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DO Current and Former Cigarette Smokers have an Attentional Bias for E-cigarette Cues?

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Abstract

The similarity of e-cigarettes to tobacco cigarettes with regard to shape and usage raises the question of whether e-cigarette cues have the same incentive motivational properties as tobacco cigarette cues. The objective of the present study was to examine whether e-cigarette cues capture and hold smokers' and former smokers' attention and whether the attentional focus is associated with subsequent craving for tobacco cigarettes. It was also examined whether device type (cigalike or mod) moderated this relationship. Participants (46 current daily smokers, 38 former smokers, 48 non-smokers) were randomly assigned to a device type condition in which their eye-movements were assessed while completing a visual probe task. Craving was assessed before and after the task. Smokers, but not former or non-smokers, maintained their gaze longer on e-cigarette than on neutral pictures ($p = 0.004$). No difference in dwell time was found between device type. None of the smoking status groups showed faster initial fixations or faster reaction times to e-cigarette compared with neutral cues. Baseline craving was associated with dwell time on e-cigarette cues ($p = 0.004$). Longer dwell time on e-cigarette cues was associated with more favorable attitudes towards e-cigarettes. These findings indicate that e-cigarette cues may contribute to craving for tobacco cigarettes and suggest the potential regulation of e-cigarette marketing.

Keywords

Attention; craving; e-cigarette; eye-tracking

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Introduction

Several theories have attributed an important role of selective attention to the development and maintenance of drug taking behavior, as well as to the occurrence of relapse. One of the most discussed theories is the incentive sensitization theory of drug addiction by Robinson and Berridge (Berridge et al., 2009; Field and Franken, 2015; Robinson and Berridge, 1993, 2001, 2008). It is proposed that through classical conditioning substance-related cues acquire incentive motivational properties and are able to produce a conditioned dopamine response themselves. Repeated cigarette smoking causes a neural sensitization in the reward systems of the brain, leading to a stronger dopamine release each time one smokes. Cues that are often paired with smoking thus become associated with its pleasurable outcome. This leads to an attribution of incentive salience to the perception and mental representation of those cues. As a result, cues become attractive, desired and capable of capturing attention automatically. Those cues can further induce incentive salience (“wanting”) by activating the mesolimbic dopamine system and an urge to smoke, which may foster automatic approach tendencies. In addition, attentional bias and craving further diminish cognitive resources required for coping strategies, and therefore smoking behavior is more likely to occur.

First generation e-cigarettes (i.e. “cigalikes”) resemble the shape of cigarettes, while second and third generation e-cigarettes (i.e. “mods”) are overall larger and look less like tobacco cigarettes. Independent of the shape of the device, the act of vaping still involves inhaling and exhaling vapor, similar to inhaling and exhaling tobacco smoke (Maloney and Cappella, 2016). The similarity of e-cigarettes to tobacco cigarettes with regard to shape and usage raises the question whether e-cigarette cues have the same incentive motivational properties as tobacco cigarette cues and therefore affect smokers’ attention and subsequently their craving for tobacco cigarettes. Tobacco and e-cigarette companies are promoting e-cigarettes on television, on the internet, through outdoor advertisements, promotional campaigns and on social media (de Andrade et al., 2013; Hua et al., 2013; Richardson et al., 2014a,b; Yamin et al., 2010). Research has shown that the marketing of e-cigarettes has increased heavily in the past five years (Noel et al., 2011), exposing people more frequently to e-cigarette cues. Moreover, previous research has shown that the exposure to *in vivo* e-cigarette use increased young adult smokers’ craving for tobacco cigarettes (King et al., 2014, 2017). In studies on the exposure to e-cigarette advertisements, smokers reported increases in their craving for tobacco cigarettes (Kim et al., 2013; King et al., 2016; Maloney and Cappella, 2016) and former smokers showed decreased abstinence efforts (Maloney and Cappella, 2016). However, it remains unclear whether e-cigarette cues capture and hold smokers’ attention and whether the attentional focus is associated with smokers’ craving for tobacco cigarettes when exposed to visual depictions of e-cigarette cues. Given the impact that e-cigarettes might have on the consumption of tobacco cigarettes, it is important to understand *how* the exposure to e-cigarette cues affects smokers and former smokers.

