Eye movements to smoking-related pictures in smokers: relationship between attentional biases and implicit and explicit measures of stimulus valence

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ABSTRACT

Aims To investigate biases in overt orienting of attention to smoking-related cues in cigarette smokers, and to examine the relationship between measures of visual orienting and the affective and motivational valence of smoking cues.

Design Smokers and non-smokers took part in a single session in which their attentional and evaluative responses to smoking-related and matched control pictures were recorded.

Participants Twenty smokers and 25 non-smokers.

Measurements Direction and duration of gaze was measured while participants completed a visual probe task. Subjective and cognitive-experimental measures of the motivational and affective valence of the stimuli were recorded.

Findings Smokers, but not non-smokers, maintained their gaze for longer on smoking-related pictures than control pictures. They were also faster to detect probes that replaced smoking-related than control pictures, consistent with an attentional bias for smoking-related cues. Furthermore, smokers showed greater preferences for smoking-related than control pictures, compared with non-smokers, on both the subjective (explicit) and cognitive-experimental (implicit) indices of stimulus valence. Within smokers, longer initial fixations of gaze on smoking-related pictures were associated with a bias to rate the smoking pictures more positively, with greater approach tendencies for smoking pictures on the cognitive-experimental task, and with a greater urge to smoke.

Conclusions These results demonstrate that smokers show biased attentional orientating to smoking cues, which is related to craving and the affective and motivational valence of the stimuli.

KEYWORDS Attentional bias, drug cues, eye movements, smoking, stimulus valence.

INTRODUCTION

Biases in selective attention appear to be an important feature of addiction, as drug-dependent individuals seem prone to having their attention captured by drug-related environmental cues. For example, Sayette & Hufford (1994) found that smokers were slower to respond to an auditory probe stimulus in the presence of smoking-related than neutral cues. Distraction effects of smoking cues have also been examined with the modified Stroop task, in which words are presented in different colours, and participants name the colour of the words while ignoring their content. Several studies indicate that smokers who are nicotine-deprived or craving are slower in colour-naming smoking-related words, which suggests difficulty in ignoring drug-related cues (Gross, Jarvik &
Rosenblatt 1993; Waters & Feyerabend 2000; Zack et al. 2001; Mogg & Bradley 2002). Similar findings have been reported in alcohol and opiate dependence (Johnsen et al. 1994; Stetter et al. 1995; Franken et al. 2000).

Such studies suggest that drug-relevant cues interfere with ongoing cognitive processing in drug-dependent populations, but they do not reveal the precise nature of the processes involved in this interference effect. For example, such effects on the modified Stroop task could arise from several different mechanisms, which include not only selective attention to the salient information, but also competition for processing resources from task-irrelevant processes (e.g. intrusive thoughts) which are triggered by the cues; or cognitive effort which is required to suppress the distracting information; or competition which occurs at later, response output stages of processing (Williams, Mathews & MacLeod 1996). Thus, interference effects do not necessarily reflect a selective attentional bias for drug-related cues.

An attentional bias for drug-related cues in addiction is of theoretical importance, as incentive theories of drug dependence predict that stimuli associated with drug-taking become highly attractive, ‘wanted’ and ‘grab attention’, because such stimuli have acquired high motivational salience for the individual. According to Robinson & Berridge (1993, 2001), the incentive-salience mechanism that underlies this process is mediated by dopamine levels in the mesolimbic dopamine system and plays a key role in maintaining drug-taking behaviour. Thus, the extent to which drug-cues capture and hold attention may reflect directly the extent to which the incentive-salience mechanism is being activated by those cues.

Several studies have used the visual probe task to assess attentional biases for drug-related cues, because this task provides a more direct measure of the deployment of visuo-spatial attention. In pictorial versions of this task (e.g. Lubman et al. 2000; Bradley et al. 2003), on each trial, two pictures are presented briefly simultaneously side by side (e.g. a smoking-related picture and a control picture). Immediately after the pictures disappear, a probe stimulus (e.g. a small dot) appears in the location of one of them, and participants are required to press a key as quickly as possible in response to the probe. The rationale for the task is that people respond faster to stimuli that appear in an attended, rather than unattended, region of a visual display (e.g. Posner, Snyder & Davidson 1980). Thus, the deployment of attention to the pictures can be inferred from the response times (RTs) to the probes. Visual probe studies have indicated an attentional bias for smoking-related pictures in smokers (Bradley et al. 2003) and drug-related pictures in opiate addicts (Lubman et al. 2000). Visual probe tasks have also been widely used to demonstrate attentional biases for other types of motivationally salient stimuli, such as threat cues in anxiety states (e.g. see Mogg & Bradley 1998; for a review).

