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Attentional Bias in Smokers and E-Cigarette Users who Formerly or Currently Smoke Cigarettes: An Eye-Tracking Study

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Abstract

Rationale

Dual use of tobacco cigarettes and e-cigarettes has become increasingly common, yet little is known about how e-cigarette use influences behavioural features underlying smoking, such as attentional bias (AB).

Objectives

We aimed to examine the influence of e-cigarette use on AB towards smoking-related cues among current and former cigarette smokers using eye-tracking technology.

Methods

Participants included 62 cigarette smokers, 67 e-cigarette users (41 dual users, 26 full-switchers), 61 former cigarette smokers and 65 non-using controls. AB was assessed using a free-viewing eye-tracking task consisting of 85 slides, each displaying 4 images. Test images contained smoking-related cues. The primary outcome was relative fixation time (RFT; milliseconds). AB was calculated by subtracting mean RFT to neutral images from mean RFT to smoking-related images.

Results

Cigarette smokers, dual users and full-switchers exhibited significantly greater AB towards smoking-related cues than former smokers and non-using controls ($p \leq 0.004$). Former smokers showed AB comparable to non-using controls ($p = 0.998$). The association between baseline smoking craving and AB differed significantly between cigarette smokers and dual users, with smoking craving more strongly associated with AB among cigarette smokers than dual users. In contrast, baseline vaping craving was not reliably associated with AB towards smoking-related cues in either dual users or full-switchers.

Conclusions

Smoking-related cues retain their incentive salience among e-cigarette users who currently smoke and those who transitioned to fully e-cigarettes. Complete nicotine abstinence reduced the salience of smoking cues to levels comparable to non-using controls, suggesting partial or full reversal of neuroadaptations underlying smoking cue salience.

Introduction

Although tobacco cigarette smoking prevalence has fallen markedly in Canada, declining from 24% in 2000 to 10% in 2020, e-cigarette use or "vaping" has become increasingly common, with 6% of Canadians aged 15 years and older reporting vaping in the past 30 days in 2022 (Reid et al., 2022; Statistics Canada, 2023). E-cigarettes have been promoted as a safer alternative to smoking cigarettes, with growing evidence supporting their efficacy for smoking cessation (Lindson et al., 2024; Lindson et al., 2023). Despite reducing or quitting smoking being the primary reason for e-cigarette use (Romijnders et al., 2018), approximately 30% of e-cigarette users in Canada and the United States report smoking cigarettes concurrently (CDC, 2023; Health Canada, 2022). While dual use may represent a temporary transition toward exclusive e-cigarette use for some individuals, others continue dual use long-term (Coleman et al., 2022). Although recent evidence suggests dual users reduce cigarette consumption, they appear less likely to quit smoking than exclusive cigarette smokers or exclusive e-cigarette users (Carpenter et al., 2025; Hamoud et al., 2025). Despite growing research on the health effects of dual use, little is currently known about how e-cigarette use may influence the cognitive processes underlying smoking behaviour.

The Incentive Sensitization Theory of addiction proposes that repeated administration of an addictive drug sensitizes dopaminergic systems, increasing the incentive salience of drug-related cues and producing attentional bias (AB) (Franken, 2003; Robinson & Berridge, 1993). AB is a well-documented feature of tobacco use disorder and is believed to share a reciprocal relationship with craving, wherein increases in one strengthen the other, ultimately reinforcing drug-seeking behaviour (Field & Cox, 2008; Field et al., 2014). Consistent with this model, a number of studies have identified positive associations between AB towards smoking-related cues and smoking craving in cigarette smokers (Creswell & Skrzynski, 2021; Field et al., 2009; Mogg & Bradley, 2002; Mogg et al., 2003). Further, higher levels of AB have been found to be associated with poorer treatment responses and greater risk of relapse in a number of substance use disorders, including smoking (Powell et al., 2010; Topbaş et al., 2025; Waters et al., 2003). As e-cigarettes have been shown to effectively alleviate smoking cravings (Dawkins et al., 2013; Etter & Bullen, 2011; Harrell et al., 2015; Lindson et al., 2024; Lindson et al., 2023), their use may disrupt the reciprocal relationship between craving and AB. Research examining AB among e-cigarette users remains limited. Existing studies suggest that e-cigarette users exhibit an AB towards e-cigarette/vaping-related cues (Fitzpatrick et al., 2022; Iturralde et al., 2025), while our group's previous study found that exclusive e-cigarette users with no history of cigarette smoking also demonstrated AB towards smoking-related cues (Iturralde et al., 2025). Notably, no studies to date have investigated whether e-cigarette use influences smoking-related AB of current or former cigarette smokers.

