. Attentional bias, measured in clinic using the visual probe task and Stroop task was not associated with noticing smoking cues, self-reported attention to smoking, or craving across multiple EMA assessments. On the other hand, EMA assessments of noticing smoking cues and self-reported attention towards smoking were associated with concurrently assessed craving. A significant attentional bias towards smoking cues was not evident in the sample at baseline on either reaction time measure.

This is the first study to show that measurements of attentional bias taken in a clinical setting are unrelated to real-world measures of attention and craving. We used two different but commonly used measures of attentional bias to maximise our chances of observing an association, but none was found. Other studies have similarly shown a lack of association between attentional bias measured in the laboratory and craving assessed at the same time (Spiegelhalter et al., 2011; Waters et al., 2003). It is worth noting that, in line with previous research (Ataya et al., 2012a), the visual probe task showed very poor internal reliability. This could have arguably compromised associations with craving. However, the Stroop task showed acceptable levels of internal reliability and so the lack of associations observed can not be explained by uncertainty around the reliability of the task.

We did, however, detect an association between noticing smoking cues, attention to smoking and craving when these constructs were assessed in the moment of their occurrence, using EMA. These findings are similar therefore to two other studies, which also reported cross-sectional associations between attentional processes and craving in smokers trying to stop smoking (Waters et al., 2014) and heroin-addicts in treatment (Marhe et al., 2013). Specifically, both studies administered the Stroop task repeatedly via EMA and found an association with craving measured at the same time. Taken together, these patterns of association suggest that attentional bias may be situational as opposed to being a stable trait, and that its occurrence coincides with increases in craving. We support the notion that attentional bias in the natural environment is associated with craving during the time of measurement and the strength of attentional bias manifest may depend upon a person's motivation with respect to substance use (Christiansen, Schoenmakers, & Field, 2015; Field, Marhe, & Franken, 2014).

It is important to note that our data and all those described above are correlational and do not reveal anything about the causal or even temporal relationship between attentional bias and craving. Studies that manipulate attentional bias would clarify whether attentional bias is a cause of craving. Those trials so far completed show little evidence that changing laboratory or clinic measures of attentional bias produce changes in craving (Field et al., 2009; McHugh et al., 2010; Begh et al., 2015). However, attentional retraining conducted in the environment using EMA methods has been shown to reduce both attentional bias and craving in smokers (Kerst & Waters, 2014). Whether this would do so in smokers who are motivated and trying to quit - the clinically relevant population - is yet to be determined. However, this does suggest there may be a role for attentional bias retraining, but our theoretical models may need further development to understand the apparently complex fleeting relationship between attentional bias and craving.

There are some limitations of the study. The list of smoking cues compiled for the study was generic. Some have argued that associations between personalised cues and craving may be stronger and more relevant than generic cues (Conklin, 2006; Conklin, 2010; Fatseas et al., 2015). Furthermore, these associations have been found to persist for a longer time-period compared with generic substance-related cues (Fatseas et al., 2015). Similarly, we used generic rather than personalised stimuli in the reaction time measures of attentional bias. Alcohol studies have shown that the internal reliability and predictive validity of reaction time tasks can be increased by using personalised stimuli rather than generic stimuli (Christiansen et al., 2014; Christiansen et al., 2015), although the tailoring of stimuli may be challenging to implement for each participant (Ataya et al., 2012b). Another limitation is that

participants were asked to report on whether a smoking-related cue was seen or not, prior to assessing craving. This could have created demand characteristics in the way that smokers responded to craving; inducing people to remember cues that were not at the time salient but became more so on reflection could have also inadvertently increased the intensity of craving reports. However, the opposite could also be true if items were reported in reverse order – asking people to report craving prior to cue exposure could prompt them to think about the cause of their craving and overstate the number of drug cues seen (Fatseas et al., 2015; Field, 2015). Administering separate random assessments of craving and cue exposure may reduce confounding (Field, 2015). Another consideration is that we used a multi-level modelling structure that combined between-subject and within-subject influences for EMA measures of attention and craving, although the latter best captures momentary processes.

Taken together, this study together with other evidence suggests that noticing smoking cues, dwelling on them, and craving are related phenomena in that they co-occur. Attentional bias is unrelated to any of these measures taken in the moment, suggesting that it may not be a stable trait. We need to develop new models of the way the environment and cognitive predispositions interact to allow us to help people with addictions find ways to overcome momentary impulses that lead to lapses.