A feature of the visual probe task is that it gives a snapshot view of attentional biases. That is, the RT measure of attentional bias is obtained after the offset of the display of the pictures (i.e. when the probe appears). When the picture pairs are shown briefly (e.g. 500 ms or less), the RT bias measure is more likely to reflect initial shifts in attention. When the picture pairs are presented for longer durations (e.g. 2000 ms), there is greater opportunity for attention to shift repeatedly between the pictures while they are displayed, so the bias measure is more likely to reflect maintained attention. Recent theories of selective attention highlight the distinction between different processes involved in the initial shift versus maintenance of attention (e.g. LaBerge 1995). However, there has been relatively little research investigating which specific orienting processes are involved in attentional biases in drug dependence. Bradley et al. (2003) found that smokers showed greater vigilance for smoking-related pictures than non-smokers when the pictures were presented for 2000 ms, which suggests that addiction-related biases may operate in the maintenance of attention. One aim of the present study was to investigate the extent to which attentional biases for drug-related cues operate in different aspects of visual orienting: specifically, the direction and duration of eye movement fixations to smoking-related cues.

Thus, we examined biases in overt orienting in smokers and non-smokers by measuring eye movements while participants completed a visual probe task with smoking-related and control pictures. Eye movement measures have several advantages over other methods of measuring attentional biases. They provide directly observable and ecologically valid measures of visual orienting. They are rapid, normally automatic, and individuals commonly look at stimuli that attract their attention (Jonides 1981; Kowler 1995). Emotion research has also indicated that eye movements provide a sensitive measure of attentional biases in aversive motivational states, such as fear and anxiety (Hermans, Vansteenhoven & Eelen 1999; Bradley, Mogg & Millar 2000; Mogg et al. 2000b). In the present study, our primary measures were the direction and duration of the initial fixation when smoking-related and control pictures were displayed simultaneously. We hypothesized that smokers would be more likely to direct their gaze towards smoking-related pictures than control pictures (i.e. a bias in the initial shift of attention) and that their gaze would be held longer on smoking-related pictures (i.e. a bias in maintaining attention on drug-related cues).

Another goal of this research was to investigate the relationships between the orienting measures and the
motivational and affective valence of the smoking-related pictures. According to incentive models of addiction, attentional biases for drug-related cues should be associated closely with the perceived attractiveness of those cues because a common mechanism underlies both, namely, a dopamine-based incentive-sensitization system (Robinson & Berridge 1993, 2001). Recent theories of emotion also propose that the valence of a stimulus is important in determining its capacity to capture attention. For example, Lang, Davis & Ohman (2000) proposed that stimuli with high affective valence (either highly pleasant or unpleasant) are more likely to attract attention processing than stimuli with mild affective valence. Indeed, there is evidence that highly aversive pictures are more likely to attract attention than mildly aversive pictures and that this bias may be influenced by individual differences in anxiety levels (Mogg et al. 2000a). In relation to nicotine dependence, pictorial scenes of smoking are generally rated as pleasant by smokers (Mucha, Geier & Pauli 1999), and also appear to elicit an attentional bias in smokers (Bradley et al. 2003). However, no studies have, as yet, examined the relationship between the perceived valence of smoking-related pictures and their effects on attentional orienting, so we sought to address this issue here. Therefore, in the present study, after participants had completed the visual probe task, they rated each of the smoking-related and control pictures for perceived pleasantness, in order to assess the subjective valence of the stimuli.

We also included a modified version of a task used by De Houwer et al. (2001), which provides an implicit measure of the motivational or affective valence of the stimuli. Previous research has shown that people categorize positively valenced stimuli faster if the appropriate categorization response is an approach movement, rather than an avoidance movement, but the reverse is true for negatively valenced stimuli (Chen & Bargh 1999; Neumann & Strack 2000). De Houwer et al. obtained similar findings using a task in which participants made symbolic approach and avoidance movements to positive and negative words by moving a manikin figure towards or away from the stimuli. The task used here is termed the ‘stimulus response compatibility’ (SRC) task, because responses to positive stimuli are compatible with behavioural tendencies to approach that stimulus, whereas responses to negative stimuli are compatible with behavioural tendencies to avoid that stimulus (De Houwer 2003).

In the SRC task, participants were asked to decide whether or not each picture was related to smoking and to respond by moving a manikin figure either towards or away from each picture. As previous research has shown that such tasks are sensitive to the motivational or affective valence of the stimuli, we expected that, if participants evaluate the smoking-related pictures as positive, they should be faster to make approach than avoidance movements to those pictures. Conversely, if they evaluate the smoking-related pictures as negative, the opposite pattern of results would be seen. We hypothesized that smokers would respond to the smoking-related stimuli as if they were motivationally positive, whereas non-smokers would respond as if they were negative. We also examined the relationship between the motivational salience of the smoking-related cues, as assessed on the SRC task, and the capacity of the stimuli to capture and hold attention, as assessed by eye movements. An advantage of the SRC task is that it does not require participants to make explicit judgements of the affective valence of the stimuli, so it may be less susceptible to demand effects that are associated commonly with direct measures of stimulus valence, such as pleasantness ratings.

In summary, the present study assessed the eye movements of smokers and non-smokers in response to smoking-related and control pictures during a visual probe task. We predicted that smokers would show attentional biases in their initial orienting to smoking-related pictures (as reflected by the direction of the first eye movement in response to the pictures) and in the maintenance of attention (as reflected by the duration of the initial fixation). A further aim of the study was to examine the relationship between the predicted attentional biases and direct and indirect measures of the affective and motivational valence of the pictorial stimuli (as measured by subjective rating and SRC tasks).