The presence of AB in former cigarette smokers is similarly unclear. Previous studies have reported findings ranging from AB comparable to current smokers to no differences from never-smokers, with these discrepancies potentially reflecting inconsistencies in how former smokers are defined in regards to their abstinence duration (Ehrman et al., 2002; Masiero et al., 2019; Munafò et al., 2003; Peuker & Bizarro, 2014; Rehme et al., 2018). These previous studies in former smokers have relied primarily on indirect measures such as the Stroop and Visual Probe task, which infer AB from reaction times (Rahmani et al., 2024). In contrast, eye-tracking technology provides a direct and continuous assessment of attention to

visual cues in a more naturalistic setting. To date, no research has utilized eye-tracking technology to examine AB towards smoking-related cues in former smokers.

This study examined the influence of e-cigarette use on the AB towards smoking cues of current and former cigarette smokers. Specifically, our first aim was to measure differences in AB towards smoking-related cues between: 1) current cigarette smokers; 2) dual users of cigarettes and e-cigarettes; 3) full-switchers who exclusively use e-cigarettes after previously smoking; 4) former smokers with no nicotine use; and 5) non-nicotine using controls. We hypothesized that cigarette smokers would have a significantly higher AB to smoking-related cues compared to all other groups. The second aim of this study was to explore the relationship between smoking craving, vaping craving, and AB towards smoking-related cues in cigarette smokers and e-cigarette users. We hypothesized that baseline smoking craving would be positively associated with AB among cigarette smokers, but not dual users, whereas baseline vaping craving would not be associated with AB among either dual users or full-switchers.

Materials & Methods

Participants

Of the 426 individuals screened as potentially eligible, 269 participants aged 18 years or older were enrolled. Of these, 255 completed the study and had usable data: 65 non-using controls, 62 cigarette smokers, 67 e-cigarette users (41 dual users, 26 full-switchers), and 61 former smokers. Cigarette smokers were required to currently smoke at least 8 tobacco cigarettes per day, have smoked more than 100 cigarettes in their lifetime, have never regularly used e-cigarettes, and not be currently using smoking cessation aids or other nicotine products. E-cigarette users were required to have used nicotine-containing e-cigarettes for at least 3 months, currently use e-cigarettes daily or almost daily for at least 1 month, have smoked more than 100 cigarettes in their lifetime, and have a history of daily cigarette smoking. E-cigarette users who reported current use of tobacco cigarettes, even occasionally, were classified as “dual users”, while e-cigarette users who reported no current or occasional use of tobacco cigarettes were classified as “full-switchers”. Former smokers were required to have formerly smoked tobacco cigarettes daily or almost daily for at least 6 months, have not smoked a cigarette in the past year, and have no use of any other nicotine containing products or cessation aids (including e-cigarettes) in the past 6 months. Non-using controls were required to have no previous regular e-cigarette use (never used e-cigarettes more than 15 days in one month) and to have not smoked more than 100 tobacco cigarettes in their lifetime. Recruitment was conducted through online advertising (Instagram, Facebook, and Google Ads), community posters throughout Toronto, Canada, and word-of-mouth referrals. Exclusion criteria for all participants were unstable psychiatric illness that would adversely impact study participation, as determined by the Qualified Investigator. Participants received compensation of $30 plus $6.70 for transit reimbursement. This research received approval from the CAMH Research Ethics Board (Protocol #030–2019).

Procedures

All study procedures were completed at the Nicotine Dependence Clinic (INTREPID Lab) at the Centre for Addiction and Mental Health (CAMH) in Toronto, Canada. Cigarette smokers and e-cigarette users were asked to refrain from smoking or vaping for 2 hours prior to the study session. Participants then attended the study session where: 1) signed, informed consent was provided, 2) an alcohol breathalyzer was used to confirm alcohol abstinence, and 3) an expired carbon monoxide breath sample was collected to confirm current smoking status. Participants were then administered the Mini-International Neuropsychiatric Interview (M.I.N.I.) to assess current psychiatric symptoms and disorders. Final eligibility decisions regarding psychiatric stability were made by the QI, with exclusion limited to participants presenting with unstable psychiatric conditions that could impact study participation. Once deemed eligible, participants completed a baseline questionnaire to collect information including demographics, smoking and e-cigarette use behaviours, cravings and mood states. They then completed the eye-tracking task.