## **References**

Ataya, A.F., Adams, S., Mullings, E., Cooper, R.M., Attwood, A.S., Munafò, M.R. (2012a). Internal reliability of measures of substance-related cognitive bias. *Drug Alcohol Depen.* 121, 148-151.

Ataya, A. F., Adams, S., Mullings, E., Cooper, R. M., Attwood, A. S. & Munafò, M. R. (2012b). Methodological considerations in cognitive bias research: The next steps. *Drug Alcohol Depend* 124, 191-192.

Begh, R., Munafò, M. R., Shiffman, S., Ferguson, S. G., Nichols, L., Mohammed, M. A., . . . Aveyard, P. (2013). Attentional bias retraining in cigarette smokers attempting smoking cessation (ARTS): Study protocol for a double blind randomised controlled trial. *Bmc Public Health*, 13.

Begh, R., Munafò, M. R., Shiffman, S., Ferguson, S. G., Nichols, L., Mohammed, M. A., . . . Aveyard, P. (2015). Lack of attentional retraining effects in cigarette smokers attempting cessation: A proof of concept double-blind randomised controlled trial. *Drug Alcohol Depend*, 149, 158-165. doi: 10.1016/j.drugalcdep.2015.01.041.

Bradley, B., Field, M., Mogg, K., De Houwer, J. (2004). Attentional and evaluative biases for smoking cues in nicotine dependence: component processes of biases in visual orienting. *Behav Pharmacol*, 15, 29-36.

Carpenter, K. M., Martinez, D., Vadhan, N. P., Barnes-Holmes, D., & Nunes, E. V. (2012). Measures of attentional bias and relational responding are associated with behavioral treatment outcome for cocaine dependence. *Am J Drug Alcohol Abuse*, 38(2), 146-154. doi: 10.3109/00952990.2011.643986.

Christiansen, P. & Bloor, J. F. (2014). Individualised but not general alcohol Stroop predicts alcohol use. *Drug Alcohol Depend* 134, 410-413.

Christiansen, P., Mansfield, R., Duckworth, J., Field, M. & Jones, A. (2015). Internal reliability of the alcohol-related visual probe task is increased by utilising personalised stimuli and eye-tracking. *Drug Alcohol Depend* 155, 170-174.

Christiansen, P., Schoenmakers, T. M., & Field, M. (2015). Less than meets the eye: Reappraising the clinical relevance of attentional bias in addiction. *Addict Behav*, 44, 43-50. doi: 10.1016/j.addbeh.2014.10.005.

Conklin, C. A. (2006). Environments as cues to smoke: Implications for human extinction-based research and treatment. *Experimental and Clinical Psychopharmacology*, 14(1), 12-19.

Conklin, C. A., Perkins, K. A., Robin, N., McClernon, F. & Salkeld, R. P. (2010). Bringing the real world into the laboratory: Personal smoking and nonsmoking environments. *Drug Alcohol Depend* 111, 58-63.

Cox, W.M., Hogan, L.M., Kristian, M.R., Race, J.H. (2002). Alcohol attentional bias as a predictor of alcohol abusers' treatment outcome. *Drug Alcohol Depend* 68, 237-243.

Cox, W. M., Fadardi, J. S., & Pothos, E. M. (2006). The addiction-stroop test: Theoretical considerations and procedural recommendations. *Psychological Bulletin*, 132(3), 443-476.

Fatseas, M., Serre, F., Alexandre, J.-M., Debrabant, R., Auriacombe, M. & Swendsen, J. (2015). Craving and substance use among patients with alcohol, tobacco, cannabis or heroin addiction: a comparison of substance- and person-specific cues. *Addiction 110*, 1035-1042.

Field, M. (2015). Ecological momentary assessment – new insights and opportunities. *Addiction 110*, 1043-1044.

Field, M., & Cox, W. M. (2008). Attentional bias in addictive behaviors: A review of its development, causes, and consequences. *Drug Alcohol Depend*, 97(1-2), 1-20.

Field, M., Duka, T., Tyler, E., & Schoenmakers, T. (2009). Attentional bias modification in tobacco smokers. *Nicotine & Tobacco Research*, 11(7), 812-822.