**METHOD**

**Participants**

Participants were recruited from the students and staff at the University of Southampton via poster advertisements and through an online experiment booking system. The group of 20 smokers consisted of 11 males and nine females, with a mean age of 23.1 years (SD = 4.0). On average, they smoked 16.2 cigarettes per day (SD = 4.1, range 10–23) and had been smoking for 5.8 years (SD = 3.4, range 1–16 years). They reported having attempted to quit smoking on average 2.1 times, and the median time elapsed since smoking their last cigarette was 1.5 hours (assessed at the end of the 50-minute session).

The control group consisted of 23 non-smokers (12 males and 11 females), with a mean age of 23.6 years (SD = 4.6) who reported never having smoked regularly. The smoker and control groups did not differ significantly in age, t < 1, or gender ratio, χ² = 0.03, NS. Two additional non-smokers were tested, but were excluded from
the analyses because they were extreme outliers [1] as they reported smoking 30 or more cigarettes in their lifetime, whereas the mean for the control group was 2.6 cigarettes in their lifetime (SD = 3.8). Additional selection criteria for all participants were that they spoke fluent English and had visual acuity within normal limits.

Materials

The pictorial stimuli were similar to those used by Bradley et al. (2003). They consisted of 20 color photographs of smoking-related scenes (e.g., woman holding cigarette to mouth, cigarette beside ashtray). Each was paired with a photograph of another scene matched as closely as possible for content, but lacking any smoking-related cues (e.g., woman applying lipstick, pen beside bowl). An additional 20 picture pairs (unrelated to smoking) were used as fillers, and three pairs for practice and buffer trials. Four of the smoking-control picture pairs from our previous study were replaced so that the smoking pictures depicted the act of smoking more clearly. The pictures were digitized using an indexed 256 color palette.

The tasks were presented on a 450 Mhz Pentium III PC, with 15” VGA monitor, attached to a MEL version 2 response box and standard keyboard. Participants’ horizontal eye movements were recorded while they completed the visual probe task using a computerized eye tracking system (Pan/Tilt optics system, Model 504, Applied Science Laboratories, Bedford, MA, USA), which uses infra-red beams directed at the eye. The eye movement software was run on a 333 Mhz Pentium Celeron PC.

Procedure

Testing took place in a dimly lit, soundproofed room. First, participants provided informed consent and their visual acuity was measured with a Snellen chart to check that it was within normal limits (20/20 or more; no one was excluded on this basis). Participants were then seated at a desk, at a distance of 111 cm from the monitor. The eye tracker sensors were placed on the desk, 50 cm in front of the participant, below their right eye. The eye tracking equipment was calibrated by displaying the numbers 1–9 on the screen in a 3 × 3 array (with 1 at the top left of the screen and 9 at the bottom right), and participants were asked to look at each number in turn while their gaze direction was recorded.

In the visual probe task, each trial started with a central fixation cross shown for 1000 ms, which was replaced by the display of a pair of pictures, side by side, for 2000 ms. Immediately after the offset of the picture pair, a probe was presented in the position of one of the preceding pictures, until the participant gave a manual response. The probe was a pair of dots (either ‘.’ or ‘...’). Participants were instructed to press one of two response buttons to indicate the identity of the probe. They were also instructed to look at the fixation cross at the start of each trial, to sit completely still throughout the task and to refrain from moving their head during each trial. There was an intertrial interval of 2000 ms. The task was presented using MEL version 2.01 software (Schneider 1995). EM data were recorded during each trial, starting immediately before the onset of the fixation cross and terminating immediately after the participant had made a response.

There were 14 practice trials, followed by two buffer trials and 120 trials in the main task (80 critical trials and 40 filler trials). During the critical trials, each of the 20 smoking-control picture pairs was presented four times. Each smoking-related picture appeared twice on the left side of the screen and twice on the right. The probe appeared in the location of either the smoking-related or the control picture with equal frequency and there was an equal number of trials with each probe type. The 20 filler picture pairs were presented twice each. Critical and filler trials were presented in a new random order for each participant. Each picture was 95 mm high by 130 mm wide when displayed on the screen, and the distance between their inner edges was 30 mm. The distance between the two probe positions was 105 mm (visual angle of 5.4 degrees).

Immediately after the visual probe task, participants in the smoker group were asked to indicate ‘how strong your urge to smoke is right now’ on an anchored rating scale which ranged from 0 (not at all) to 10 (extremely). Participants then completed the picture rating task and the SRC task; the order of these tasks was counterbalanced across participants.

The picture rating task consisted of two practice trials, which used filler pictures, followed by 40 test trials in which each smoking-related picture and control picture from the visual probe task was presented, one at a time, in a new random order for each participant. Each picture (73 mm × 100 mm) was presented for 2000 ms and, after a pause of 500 ms a seven-point anchored rating scale was displayed on the screen until the participant’s response. The rating scale ranged from −3 (very unpleasant) to +3 (very pleasant), and participants were asked to press one of seven keys, which were correspondingly labelled from −3 to +3, to indicate how pleasant or unpleasant they found each picture. The intertrial interval was 500 ms. The task was presented using MEL version 2.01 software.