Eye-tracking Task

The eye-tracking task utilized the free-viewing paradigm for AB assessment developed by Guestrin and Eizenman (2006) where participants freely view multiple visual stimuli that are presented simultaneously to compete for their attention. This paradigm has been previously used to examine AB in populations with eating disorders, mood disorders, Alzheimer's disease, tobacco dependence, and e-cigarette dependence (Chau et al., 2015; Eizenman et al., 2003; Pinhas et al., 2014; Rahmani et al., 2022).

Eye-movements were recorded using the Visual Attention Scanning Technology (VAST) (EL-MAR Inc. Toronto, Ontario, Canada). Participants were seated approximately 65 cm from the monitor and completed an eye-tracking calibration procedure. Upon successful calibration, participants viewed a total of 85 slides, each containing 4 images arranged in a 2x2 configuration. Consistent with procedures used in previous studies (Iturralde et al., 2025; Rahmani et al., 2022), 48 slides were test slides, 32 filler slides, and 5 practice slides. Of the 48 test slides, 16 were smoking-related slides. Each test slide contained 4 images: 1 image of interest (i.e. smoking or affective or sensation-seeking), 1 neutral, and 2 social images. Neutral and social images were chosen from the International Affective Picture System (IAPS), using standardized valence and arousal ratings (Bradley & Lang, 2017). Neutral images typically depicted inanimate objects (i.e. a pencil sharpener, a spoon, etc.). Social images depicted diverse social situations (i.e. a bride and groom, a couple walking, etc.). Smoking-related images were selected from the Geneva Smoking Pictures (GSP), a validated set of 60 tobacco-related images that were developed using the same standardization procedures as the IAPS (Khazaal et al., 2012). Each slide was presented for 10.5 seconds to allow for both scanning and re-scanning of cues. The total duration of the eye-tracking task was approximately 18 minutes.

Measures

Baseline Questionnaire

Baseline characteristics such as age, sex, smoking/vaping history, dependence and cravings were collected prior to the eye-tracking task. Cigarette smokers reported the age of their first cigarette, cigarettes smoked per day, and how soon they smoke after waking up. Tobacco cigarette dependence and craving was evaluated using the Fagerström Test of Nicotine Dependence (FTND) and Questionnaire for Smoking Urges (QSU) respectively (Heatherton et al. 1991; Tiffany and Drobes 1991). E-cigarette users reported the age of their first e-cigarette use, how many puffs they take from their e-cigarette per day, and how soon they vape after waking up. E-cigarette dependence and craving was evaluated using the E-cigarette Fagerström Test of Nicotine Dependence (eFTND) and Questionnaire for Vaping Craving (QVC) respectively (Dowd et al. 2019; Rahman et al. 2020). Both Fagerström Dependence tests consist of 6 items assessing e-cigarette/tobacco cigarette usage and behaviour (e.g. “Do you find it difficult to refrain from smoking/vaping in places where it is forbidden?”). The QVC and QSU are both 10 item self-report questionnaires that measure an individual’s craving for e-cigarettes or tobacco cigarettes by evaluating desire, intention and anticipation of positive outcomes (e.g. “I have a strong desire for an e-cigarette/cigarette right now”). Former cigarette smokers reported the age they started smoking, the age they quit smoking, cigarettes smoked per day before quitting, and the strategy they primarily used when they successfully quit smoking.

Eye-tracking

The primary outcome of the eye-tracking task is relative fixation time (RFT), measured in milliseconds. RFT is a validated measure of AB that has been utilized in studies using the same eye-tracking paradigm (Chau et al. 2015; Eizenman et al. 2003; Pinhas et al. 2014; Rahmani et al. 2022). RFT represents the proportion of time a participant fixates on a given image relative to their total fixation time across all four images presented on a slide. The mean relative fixation time (mRFT) of each cue category (smoking-related, affective and sensation-seeking) is calculated by averaging RFT values across all slides. AB is then determined by subtracting the mRFT of the neutral images from that of the test images, with positive values indicating a bias towards test images.