Field, M., Marhe, R., & Franken, I. H. (2014). The clinical relevance of attentional bias in substance use disorders. *CNS Spectr*, 19(3), 225-230. doi: 10.1017/s1092852913000321.

Field, M., Mogg, K., Mann, B., Bennett, G. A., & Bradley, B. P. (2013). Attentional biases in abstinent alcoholics and their association with craving. *Psychol Addict Behav*, 27(1), 71-80. doi: 10.1037/a0029626.

Field, M., Munafò, M. R., & Franken, I. H. A. (2009). A Meta-Analytic Investigation of the Relationship Between Attentional Bias and Subjective Craving in Substance Abuse. *Psychological Bulletin*, 135(4), 589-607.

Franken, I. H. A. (2003). Drug craving and addiction: integrating psychological and neuropsychopharmacological approaches. *Progress in Neuro-Psychopharmacology & Biological Psychiatry*, 27(4), 563-579.

Kline, P. (1999). *The Handbook of Psychological Testing*. Routledge, London.

Leventhal, A. M., Waters, A. J., Boyd, S., Moolchan, E. T., Lerman, C., & Pickworth, W. B. (2007). Gender differences in acute tobacco withdrawal: effects on subjective, cognitive, and physiological measures. *Exp Clin Psychopharmacol*, 15(1), 21-36. doi: 10.1037/1064-1297.15.1.21.

Marhe, R., Waters, A. J., van de Wetering, B. J., & Franken, I. H. (2013). Implicit and explicit drug-related cognitions during detoxification treatment are associated with drug relapse: an ecological momentary assessment study. *J Consult Clin Psychol*, 81(1), 1-12. doi: 10.1037/a0030754.

Marissen, M.A.E., Franken, I.H.A., Waters, A.J., Blanken, P., van den Brink, W., Hendriks, V.M. (2006). Attentional bias predicts heroin relapse following treatment. *Addiction*. 101, 1306-1312.

McClernon, F. J., Kozink, R. V., & Rose, J. E. (2008). Individual differences in nicotine dependence, withdrawal symptoms, and sex predict transient fMRI-BOLD responses to smoking cues. *Neuropsychopharmacology*, 33(9), 2148-2157.



McHugh, R. K., Murray, H. W., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2010). Attentional Bias and Craving in Smokers: The Impact of a Single Attentional Training Session. *Nicotine & Tobacco Research, 12*(12), 1261-1264.

Mitchell, M. R., Balodis, I. M., Devito, E. E., Lacadie, C. M., Yeston, J., Scheinost, D., . . . Potenza, M. N. (2013). A preliminary investigation of Stroop-related intrinsic connectivity in cocaine dependence: associations with treatment outcomes. *Am J Drug Alcohol Abuse, 39*(6), 392-402. doi: 10.3109/00952990.2013.841711.

Munafò, M., Mogg, K., Roberts, S., Bradley, B. P., & Murphy, M. (2003). Selective processing of smoking-related cues in current smokers, ex-smokers and never-smokers on the modified Stroop task. *Journal of Psychopharmacology, 17*(3), 310-316.

Powell, J., Dawkins, L., West, R., Powell, J., Pickering, A. (2010). Relapse to smoking during unaided cessation: clinical, cognitive and motivational predictors. *Psychopharmacol, 212*, 537-549.

Robinson, T. E., & Berridge, K. C. (1993). The Neural Basis of Drug Craving - An Incentive-Sensitization Theory of Addiction. *Brain Research Reviews, 18*(3), 247-291.

Robinson, T. E., & Berridge, K. C. (2001). Incentive-sensitization and addiction. *Addiction, 96*(1), 103-114.

Serre, F., Fatseas, M., Swendsen, J. & Auriacombe, M. (2015). Ecological momentary assessment in the investigation of craving and substance use in daily life: a systematic review. *Drug Alcohol Depend* 148, 1-20.

Sharma, D., Albery, I. P., & Cook, C. (2001). Selective attentional bias to alcohol related stimuli in problem drinkers and non-problem drinkers. *Addiction*, 96(2), 285-295.

Shiffman, S., Dunbar, M., Kirchner, T., Li, X., Tindle, H., Anderson, S., & Scholl, S. (2013). Smoker reactivity to cues: effects on craving and on smoking behavior. *J Abnorm Psychol*, 122(1), 264-280. doi: 10.1037/a0028339.