The SRC task consisted of two blocks, each of 100 trials. In each trial, a picture was displayed in the centre of the screen and a manikin figure was presented either above or below the picture. The picture was either a
smoking-related or a control picture (which were those used in critical trials of the visual probe task). Each block of trials had a different stimulus–response assignment: in assignment 1, participants were instructed to move the manikin towards the picture if it depicted a smoking-related scene, and away from the picture if the scene was not smoking-related. In assignment 2, these stimulus–response relationships were reversed (i.e. participants were instructed to move the manikin away from smoking-related pictures, and towards smoking-unrelated pictures). The order of assignments 1 and 2 was counterbalanced across participants.

For each assignment there were 20 practice trials, in which 10 smoking-related and 10 control pictures were presented, followed by 80 test trials, with a short break after 40 trials. During the test trials, each of the 20 smoking-related and 20 control pictures was presented twice. Each picture was 115 mm high x 145 mm wide, and the manikin (a matchstick figure of a man) was approximately 18 mm high by 10 mm wide, which was presented either 25 mm above or below the picture. The manikin appeared above the picture on 50% of trials, and below it on the other 50%. Participants responded by pressing the up or down arrows on the keyboard, which moved the manikin figure up or down the screen, respectively. The picture and manikin disappeared as soon as the manikin reached the edge of the screen or the picture. There was a 500-ms interval between trials. The latency was recorded between each picture onset and the response. Within each assignment block the trials were presented in a new random order for each participant, so that picture type and manikin position varied over trials. The SRC task avoids a direct one-to-one mapping between the required response on each trial and the approach/avoid instructions because, within each block, the manikin appeared above the pictures on half the trials (when ‘approach smoking’ required a ‘down’ response to smoking-related pictures) and below the pictures on the other half of trials (when ‘approach smoking’ required a ‘up’ response to smoking-related pictures). The SRC task was programmed in Turbo Pascal.

After the computer tasks, participants in the smoking group completed the Questionnaire of Smoking Urges—brief form (QSU, Tiffany & Drobles 1991; Cox, Tiffany & Christen 2001), shortened state and trait versions of the tension–anxiety, depression and vigour scales of the Profile of Mood States (POMS, with six items per scale, McNair, Lorr & Droppleman 1981), the Fagerstrom Test for Nicotine Dependence (FTND, Heatherton et al. 1991) and questionnaires about smoking habits and history, and attitudes to smoking. The latter comprised four items about the perceived aversiveness of smoking [How irritating do you find cigarette smoke in public places (e.g. pubs, restaurants)? If you walk into a room how likely is it that you would notice someone smoking? How likely is it that you would avoid sitting next to someone who is smoking? In general how bothered or upset do you feel by other people smoking?]. Responses to each item were given on a nine-point anchored scale ranging from 0 (not at all) to 8 (extremely), and scores were averaged across the items to provide an overall index of negative attitudes to smoking. Participants in the non-smoker group completed the POMS, the attitudes to smoking questionnaire and answered questions about their smoking experience (e.g. ‘How many cigarettes have you smoked in your lifetime?’). After completing the questionnaires, participants were debriefed, thanked for their time, and paid £7 sterling.

Preparation of eye movement data

Data were analysed using the Eyenial Data Analysis Program (Applied Science Laboratories, Bedford, MA, USA). The direction of gaze, measured in degrees, was measured once every 17 ms. If eye movements were stable within one visual degree for 100 ms or more, this was classified as a fixation to that position, the duration of which could be recorded. Fixation latency was calculated as the interval between picture onset and the onset of the first fixation. Fixations were classified as being directed at the left or right pictures if they were more than 1.03 degrees wide of the central position (the position that had been occupied by the fixation cross before picture onset) on the horizontal plane.

Eye movement (EM) data were analysed from critical trials in which only smoking-related and control pictures were presented. Initial fixations on either picture were identified if (a) participants were fixated in the central region before picture onset, (b) EMs occurred at least 100 ms after picture onset (fixations with shorter latencies are unlikely to be contingent on the pictures, and may instead reflect express saccades or anticipatory eye movements; Fischer & Weber 1993) and before picture offset, and (c) fixations were directed at either picture, rather than remaining at the central position during picture presentation. In accordance with previous studies (e.g. Bradley et al. 2000; Mogg et al. 2000), participants with excessive missing data were excluded from the EM analyses to avoid problems of floor effects. Thus, data from four participants (all non-smokers) were excluded because fixations on the pictures were recorded on fewer than 15% of the 80 critical trials for these participants, which was due mainly to calibration difficulties (e.g. gaze not centrally fixated before picture onset) or because no fixation was detected for either picture, but occurred instead only to the probe. Due to technical problems with the eye tracking equipment, no EM data were recorded from another non-smoker. Thus, in the analyses of the
EM direction and latency data, there were 20 smokers and 18 non-smokers. These participants made a fixation to one of the pictures on average on 7.3% of the 80 critical trials which presented smoking-control picture pairs (they were not fixated on the central cross before picture onset on 22% of trials, and a fixation was not made to either picture on 4% of trials), with no significant difference between the groups in the number of trials providing EM data.