To assess biases in the attentional processing of smoking cues, a range of indirect measures, like the Stroop task or the Visual probe task (VPT), as well as direct measures, such as eye movement paradigms (e.g. monitoring participants’ eye movements while completing a VPT) have been used. Eye-tracking paradigms are considered to be a preferred method for investigating attentional biases as they provide a direct measure of attention and do not infer

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attentional processes on the basis of reaction times (Field et al., 2009). Moreover, compared with indirect measures, direct measures have an increased internal reliability (Ataya et al., 2012; Christiansen et al., 2015; Field and Christiansen, 2012). In a smoking VPT, a pair of pictures is presented simultaneously, one picture being smoking-related and the other unrelated to smoking. After a certain exposure time, the pictures disappear and a probe appears in the location of one of them. Participants are requested to indicate the identity of the probe as quickly as possible by pressing one of two possible keys. In VPTs, the exposure duration (the stimulus onset asynchrony (SOA)) has been manipulated in order to investigate different aspects of attention (initial orienting versus maintenance/delayed disengagement of attention) (Field and Cox, 2008). The direction of the initial shift of gaze (when two or more pictures are presented simultaneously) can be examined by presenting pictures briefly (SOA < 200 ms). A longer stimulus exposure (> 500 ms) provides the possibility to make multiple shifts in attention between the two stimuli which allows for investigating the maintenance/delayed disengagement of attention (Field and Cox, 2008). Eye-tracking allows for assessing the initial shift of gaze as well as maintenance/delayed disengagement of attention. Several studies have revealed that smokers have a bias in the maintenance of attention (Bradley et al., 2003; Bradley et al., 2004; Mogg et al., 2003) and in initial orienting to smoking-related cues (Bradley et al., 2004; Field et al., 2004). However, the only study assessing smokers' attentional bias to smoking cues using an eye-tracking VPT has found a significant bias effect for the maintenance of attention but not for the initial orienting of attention (Mogg et al., 2003). Research on the attentional processing of smoking cues in former smokers has been scarce. One study that used a VPT and displayed images for 500 ms found that the bias level of former smokers was between the one of non-smokers and current smokers, however, it did not significantly differ from the bias of either of those groups (Ehrman et al., 2002). Another study showed no differences between former smokers and never smokers on color-naming times for smoking-related versus control words (Munafò et al., 2003). No study has assessed the effects of smoking cues on former smokers' attentional processing using an eye-tracking paradigm. In the current study, we used an eye-tracking VPT to assess initial orienting (latency of initial fixations) as well as maintenance of attention (dwell time) to e-cigarette cues among smokers, former smokers and non-smokers (Field et al., 2006; Mogg et al., 2003; Mogg et al., 2005; Schoenmakers et al., 2008).

Understanding motivational and cognitive processes underlying the exposure to e-cigarette cues has clinical relevance as well as implications for policy regulations. Health care providers, smokers, and former smokers need to be informed about the role that e-cigarette cues might play in maintaining tobacco smoking or restarting the unwanted behavior. Moreover, if e-cigarette cues capture and hold smokers' and former smokers' attention and increase their craving for tobacco cigarettes, it will be pivotal to regulate the exposure to e-cigarette marketing or to limit content that could be deleterious to smokers or former smokers. In the US, the Food and Drug Administration (FDA) now has the legal authority to regulate e-cigarettes including their marketing (U.S. Food and Drug Administration, 2017).

The aim of the present study is therefore to investigate whether e-cigarette cues capture and hold smokers' and former smokers' attention and whether the attentional focus is associated with craving for tobacco cigarettes when exposed to visual depictions of e-cigarette cues. Using a 3 × 2 factorial design experiment, manipulating smoking status (smokers/former

smokers/non-smokers) and device type (cigalike/mod), we assessed participants' eye movements while completing a VPT. Based on previous research (Bradley et al., 2003, 2004; Field et al., 2004; Mogg et al., 2003), we hypothesized that e-cigarette cues capture and hold smokers' attentional focus faster and longer compared to non-smokers and former smokers, and that variation in smokers' attentional focus correlates with subsequently reported craving for tobacco cigarettes. Although previous research has not found differences in the attentional focus to smoking-related cues between never smokers and former smokers (Ehrman et al., 2002; Munafò et al., 2003), we aimed to explore whether the attentional focus of former smokers is associated with more favorable attitudes towards e-cigarettes and with the intention to use e-cigarettes. Furthermore, due to a greater similarity of cigalikes to tobacco cigarettes, we predicted a greater effect of cigalike pictures compared to the pictures portraying mods.