Shiffman, S., Engberg, J. B., Paty, J. A., Perz, W. G., Gnys, M., Kassel, J. D., & Hickcox, M. (1997). A Day at a time: Predicting smoking lapse from daily urge. *Journal of Abnormal Psychology*, 106(1), 104-116.

Shiffman, S., Gnys, M., Richards, T. J., Paty, J. A., Hickcox, M., & Kassel, J. D. (1996). Temptations to smoke after quitting: A comparison of lapsers and maintainers. *Health Psychology*, 15(6), 455-461.

Shiffman, S., Gwaltney, C. J., Balabanis, M. H., Liu, K. S., Paty, J. A., Kassel, J. D., . . . Gnys, M. (2002). Immediate antecedents of cigarette smoking: An analysis from ecological momentary assessment. *Journal of Abnormal Psychology*, 111(4), 531-545.

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology*, 4, 1-32.

Shiffman, S., & Waters, A. J. (2004). Negative affect and smoking lapses: A prospective analysis. *Journal of Consulting and Clinical Psychology, 72*(2), 192-201.

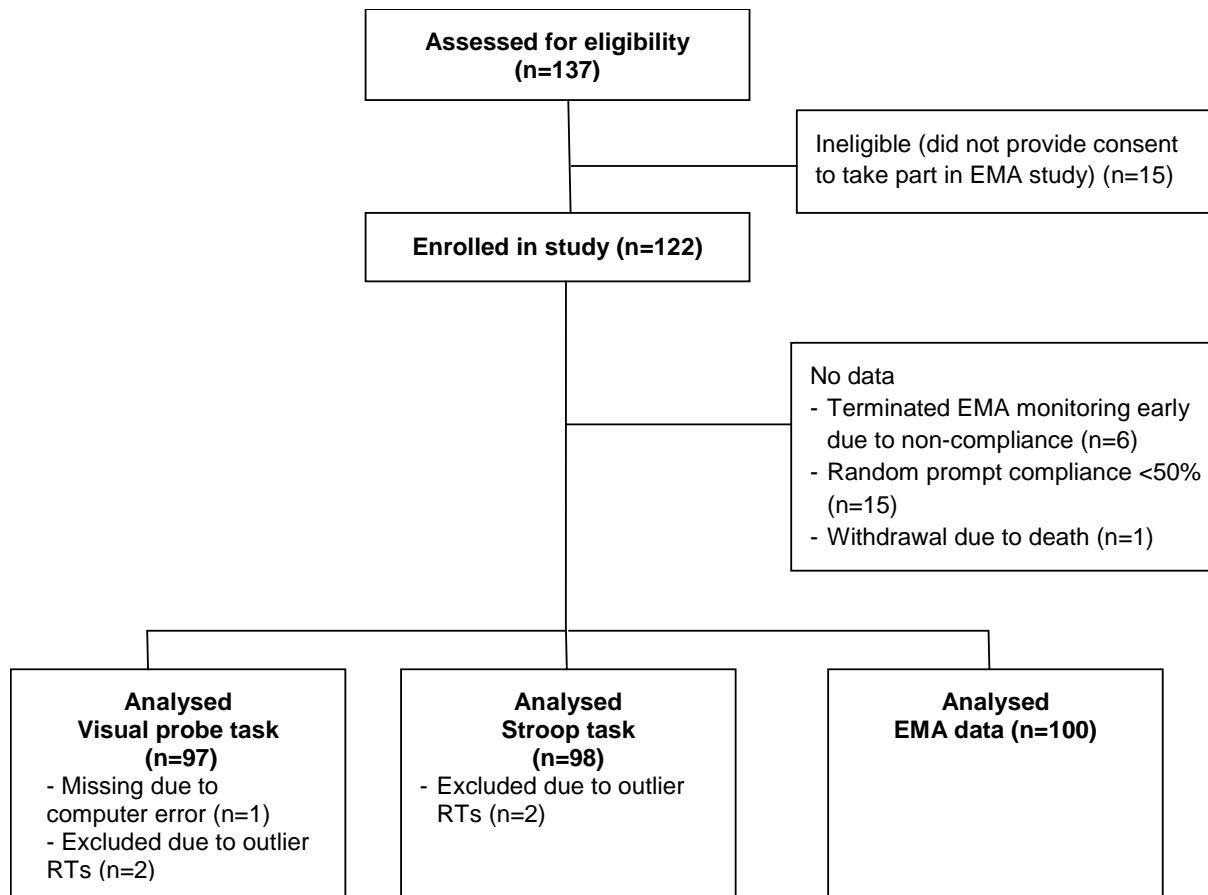
Spiegelhalder, K., Jahne, A., Kyle, S. D., Beil, M., Doll, C., Feige, B., & Riemann, D. (2011). Is Smoking-related Attentional Bias a Useful Marker for Treatment Effects? *Behavioral Medicine, 37*(1), 26-34.