The mean duration of initial fixations was calculated separately for smoking and control pictures for each participant. Before calculating these means, fixation durations which persisted beyond picture offset, or those which were more than 3 SD above each participants’ mean (1% of data) were excluded in order to reduce the influence of outliers. To avoid floor effects, means were not calculated if there were less than four trials with duration data for each picture type; one smoker was excluded from these analyses because of insufficient fixation duration data.

RESULTS

Eye movement data

Direction of initial fixation

A direction bias score was calculated for each participant by expressing the number of trials when the EM was directed initially towards the smoking-related picture as a proportion of the total number of trials in which an EM was made to either the smoking-related or control picture. Scores greater than 50% reflect a bias in orienting towards smoking-related pictures, relative to control pictures (50% indicates no bias). To test our hypothesis that smokers preferentially orient their attention to smoking pictures rather than control pictures, their bias scores were compared with 50%. Smokers made their first fixation to the smoking-related picture on 54.0% of trials (SD = 6.3), which is significantly greater than 50%, t(19) = 2.84, P < 0.05. Non-smokers made their first fixation to the smoking picture on 50.4% of trials (SD = 7.4), which does not significantly differ from 50%, t < 1, NS. However, comparison of the two groups on their direction bias scores did not show a significant result, t(36) = 1.63, P = 0.11.

Duration of initial fixation

The mean duration of initial fixations for each picture type and group is shown in Fig. 1. A mixed design 2 × 2 analysis of variance (ANOVA) of the duration data, with picture type (smoking-related, control) as the within-subjects variable and group (smokers, non-smokers) as the between-subjects variable, showed a significant picture type–group interaction (F1,35 = 5.73, P < 0.05). Within-group contrasts showed that smokers had longer fixation durations for smoking-related pictures than control pictures (409 ms versus 369 ms, t(18) = 2.50, P < 0.05), whereas non-smokers showed no significant difference in their fixation durations for smoking-related and control pictures (409 ms versus 428 ms, t(17) = 1.01, NS).

Latency of initial fixation

Mean latencies of fixations for each picture type were calculated after excluding latencies more than 3 SD above each participant’s mean as outliers. Mean latencies of fixations on smoking and control pictures were 312 ms and 311 ms, respectively, for smokers and 387 ms and 418 ms for non-smokers. A 2 × 2 ANOVA, with group (smokers, non-smokers) and picture type (smoking-related, control) as independent variables, showed a significant main effect of group, F1,16 = 6.42, P < 0.05, as smokers had shorter latencies overall than non-smokers. There were no other significant results.

Visual probe task: manual RTs to probes

RT data from filler trials, and from trials with errors (2% of data), were discarded. Consistent with previous research (e.g. Mogg et al., 1997; Bradley et al., 2000), data from one participant (a smoker) were excluded from these analyses because of an outlying high error rate (23% of trials). In addition, RTs more than 3 SD above the mean were excluded as outliers (4% of data) [2]. A 2 × 2 ANOVA of the probe RT data with group (smokers, non-smokers) as the between-subject variable, and probe position (probe

Figure 1 Mean duration of initial fixations (in ms with standard error bars) on smoking-related and control pictures in smokers and non-smokers. *P < 0.05 refers to contrast between smoking and control pictures in smokers.

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in same versus different location to smoking picture) as the within-subject variable, showed that the predicted group × probe position interaction approximated significance, $F_{1,40} = 3.94, P = 0.054$ (see Fig. 2 for means).

To test our hypothesis that smokers have an attentional bias for smoking-related cues, a paired t-test was used to compare their mean RT to probes replacing smoking pictures with their mean RT to probes replacing control pictures. Smokers were on average 11 ms faster to respond to probes replacing smoking pictures (627 ms) relative to control pictures (638 ms), which reflects significant vigilance for smoking pictures, $t(18) = 2.27$, $P < 0.05$. Non-smokers were on average 5 ms slower to respond to probes replacing smoking pictures (609 ms) compared to control pictures (604 ms), which is not significant, $t(22) = 0.77$, NS.

**Stimulus valence measures**

**Picture rating task**

Mean pleasantness ratings were calculated for the smoking-related and control pictures for each participant. Data from one smoker and one non-smoker were missing due to technical problems. A 2 × 2 mixed design ANOVA of the ratings, with group (smokers, non-smokers) and picture type (smoking-related, control) as independent variables, showed a significant main effect of group $F_{1,39} = 120.9, P < 0.01$, picture type, $F_{1,39} = 48.3, P < 0.01$ and a significant group × picture type interaction, $F_{1,39} = 109.1, P < 0.01$, which is illustrated in Fig. 3. Smokers rated the smoking-related pictures as more pleasant than the control pictures, $t(18) = 2.43$, $P < 0.05$, whereas the reverse was true for non-smokers, who rated the smoking-related pictures as significantly more unpleasant than control pictures, $t(21) = 12.60$, $P < 0.01$.