Methods

Sample and procedure

A total of 132 participants (46 current daily smokers, 38 former smokers and 48 non-smokers) took part in the study. Smokers had to fulfill the following inclusion criteria: not currently trying to quit smoking, smoking at least 10 cigarettes/day, have been smoking for a minimum of five years, have a carbon monoxide value (CO) ≥ 10 ppm at intake session (baseline CO to confirm that they are daily smokers) and a CO < 10 ppm or 50% lower than baseline at the beginning of the experimental session (to confirm their six hour smoking deprivation). Non-smokers had to have not smoked more than 100 cigarettes in their life, had to have not smoked at all in the last two years, and had to have a CO ≤ 2 ppm. Former smokers had to have not smoked in the past three months, but had to be daily smokers for at least two consecutive years and had to have a CO ≤ 2 ppm. Additional selection criteria for all participants were that they spoke fluent English and had visual acuity within normal limits (Lochbuehler et al., 2016; Mogg et al., 2003). Participants responding to advertisements were screened for eligibility by telephone and those deemed eligible were scheduled. The study consisted of two sessions. In the first session, a research assistant explained the procedure, demonstrated the equipment, and participants gave informed consent. Then, participants provided a CO breath sample to biochemically verify their smoking status and completed baseline questionnaires (see measures at intake session). In the experimental session, participants provided a CO breath sample to verify their six hour smoke deprivation. Next, they completed the baseline questionnaire and were seated in front of the eye-tracker. Participants were randomly assigned to either the cigalike or the mod condition. After completing the VPT, participants completed post-task measures. Finally, they were debriefed to the purpose of the study, had any questions answered and received \$60 compensation. The protocol was approved by the University of Pennsylvania Institutional Review Board.

Measures

Measures at Intake Session—The following demographic measures were taken: smokers' cigarettes per day, the age of their first cigarette, their readiness to consider smoking cessation (Biener and Abrams, 1991), and their nicotine dependence (Heatherton et

al., 1991). We assessed former smokers' years of regular smoking, and the age of their first cigarette. All three groups reported on their knowledge ("Have you ever heard of e-cigarettes?": yes/no) and usage of e-cigarettes ("Do you use e-cigarettes": every day/some days/not at all) (Foulds et al., 2014).

Baseline measure—Baseline craving was assessed with the QSU-B (Questionnaire of Smoking Urges - brief) (Cox et al., 2001). Participants were asked to indicate their level of agreement of 10 statements ranging from 0 (strongly disagree) to 100 (strongly agree). Cronbach's $\alpha = .98$. The QSU-B measure is a well validated and used assessment of urge to smoke (Cox et al., 2001).

Eye-tracking VPT—The VPTs were programmed in *Paradigm* (Perception Research Systems, 2007). Participants were seated at a desk, at a distance of 60 cm from the monitor. Then the eye-tracking equipment was calibrated (Falcone et al., 2013; Lochbuehler et al., 2016; Strasser et al., 2012). Each VPT consisted of 106 trials. The task commenced with eight practice trials and consisted of 96 trials in the main task (64 critical trials and 32 filler trials) which were divided into two blocks of 48 trials. Each trial started with a central fixation cross which was shown for 1000 ms. The fixation cross was replaced by two pictures (an e-cigarette-related and its matching neutral picture). The two pictures were presented side by side for 2000 ms. After the presentation of the picture pair, a probe replaced the position of one of the pictures, until the participant gave a manual response. The probe was a small arrow pointing either up or down. The distance between the two probe positions was 105 mm. Participants were instructed to press one of two keys on the keyboard to indicate the identity of the probe (arrow pointing up or down) as quickly as possible while avoiding mistakes. Participants were also instructed to look at the fixation cross at the start of each trial. There was an inter-trial interval of 1000 ms. Eye movement data were recorded during each trial, starting immediately before the onset of the fixation cross and terminating immediately after the participant has made a response. During the critical trials, each of the 16 picture pairs was presented four times. Each e-cigarette picture appeared twice on the left side of the screen and twice on the right. The probe appeared in the location of either the e-cigarette or the neutral picture with equal frequency. The 16 filler picture pairs were each presented twice. Critical and filler trials were presented in a new random order for each participant (Christiansen et al., 2015; Mogg et al., 2003, 2005). Participants' horizontal eye movements were recorded while they completed the VPT using a computerized eye-tracking system (Pan/Tilt optics system, Model 504, Applied Science Laboratories, Bedford, MA, USA), and reaction times to probes were measured on each trial. Each VPT yielded three measures of attentional bias, one based on reaction time, the other two based on eye movements (latency of initial fixation, dwell time).