Waters, A. J., Marhe, R., & Franken, I. H. A. (2012). Attentional bias to drug cues is elevated before and during temptations to use heroin and cocaine. *Psychopharmacology, 219*(3), 909-921.

Waters, A. J., Shiffman, S., Sayette, M. A., Paty, J. A., Gwaltney, C. J., & Balabanis, M. H. (2003). Attentional bias predicts outcome in smoking cessation. *Health Psychology, 22*(4), 378-387.

Waters, A. J., Szeto, E. H., Wetter, D. W., Cinciripini, P. M., Robinson, J. D., & Li, Y. S. (2014). Cognition and Craving During Smoking Cessation: An Ecological Momentary Assessment Study. *Nicotine & Tobacco Research, 16*, S111-S118.

West, R., Hajek, P., Stead, L., & Stapleton, J. (2005). Outcome criteria in smoking cessation trials: proposal for a common standard. *Addiction, 100*(3), 299-303.



**Figure 1. Participants flow through study**

**Table 1. ORs (95% CI) for association between clinic measures of attentional bias and whether smoking cues were seen, number seen, and self-reported attention to smoking**

Variable	Visual probe task			Stroop task		
	OR	95% CI	p value	OR	95% CI	p value
Saw at least one smoking cue	1.00	0.99, 1.01	0.88	1.00	0.99, 1.00	0.74
No. of smoking cues seen	1.00	0.98, 1.01	0.66	1.00	0.99, 1.01	0.95
Self-reported attention <sup>a</sup>	1.00	0.99, 1.02	0.70	1.00	0.99, 1.00	0.37

<sup>a</sup> Self-reported attention score derived from the combined average score for items “Attention drawn to cigarettes?” “Stared at cigarettes/cigarette smoke” and “Had thoughts/images of smoking?” each rated 1-7 where higher values indicate higher level of attention. Self-reported attention items were administered if participants reported seeing at least one smoking cue. *Note.* Smoking cues were modelled as binary or ordinal dependent variables as appropriate. Self-reported attention score was transformed into a 6-category ordinal variable for this analysis. Stroop and visual probe task scores were included as continuous covariates in the models.

**Table 2. ORs (95% CI) for EMA assessed measures of noticing smoking cues and self-reported attention as predictors of craving**

Variable	OR	95% CI	Cohen's <i>d</i>	p value
Saw at least one smoking cue	1.94	1.74, 2.16	0.37	<0.0001
No. of smoking cues seen	1.10	1.03, 1.17	0.05	0.0027
Self-reported attention <sup>a</sup>	3.69	3.42, 3.98	0.72	<0.0001

<sup>a</sup> Self-reported attention score derived from the combined average score for items "Attention drawn to cigarettes?" "Stared at cigarettes/cigarette smoke" and "Had thoughts/images of smoking?" each rated 1-7 where higher values indicate higher level of attention; self-reported attention items were administered if participants reported seeing at least one smoking cue. *Note.* Craving was modelled as the dependent ordinal variable. Covariate predictors of craving were included as continuous (no. of smoking cues seen, self-reported attention) or binary (saw at least one smoking cue). Cohen's *d* was calculated by transformation of the odds ratio to the standardised mean difference *d*.

**Table S1. ORs (95% CI) for individual smoking cues as predictors of craving**

Variable	OR	95% CI	p value
Saw cigarette	1.96	1.75, 2.20	<0.0001
Saw lighter or matches	1.81	1.59, 2.07	<0.0001
Saw cigarette packet	1.76	1.54, 2.01	<0.0001
Saw ashtray	1.65	1.44, 1.90	<0.0001
Saw cigarette on TV/film/ad	1.01	0.74, 1.37	0.97
Saw someone smoking	1.32	1.15, 1.51	0.0001
Saw other smoking things	1.14	0.86, 1.50	0.36