![Figure 2](image1.png)

**Figure 2** Mean RTs to probes (in ms with standard error bars) replacing smoking-related and control pictures in smokers and non-smokers. *P < 0.05 refers to contrast between probes replacing smoking and control pictures in smokers

![Figure 3](image2.png)

**Figure 3** Mean pleasantness ratings (with standard error bars) for smoking-related and control pictures for smokers and non-smokers. *P < 0.05; **P < 0.001 refers to contrast between smoking and control pictures in smokers and non-smokers, respectively

**Stimulus–response compatibility task**

Due to technical difficulties, data from four participants (two from each group) were missing. RT data from trials with errors were discarded (5% of data) and, to eliminate outliers, RTs were excluded if they were less than 200 ms or more than 3 SD above the mean (10% of data). Our main prediction was that smokers would be faster to approach smoking-related and avoid smoking-unrelated pictures (assignment 1), compared with avoiding smoking-related pictures and approaching smoking-unrelated pictures (assignment 2), whereas non-smokers should show the converse (i.e. a group–assignment interaction effect on RTs). To test this hypothesis, a 2 × 2 mixed design ANOVA was carried out with group (smokers versus non-smokers) as a between-subjects variable, and assignment type (1) approach smoking-related and avoid smoking-unrelated pictures versus (2) avoid smoking-related and approach smoking-unrelated pictures as a within-subject variable. This showed a significant main effect of assignment type, $F_{1,37} = 24.93$, $P < 0.01$, and a significant group × assignment type interaction, $F_{1,37} = 6.90, P < 0.01$.

The group × assignment type interaction is illustrated in Fig. 4 and was clarified using paired-samples t-tests for each group. Smokers were faster to respond when instructed to approach smoking-related and avoid smoking-unrelated pictures (mean RT for assignment 1 was 712 ms) compared with when they were asked to avoid smoking-related and approach smoking-unrelated pictures (mean RT for assignment 2 was 865 ms), $t(17) = 4.46, P < 0.01$. This indicates a preferential bias in smokers to approach, rather than avoid, smoking-related cues. Non-smokers were also faster to respond during assignment 1 than during assignment 2 (796 versus 844 ms), $t(20) = 2.09, P = 0.05$. However, the magnitude of this effect (difference between RTs during assignments 1 and 2) was significantly greater in
from that of smoking-related pictures, so that positive scores reflect a more positive evaluation of smoking pictures; and (v) for the SRC task, the mean RT for assignment 1 (approach smoking, avoid control pictures) was subtracted from the mean RT for assignment 2 (avoid smoking, approach control pictures), so positive SRC bias scores reflect faster RTs when participants are instructed to approach rather than avoid smoking-related pictures, i.e. suggesting a bias to approach smoking-related cues. Pearson correlations were used to examine the relationships among the bias measures and smoking-related variables (daily cigarette intake, urge to smoke, attitudes to smoking, years of smoking, number of previous quit attempts and time since last cigarette; the latter three measures were log transformed before analyses to reduce skewness).

There were several significant intercorrelations between the attentional and valence bias measures. In smokers, longer gaze times at smoking pictures (EM duration bias) correlated positively not only with greater vigilance for them on the probe RT task (0.49, \( P < 0.05 \)), but also with more positive evaluations of smoking pictures on the rating task (0.74, \( P < 0.01 \)), and with greater approach tendencies for smoking pictures on the SRC task (0.49, \( P < 0.05 \)). The latter three measures were also intercorrelated: the probe RT bias correlated 0.56 with the pleasantness ratings bias, and 0.59 with the approach bias on SRC task (\( P < 0.05 \)). The latter two valence indices correlated 0.69 with each other (\( P < 0.01 \)).

The attentional and valence bias measures also correlated significantly with several smoking-related variables. For example, longer gaze times at smoking pictures (EM duration bias) correlated positively with increased urge to smoke, as indicated by both QSU (0.55, \( P < 0.05 \)) and the (mid-session) single-item urge rating (0.49, \( P < 0.05 \)) in smokers. Greater vigilance for smoking-related cues on the manual probe RT task was associated with longer times since smoking the last cigarette before the session (\( r = 0.51, P < 0.05 \)).

Partial correlations were used to clarify the relationships between the EM duration bias, stimulus valence measures (pleasantness rating bias; approach bias on SRC task) and urge to smoke (QSU; mid-session urge rating). When the effects of the urge measures were controlled, the gaze duration bias remained associated significantly with the pleasantness rating bias for smoking-related pictures (0.61, \( P < 0.05 \)), but not significantly with the approach bias on the SRC task (0.37, NS). When the effects of the valence measures were controlled, the gaze duration bias showed a trend to correlate with QSU (0.50, \( P < 0.07 \)). Partial correlations were also used to examine the relationships between the probe RT bias, stimulus valence measures (pleasantness ratings...
and SRC approach bias) and time since last cigarette. After controlling the time since last cigarette, the probe RT bias correlated 0.54 with the ratings bias and 0.53 with the approach bias (P < 0.05). When the effects of the valence measures were controlled, the probe RT bias was not significantly associated with time since last cigarette (0.24, NS).

In non-smokers, the EM duration bias also positively correlated with the attentional bias on the probe RT task (0.58, P < 0.05). In addition, lower pleasantness ratings of the smoking pictures were associated with more negative attitudes to smoking (−0.51, P < 0.05).