Stimulus material—The cigalike as well as the mod VPT consisted of 16 e-cigarette pictures that represented different cigalike- or mod-related scenes respectively. All pictures were created in house in order to pair each picture with a picture of another scene matched as closely as possible for structural content and perceptual characteristics, but lacking any e-cigarette-related cues (Field and Cox, 2008). An example of a picture pair: woman using an e-cigarette and woman applying lipstick. In the cigalike VPT, six pictures included parts of a

person (hand or lower part of a face) while in the mod VPT 8 pictures portrayed a person actively using an e-cigarette. An additional 26 picture pairs (unrelated to e-cigarettes) were used in the practice and filler trials. All pictures were taken in the same room with similar perspectives and were scanned into a computer and resized to the same dimensions. Each picture was 95 mm high and 130 mm wide. The pictures were displayed on a 20 inch Dell color monitor, and the distance between their inner edges was 30 mm.

Post-task measures—We assessed craving for tobacco cigarettes with the brief QSU (Cox et al., 2001), Cronbach's $\alpha = 0.98$; intentions to use e-cigarettes were assessed with the items "I would use an e-cigarette if my friend were to offer me one," "I intend to buy an e-cigarette in the next 3 months," and "I will use an e-cigarette if free samples are given out." Answer categories ranged on a five point scale from strongly disagree (0) to strongly agree (4). Cronbach's $\alpha = 0.89$ (Maloney and Cappella, 2016); attitudes towards using e-cigarettes were assessed with six items measured on a seven point scale. Example items are: "Using e-cigarettes in the next three months would be unpleasant (1)/pleasant (7), harmful (1)/beneficial (7)." Cronbach's $\alpha = 0.96$ (Dijkstra et al., 2001).

Preparation of data

Eye movement data—Eye movement data were only analyzed from critical trials in which e-cigarette and neutral pictures were presented. 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 (Mogg et al., 2003, 2005). Fixations were classified as being directed at the left or right picture if they fell within the region that was occupied by the picture. Similar to previous studies, participants with excessive missing data (less than 15% of the critical trials) were excluded from the analyses (Bradley et al., 2000; Mogg et al., 2003). Data from six participants (one non-smoker, one smoker and four former smokers) were excluded resulting in a final sample of 45 smokers, 34 former smokers and 47 non-smokers. Missing data were mainly due to calibration difficulties (e.g., gaze not centrally fixated before picture onset) or because no fixation was detected for either picture. For each eye-tracking measure, an attentional bias score was calculated separately for each participant. Positive values of bias scores reflect an attentional bias favoring e-cigarette cues relative to neutral cues, while negative values of bias scores reflect an attentional bias towards neutral cues (attentional avoidance of e-cigarette cues). A score of zero indicates no bias (Frankland et al., 2016). The total *dwell time* was computed as the amount of time (in ms) that participants spent fixating on each picture over the 2000 ms of each trial. Attentional bias scores were computed by subtracting the mean dwell time on neutral pictures from the mean dwell time on e-cigarette pictures, so positive bias scores reflect more time spent looking at e-cigarette pictures (Christiansen et al., 2015; Mogg et al., 2005; Schoenmakers et al., 2008). *Latency of initial fixation* was calculated as the interval between picture onset and the onset of the first fixation. Initial fixations on either picture were identified if: (a) participants fixated the cross before picture onset; (b) eye movements occurred at least 100 ms after picture onset; and (c) fixations were directed at either picture, rather than remaining at the central position during picture presentation. Attentional bias scores were computed by subtracting the mean latency to e-

cigarette pictures from the mean latency of neutral pictures, so positive bias scores reflect looking faster at e-cigarette pictures (Mogg et al., 2003).

Reaction time data—Reaction times (RT) from filler trials and trials with errors were excluded (Mogg et al., 2003, 2005). RTs faster than 200 ms and slower than 2000 ms were removed prior to analysis (Christiansen et al., 2015; Frankland et al., 2016; Schoenmakers et al., 2008). Attentional bias scores were created by computing mean RTs to congruent probes (those that appeared in the same location as e-cigarette pictures) and incongruent probes (those that appeared in the same location as neutral pictures). Congruent RTs were then subtracted from incongruent RTs, so that positive values indicate relative speeding of RTs to probes replacing e-cigarette pictures (Christiansen et al., 2015; Frankland et al., 2016; Mogg et al., 2003, 2005; Schoenmakers et al., 2008).