**DISCUSSION**

The results from eye movement monitoring and the probe RT data provide converging evidence of biases in visual orienting to smoking-related cues in smokers. Smokers looked longer at smoking-related pictures than control pictures, in contrast with non-smokers who spent a similar time looking at these two picture types. The results from the probe RT data also indicated vigilance for smoking-related cues in smokers, but not in non-smokers; as smokers were faster to detect probes replacing smoking-related than control pictures. With regard to the direction of the initial EM, smokers were more likely to look initially at smoking-related than control pictures, and non-smokers did not show a significant bias on this measure. However, the EM direction results are suggestive, rather than conclusive, because smokers and non-smokers did not differ significantly on this measure.

One aim of the present study was to examine whether attentional biases operate in different aspects of orienting processes, such as initial shifts versus the maintenance of attention (LaBarge 1995). Our previous visual probe study, which assessed attentional biases from manual RTs to probes, indicated that smokers were more vigilant than non-smokers for smoking-related pictures presented for 2000 ms (Bradley et al. 2003; experiment 2), which is consistent with the probe RT results from the present study. This stimulus duration of 2000 ms allows opportunity for several shifts of attention between the picture pairs before the probe appears, and so these findings suggest that smokers have a tendency to maintain attention on smoking-related cues. However, as noted earlier, the visual probe task provides a limited snap-shot view of attentional responses (i.e. at the time of offset of the pictures), whereas eye movement monitoring provides a more dynamic, ecologically valid index of visual orienting. The present finding that smokers hold their gaze longer on smoking-related than control pictures provides further evidence which is consistent with a bias in the maintenance of attention on drug-related cues.

Recent research into attentional biases in other motivational states also suggests that biases for motivationally salient stimuli operate in attentional disengagement mechanisms. Anxious individuals appear to have difficulty in disengaging their attention from mildly unpleasant stimuli (Fox et al. 2001). The present results concerning the duration of gaze similarly suggest that biases for drug-related cues may operate in attentional disengagement mechanisms. That is, once fixated on a smoking-related cue, smokers may have greater difficulty in disengaging their attention from it. The present study suggests that a bias may also operate in initial attentional shift mechanisms, as smokers preferentially directed their gaze towards smoking-related scenes, while non-smokers showed no bias; although this evidence is not conclusive as the groups did not differ significantly on this eye movement index. Although further research is required to clarify this issue, the limited evidence available so far suggests that attentional biases for smoking-related cues may operate in multiple aspects of attentional processes, as there was evidence consistent with vigilance for smoking-related cues in smokers from the three main measures of attentional bias (initial EM direction, fixation duration and manual probe RT).

A second aim of the present study was to examine the motivational and affective valence of smoking-related cues in smokers versus non-smokers using both implicit and explicit measures, and to examine the relationship between the stimulus valence and attentional bias measures. Both measures of stimulus valence showed significant differences between smokers and non-smokers in their preferences for smoking-related cues. On the picture rating task, which involves explicit evaluation of the stimuli, smokers rated the smoking-related pictures more positively than the control pictures, whereas non-smokers rated them more negatively. This pattern of results is compatible with previous research findings from rating tasks (Mucha et al. 1999).

The SRC task provides an implicit measure of stimulus valence, which is inferred from the speed of behavioural responses in a symbolic approach/avoidance paradigm. This task does not require participants to make explicit judgements about the attractiveness of the stimuli; thus, it may reflect an individual’s affective or motivational disposition towards drug cues, while being less confounded by response bias. (For example, on explicit tasks, smokers may believe that the experimenter wants them to evaluate the smoking cues positively, which may influence their ratings.) On the SRC task, smokers were faster to make approach, than avoidance, responses to smoking-related pictures, and this bias was significantly greater in smokers than non-smokers. These results suggest that smokers and non-smokers differ in their motivational disposition towards smoking-related stimuli, with smokers...
having a greater bias to approach them, which is consistent with an appetitive motivational state for smoking-related cues.

The present study also showed significant relationships between the attentional bias measures and the implicit and explicit measures of stimulus valence within smokers. The bias in duration of gaze for smoking-related pictures was associated with a greater tendency to evaluate these pictures more positively (on the rating task) and to approach them more quickly (on the SRC task), and also with a greater urge to smoke. These findings are relevant to incentive and habit-based models of drug dependence (Tiffany 1990; Robinson & Berridge 1993, 2001), which both predict attentional biases for drug-related cues, although they differ in their descriptions of the processes which mediate such biases. Robinson & Berridge (1993, 2001) suggest that attentional biases for drug-related cues are primarily mediated by an incentive-salience mechanism. As a result of this mechanism, drug-related cues acquire incentive salience, which causes them to be perceived as ‘attractive’, and to be highly noticeable and difficult to ignore. As a consequence, drug-related stimuli become ‘wanted’, capture attention and elicit approach behaviours. These processes operate outside awareness and are not mediated primarily by effortful or intentional processing strategies; the consequence of high levels of incentive salience is the subjective experience of craving.

According to Tiffany’s (1990) schema model, drug-taking behaviour is driven primarily by habit, but when it is impeded or obstructed the person experiences an increase in drug urges, and non-automatic, effortful processing resources are recruited to pursue the goal of obtaining the drug. Hence, when the drug is not available, the person will experience increased drug urges, accompanied by an attentional bias for drug-related cues. Recent research suggests that both incentive and habit-based mechanisms contribute to the maintenance of drug dependence (see reviews by Di Chiara 2000; Everitt, Dickinson & Robbins 2001), so these models may be regarded as complementary, rather than mutually exclusive.

The present findings appear compatible with the incentive salience model, in that smokers showed enhanced attention to smoking cues, in particular, from the duration of gaze; they rated the smoking cues more positively (which is consistent with increased perceived attractiveness); and also showed faster approach tendencies for smoking-related cues on the SRC task. Moreover, the finding that these three measures (i.e. gaze duration, valence ratings and approach tendencies) were intercorrelated significantly within smokers would seem consistent with the view that these cognitive and behavioural responses to drug-related cues are mediated by a common underlying mechanism of incentive motivation. According to Robinson & Berridge (1993), the perceived attractiveness of drug-related cues and their ability to capture attention are fundamental features of incentive-salience, which in turn reflects the degree of activation of the dopamine systems that mediate addictive behaviour. Thus, the eye movement measure of gaze duration may provide an invaluable objective index of the strength of activation of incentive motivation processes, which are proposed to play a critical role not only in maintaining drug-taking behaviour, but also in underlying individual differences in vulnerability to addiction (Robinson & Berridge 2001). An important potential advantage of the eye movement index of attentional bias is that it does not involve subjective self-report, or introspection, and so may be more likely to reflect the postulated automatic, non-conscious incentive salience processes. Thus, it would seem a useful goal for future research to investigate the extent to which this eye movement index of attentional capture is predictive of smoking behaviour, such as relapse after attempts at abstinence.

The present finding of an association between longer gaze duration for smoking pictures and increased urge to smoke is also consistent with Tiffany’s (1990) model which proposes that, when the drug is not readily available, drug urges play an important role in mobilizing drug-seeking behaviours and eliciting attentional biases for drug cues. However, partial correlations indicated that the relationship between the bias measures of gaze duration and the subjective attractiveness of the smoking-related pictures appeared to be independent of the effect of urge to smoke, which suggests that the subjective experience of drug urge is not the paramount factor mediating attentional biases. However, the smokers in the present study were relatively young and not heavily dependent, as just over half the sample (60%) smoked less than 20 cigarettes per day and the majority (75%) had smoked for less than 7 years. In addition, the present study did not manipulate deprivation level, so urge to smoke may not have been very high in many participants. Thus, it would be helpful for future research to examine whether the relationships between the attentional bias, stimulus valence measures and urge to smoke, which were observed in the present study, generalize to samples of heavier, long-term smokers tested under deprived versus non-deprived conditions.

Furthermore, it would be helpful to investigate whether the attentional bias plays a maintaining role in addiction (e.g. in eliciting drug-seeking behaviour), or whether it is largely a consequence of drug dependence. If the latter, it may still be important, both theoretically and practically, as an index of activation of the incentive salience system. Unfortunately, such issues cannot be resolved by the present study.
The present study is the first to use eye movement monitoring, in combination with an experimental index of attentional bias from the visual probe task, in order to examine attentional biases in smokers. There has been little previous research assessing eye movement responses to drug cues in addiction. One exception is a study of crack-cocaine users, which suggested that increased craving is associated with enhanced overt orienting to drug cues (Rosse et al. 1993). This preliminary study examined visual scan paths for only two stimuli (a cocaine pipe and flower) and lacked a control group of participants. Nevertheless, these results from cocaine addicts suggest similarly that eye movements to drug cues may provide a useful index of the intensity of a person’s motivation to use drugs.

In summary, the present study provides evidence of attentional and evaluative biases for drug cues in smokers. Compared to non-smokers, smokers looked longer initially at smoking-related cues, evaluated such cues more positively, and showed greater behavioural approach tendencies for smoking-related cues on the SRC task. The gaze duration measure of attentional bias and implicit and explicit measures of stimulus valence were intercorrelated, suggesting that they may be mediated by a common underlying mechanism. The present findings suggest that the gaze duration measure of attentional bias may provide a useful, objective index of the degree of activation of appetitive motivational mechanisms, which may play a key role in causing and maintaining drug dependence.

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NOTES

[1] For non-smokers, the median number of cigarettes smoked per life-time was 1.0, upper quartile = 5, interquartile range = 5. The two participants who smoked 30 or more cigarettes per life-time were identified by a box-and-whisker plot as ‘extreme’ outliers (defined in SPSS as values more than three times the interquartile range above the upper quartile) and, because this showed that they were unrepresentative of non-smokers, they were excluded to preserve the integrity of the sample. Importantly, their exclusion did not alter the pattern of significant findings from the eye movement data. The group × probe position interaction in the manual RT data of the visual probe task fell from the 0.054 to the 0.08 level of significance, although the significance of the hypothesis-driven contrasts in the RT data was unchanged by the exclusion of these two participants.

[2] For the visual probe task data, no short RT outliers were detected using box-and-whisker plots, so no lower cut-off was required for these analyses. For the SRC task, box-and-whisker plots indicated one short RT outlier that was less than 200 ms, which was likely to be an anticipatory response, and consequently was eliminated.

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