Analysis plan

Data were analyzed in Stata (v14) and SPSS (v24). Descriptive statistics were used to characterize the overall sample by smoking status and device type. Analyses of variance (ANOVAs) and chi-square tests (χ^2) were conducted to identify potential group differences. Two independent generalized estimating equation (GEE) models tested the effects of smoking status and device type on attentional focus (dwell time bias, latency bias), controlling for age, gender, and e-cigarette use. A third GEE model regressed reaction time onto probe position (congruent/incongruent), smoking status and device type, controlling for age, gender, and e-cigarette use. We controlled for age and gender because the three smoking status groups differed significantly in those variables ($p < 0.001$). ANOVAs were performed to test differences in craving, intentions to use e-cigarettes, and attitudes towards using e-cigarettes between smoking status groups and device types controlling for e-cigarette use. GEE models were used to determine the relationship between correct variance estimates for repeated measures analyses of attentional focus and subjective responses (craving for tobacco cigarettes, intentions to use e-cigarettes, and attitudes towards using e-cigarettes).

Results

Descriptive statistics and randomization verification

Table 1 displays sample characteristics by condition and smoking status. Participants were on average 44.70 years old ($SD = 12.30$; range = 22–64), 54.8% of the sample was male, 38.1% was Caucasian and 46.8% African American. The group of 45 smokers consisted of 36 males and nine females, with a mean age of 48.09 years ($SD = 10.90$). On average, they reported smoking 13.07 cigarettes/day ($SD = 5.29$) and a low to moderate nicotine dependence ($M = 4.49$, $SD = 1.75$). They reported having smoked their first cigarette at the age of 15.22 ($SD = 3.23$). CO-levels measured at the intake session were on average 15.36 ppm ($SD = 6.53$) and at the experimental session 8.02 ($SD = 3.51$). The group of 34 former smokers (13 males and 21 females), with a mean age of 51.38 years ($SD = 9.40$) reported on average having smoked regularly for 24.53 years ($SD = 13.43$) and having stopped smoking 34.32 ($SD = 26.99$) months ago. The group of 44 non-smokers (20 males and 24 females), with a mean age of 36.07 years ($SD = 10.77$) reported not having smoked more than 100

cigarettes in their lifetime and not at all in the past two years. Six smokers reported using e-cigarettes some days and 2 former smokers reported using them on a daily basis. ANOVAs and χ^2 -tests were conducted to examine whether randomization over the device type conditions was successful. Analyses showed no differences in demographic and smoking characteristics between device type conditions. With regard to differences between the three smoking status groups, smokers and former smokers were significantly older than non-smokers ($p < 0.001$). Also, smokers and former smokers differed significantly in their gender ratio ($p < 0.001$) (see Table 1). Table 2 presents unadjusted means for dwell times, latency of initial fixations, and reaction times by smoking status.

Attentional bias scores

Dwell time—The GEE model regressing dwell time bias onto smoking status, device type, gender, age, and e-cigarette use found that smoking status ($b = 0.09$, $z = 2.88$, $p = 0.004$), gender ($b = -0.06$, $z = -2.05$, $p = 0.04$), and e-cigarette use ($b = -0.20$, $z = -2.34$, $p = 0.02$) were significant predictors of dwell time bias (Table 3). Smokers were more likely to favor e-cigarette cues relative to neutral cues than non-smokers and former smokers. Also, women were more likely to favor e-cigarette cues relative to neutral cues than men. There were no significant interaction effects.

Latency of initial fixation—The GEE model regressing latency bias onto smoking status, device type, gender, age, and e-cigarette use found no significant predictors of latency bias.

Reaction time

The GEE model regressing reaction time onto smoking status, device type, probe position, gender, age, and e-cigarette use found that smoking status ($b = 84.77$, $z = 2.52$, $p = 0.01$), and age ($b = 3.79$, $z = 3.13$, $p = 0.002$) were significant predictors of reaction time (Table 4). There were no significant interaction effects with probe position. Smokers, compared with non-smokers and former smokers, were slower in reacting to congruent as well as incongruent probes. Also, older participants were more likely to have longer reaction times.

Subjective responses

Craving assessed before and after the VPT were highly correlated ($r(122) = 0.99$, $p < 0.001$). Repeated-measures ANOVAs were conducted to examine change in craving over time using smoking group and condition as between-subject factors, and time as within-subject factor. There was no significant effect of time ($F(1, 116) = 0.05$, $p = 0.82$) or condition ($F(1, 116) = .12$, $p = 0.73$), but a significant effect of smoking group ($F(2, 116) = 169.39$, $p < .001$) on craving. Smokers reported higher craving levels (before: $M = 62.14$, $SD = 27.91$; after: $M = 62.90$, $SD = 26.96$) than former smokers (before: $M = 3.33$, $SD = 7.77$; after: $M = 3.83$, $SD = 11.83$). A 2×3 ANOVA of intentions to use e-cigarettes, with condition (cigalike, mod) and smoking group (smokers, former smokers, non-smokers) as independent variables, controlling for e-cigarette use, showed significant effects of the smoking group, $F(2, 115) = 55.13$, $p < 0.001$. Smokers had higher intentions to use e-cigarettes ($M = 2.02$, $SD = 0.92$) than former smokers ($M = 0.53$, $SD = 1.08$) and non-smokers ($M = 0.42$, $SD = 0.59$). The interaction effect and the main effect of condition were not significant. A 2×3 ANOVA of attitudes towards using e-cigarettes, with condition (cigalike, mod) and smoking group

(smokers, former smokers, non-smokers) as independent variables, controlling for e-cigarette use, showed significant effects of smoking group, $F(2, 110) = 50.20, p < 0.001$. Smokers had more favorable attitudes towards e-cigarettes ($M = 4.56, SD = 1.54$) than former smokers ($M = 1.87, SD = 1.63$) and non-smokers ($M = 1.68, SD = 1.26$). The interaction effect and the main effect of condition were not significant.

Relationship between attention measures and subjective responses

GEE models were performed to test the associations between attention measures and craving for tobacco cigarettes, intentions to use e-cigarettes and attitudes towards using e-cigarettes. All models controlled for e-cigarette use. Baseline craving ($b = 0.001, z = 2.86, p = 0.004$) and e-cigarette use ($b = -0.21, z = -2.42, p = 0.02$) significantly predicted dwell time bias. The lack of change in craving over time did not allow testing as to whether dwell time bias predicted subsequent craving. Dwell time bias significantly predicted attitudes towards using e-cigarettes ($b = 0.02, z = 2.61, p = 0.01$), but did not predict intentions to use e-cigarettes ($b = 0.02, z = 3.18, p = 0.17$). Latency bias did not significantly predict intentions to use e-cigarettes ($p = 0.48$), or attitudes towards using e-cigarettes ($p = 0.26$). Reaction time bias also did not significantly predict intentions to use e-cigarettes ($p = 0.27$), or attitudes towards using e-cigarettes ($p = 0.80$).

Discussion

This study showed that current smokers have an attentional bias for e-cigarette cues, as indicated by their longer dwell time on such cues compared to neutral cues. Results did not differ by device type; cigalike and mod cues evenly affected viewing. Craving did not significantly change over time, but baseline craving significantly predicted dwell time bias. Dwell time was also associated with more favorable attitudes towards e-cigarettes. In contrast, other measures of attentional bias (latency of initial fixations and reaction time to probes) neither showed significant differences in time to e-cigarette compared to neutral cues, nor differences between smoking status groups.

The results on dwell time support previous research on smoking-related cues in smokers. Previous studies have shown that smokers, compared to non-smokers, maintained their gaze longer on smoking-related cues than on neutral cues (Bradley et al., 2003, 2004; Mogg et al., 2003). The results of previous research on smokers' initial fixations towards smoking-related cues, compared to neutral cues, is mixed. While two studies (Bradley et al., 2004; Field et al., 2004) found preferential initial shifts in gaze toward smoking-related pictures using VPTs in smokers, the only study using an eye-tracking smoking VPT found no significant bias effect for the initial orienting of attention (Mogg et al., 2003). In the current study, smoking groups did not differ in their initial shift in gaze. Although the attentional bias effect was found with the dwell time measure, the concurrent reaction time measure did not show such an effect. A possible reason for the inconsistent finding might be that the reaction time measure only assesses the focus of attention at a single point in time during the trial (i.e., at the offset of the pictures) (Mogg et al., 2005). However, eye movement data provide the possibility to assess attention during the entire length of cue presentation as represented by the overall dwell time. Regarding the reaction time results, smokers and older participants

demonstrated overall slower reaction times independent of the position of the probe (replacing e-cigarette or neutral cues). Slower overall reaction time in smokers might be explained by their smoking deprivation as research has shown that nicotine withdrawal is associated with deficits in cognitive functioning (e.g., Ashare, 2014). The results of the current study suggest that e-cigarette cues affect certain aspects of attention differently. While e-cigarette cues do not influence the initial attention-grabbing properties, they do affect the maintenance of attention. The dwell time measure, which reflects a bias to hold attention on motivationally salient cues (LaBerge, 1995; Mogg, 2005), demonstrates that e-cigarette cues hold smokers' attention longer than neutral cues. Once fixated on an e-cigarette cue, smokers have greater difficulty in disengaging their attention from it.

In accordance with previous research (Ehrman et al., 2002; Munafò et al., 2003), former smokers, compared to smokers, did not show a longer dwell time on e-cigarette compared to neutral cues. Scholars have suggested that through successful smoking cessation neuroadaptations in dopaminergic pathways might be reversed (Munafò et al., 2003). Also, SOAs of 2000 ms provide the opportunity for the influence of controlled processes (like self-regulation strategies). Former smokers might direct attention away from e-cigarette cues in order to support abstinence (Frankland et al., 2016). Although former smokers did not show an attentional bias for e-cigarette cues, individual differences in the attentional bias were associated with more favorable attitudes towards using e-cigarettes. Future research is needed to examine whether certain smoking characteristics are associated with the attentional processing of e-cigarette cues in former smokers.

Some limitations need to be acknowledged. First, due to lack of change in craving scores over time, the question whether variation in dwell time is associated with subsequent craving, could not be answered. The results of the current study did show that baseline craving significantly predicted dwell time to e-cigarette cues which might indicate that e-cigarette cues affect the feedback loop between attention and craving. Franken (2003) suggested that attentional bias and craving have reciprocal effects on each other. Once a smoker is exposed to a smoking-related cue, (s)he experiences craving, which in turn leads to increased attention to substance-related cues. This mutual activation continues until the substance is finally sought out and administered. However, subsequent designs in future research could use different stimulus material that produces change in craving and/or could abstain from smoking deprivation in smokers in order to address this question. Second, the current study was not designed to examine a causal relationship between attentional processing of e-cigarette cues and craving. Independently of the lack of change in craving, an association between dwell time and subsequent craving could not have been interpreted as causal. Further research should examine whether attentional focus to e-cigarette cues leads to craving for tobacco cigarettes. Third, the assessment of smoking characteristics of the group of former smokers was incomplete. A more complete characterization of the former smoker group would allow a better comparison with the current smoker group across several key variables that might impact their sensitivity to e-cigarette cues.

The results of the current study are of clinical importance as they provide important information to health care providers and smokers about how e-cigarette cues contribute to craving for tobacco cigarettes. The results of this study also inform the regulation of e-

cigarette marketing, which in the US is now under control of the FDA. As pictures of e-cigarettes hold smokers attention, the regulation of e-cigarette marketing should consider the presence of e-cigarettes in advertisements. Two findings of the current study are crucial regarding the implementation of regulations. First, cues of cigalike and mod devices evenly increased smokers' dwell time to such cues which suggests that all types of e-cigarettes should fall under the regulation. Second, dwell time was positively associated with more favorable attitudes towards e-cigarettes in all smoking status groups suggesting that exposure to pictures of e-cigarettes also affect former and non-smokers. This is particularly important as research has shown that almost all e-cigarette products sold in US convenience stores contained nicotine (Marynak et al., 2017).

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Table 1

Descriptive statistics and smoking characteristics by condition and smoking status.

Characteristics	Cigalike condition			Mod condition		
	Smokers	Non-smokers	Former smokers	Smokers	Non-smokers	Former smokers
<i>N</i>	20	21	16	25	23	18
Gender male (count)	16	11	7	20	9	6
Age (<i>M, SD</i>)	48.00 (11.12)	36.52 (10.11)	51.63 (8.48)	48.16 (10.95)	35.65 (11.54)	51.17 (10.40)
Race (count)						
Caucasian	8	8	7	8	9	8
Asian	1	1	0	1	2	0
African-American	10	10	6	15	10	8
Other	1	2	3	1	2	2
Education (count)						
High School	17	6	11	18	10	12
College	2	15	4	5	11	5
CO-level intake (<i>M, SD</i>)	15.55 (6.92)	1.57 (.87)	1.63 (1.26)	15.20 (6.34)	1.22 (.52)	1.94 (1.26)
CO-level session 2 (<i>M, SD</i>)	8.10 (3.64)	1.52 (.75)	2.25 (2.18)	7.96 (3.47)	1.39 (.50)	2.33 (2.28)
Cigarettes per day (<i>M, SD</i>)	12.65 (5.20)	–	–	13.40 (5.44)	–	–
FTND (<i>M, SD</i>)	4.40 (1.79)	–	–	4.56 (1.76)	–	–
Contemplation ladder (<i>M, SD</i>)	4.55 (3.00)	–	–	4.20 (2.52)	–	–
Age of first cigarette (<i>M, SD</i>)	14.70 (2.49)	–	16.69 (4.96)	15.64 (3.71)	–	15.33 (3.96)
Months since quitting (<i>M, SD</i>)	–	–	36.30 (28.87)	–	–	32.67 (26.05)
Years regular smoking (<i>M, SD</i>)	–	–	24.03 (13.60)	–	–	24.97 (13.66)
E-cigarette awareness (yes)	19	16	12	25	17	16
E-cigarette use (count)						
Every day	0	0	1	0	0	1
Some days	3	0	0	3	0	0
Not at all	20	21	16	23	22	17
Craving before (<i>M, SD</i>)	62.35 (28.51)	–	4.56 (10.70)	61.98 (28.01)	–	2.05 (3.18)

Note. No significant differences between conditions.

Table 2

Unadjusted means (*SD*) for dwell times (ms), latency of initial fixations (ms), and reaction times (ms) by smoking status.

	Dwell time		Latency		Reaction time	
	E-cigarette pics	Neutral pics	E-cigarette pics	Neutral pics	Incongruent trial	Congruent trial
Non-smokers	743.89 (414.22)	760.85 (407.91)	538.06 (417.93)	572.89 (421.80)	776.62 (226.24)	767.72 (207.89)
Smokers	872.48 (486.65)	805.69 (458.09)	534.91 (423.11)	547.02 (423.24)	856.92 (262.12)	852.10 (258.78)
Former smokers	829.49 (410.00)	838.52 (415.35)	521.11 (419.82)	539.83 (422.49)	761.05 (181.53)	760.31 (192.99)

Table 3

Results from the GEE model regressing dwell time bias onto smoking status, device type, gender, age, and e-cigarette use.

	<i>b</i> (SE)	<i>z</i>	<i>p</i>	95% CI	Effect size
Intercept	0.29 (.10)	2.94	0.003	0.10, 0.49	0.53
Smoking status					
Non-smoker	REF	REF	REF	REF	REF
Smoker	0.09 (0.03)	2.88	0.004	0.03, 0.15	0.60
Former smoker	0.008 (0.03)	0.25	0.81	-0.06, 0.07	0.05
Device type					
Cigalike	REF	REF	REF	REF	REF
Mod	-0.001 (0.02)	-0.05	0.96	-0.05, 0.04	0.009
Gender					
Female	REF	REF	REF	REF	REF
Male	-0.05 (0.03)	-2.05	0.04	-0.10, -0.002	0.37
Age	-0.002 (0.001)	-1.45	0.15	-0.004, 0.001	0.26
E-cigarette use					
No	REF	REF	REF	REF	REF
Yes	-0.20 (0.09)	-2.34	0.02	-0.38, -0.03	0.42

Table 4

Results from the GEE model regressing reaction time onto smoking status, device type, probe position, gender, age, and e-cigarette use.

	<i>b</i> (SE)	<i>z</i>	<i>p</i>	95% CI	Effect size
Intercept	538.42 (113.67)	4.74	2.17	315.64, 761.20	0.85
Smoking status					
Non-smoker	REF	REF	REF	REF	
Smoker	84.77 (33.70)	2.52	0.01	18.72, 150.82	0.52
Former smoker	-55.79 (36.85)	-1.51	0.13	-128.02, 16.44	0.33
Device type					
Cigalike	REF	REF	REF	REF	
Mod	36.59 (25.11)	1.46	0.15	-12.63, 85.81	0.26
Probe position					
E-cigarette	-4.05 (4.05)	-1.00	0.32	-11.99, 3.89	0.18
Neutral	REF	REF	REF	REF	
Gender					
Female	REF	REF	REF	REF	
Male	-42.07 (27.67)	-1.52	0.13	-96.31, 12.17	0.27
Age	3.79 (1.21)	3.13	0.002	1.42, 6.16	0.56
E-cigarette use					
No	REF	REF	REF	REF	REF
Yes	83.50 (100.85)	0.83	0.41	-114.16, 281.16	0.15