Statistical analyses

Baseline characteristics were analyzed using an ANOVA and subsequent independent sample t-tests. Group differences in AB were assessed using a one-way ANOVA, with pairwise comparisons conducted using Tukey’s HSD post hoc tests.

Associations between AB and smoking or vaping craving were examined using two linear regression models. Smoking status was entered as a categorical predictor, with separate models conducted for baseline smoking craving (cigarette smokers vs. dual users) and baseline vaping craving (dual users vs. full-switchers). Each model included the main effects of craving and smoking status, and their interaction. Statistical significance was set at $p < 0.05$. All data analysis was conducted using IBM SPSS Statistics 25 (IBM, 2017).

Participants with more than 50% unreliable eye-tracking trials, as determined automatically by the VAST system (≥ 70% fixation tracking required for a reliable trial), were excluded from analyses.

Results

Data Preparation

In total, 269 participants were enrolled in the study and completed the eye-tracking task between August 2019 and May 2024. 14 participants (5%) had missing or unreliable eye-tracking data and were excluded from the analysis. The final sample size was 255 participants (65 non-using controls, 62 cigarette smokers, 67 e-cigarette users [41 dual users, 26 full-switchers], and 61 former cigarette smokers).

Baseline Characteristics

Baseline characteristics are presented in Table 1. No significant group differences were detected between the five groups for sex, age of first cigarette or age of first e-cigarette. However, mean age differed significantly between groups ($F = 46.136$, $p < 0.001$). Cigarette smokers reported significantly higher CPD ($t = 5.897$, $p < 0.001$) and FTND scores ($t = 17.906$, $p < 0.001$) compared with dual users. Additionally, full-switchers had significantly higher eFTND scores than dual users ($t = 3.655$, $p = 0.032$).

Table 1

Baseline characteristics of non-using controls, cigarette smokers, dual users, full-switchers and former smokers. *SD*: Standard Deviation; *CPD*: Cigarettes per day; FTND Fagerström test for nicotine dependence; eFTND E-cigarette Fagerström test for dependence. Test statistic: F values reported for ANOVA, t values reported for independent sample t-tests. Effect size: η2 reported for ANOVA and Cohen's *d* reported for independent sample t-tests.

Variable	**Non-using Controls (n = 65)**	**Cigarette Smokers (n = 62)**	**E-Cigarette Users (n = 67)**		**Former Cigarette Smokers (n = 61)**	**Test statistic (F, t)**	**p-value**	**Effect size (η2, *d*)**
			Dual Users (n = 41)	**Full-Switchers (n = 26)**				
Age (SD)	36.22 (13.43) [20, 65]	39.37 (12.25) [18, 66]	27.8 (11.41) [18, 62]	27.92 (7.46) [18, 49]	55.87 (11.65) [30, 81]	46.136	< 0.001	0.424
Sex, male (%)	33 (49.2%)	31 (50%)	21 (51.2%)	13 (50%)	30 (49.2%)	0.003	1.000	0.000
CPD (SD) [min to max]		12.59 (7.59)	5.09 (3.75) [0.07, 15]			5.897	< 0.001	1.187
Age of first cigarette [min to max]		17.33 (4.01) [11, 31]	16.17 (2.65) [12, 23]	15.65 (2.99) [11, 23]	16.90 (5.02) [11, 36]	1.319	0.270	0.023
Age of first e-cigarette use [min to max]			22.34 (11.58) [10, 58]	22.35 (7.62) [12, 43]		-0.003	0.998	-0.001
Time to first cigarette after waking						-5.005	< 0.001	-1.007
Within 5 min (%)		17 (28.3%)	1 (2.9%)					
6 to 30 min (%)		16 (26.7%)	8 (22.9%)					
31 to 60 min (%)		18 (30.0%)	6 (17.1%)					

Variable	Non-using Controls (n = 65)	Cigarette Smokers (n = 62)	E-Cigarette Users (n = 67)		Former Cigarette Smokers (n = 61)	Test statistic (F, t)	p-value	Effect size (η2, *d*)
			Dual Users (n = 41)	Full-Switchers (n = 26)				
More than 60 min (%)		9 (15.0%)	20 (57.1%)					
Time to first e-cigarette after waking						-1.311	0.194	-0.329
Within 5 min (%)			11 (32.4%)	2 (9.5%)				
6 to 30 min (%)			7 (20.6%)	4 (19.0%)				
31 to 60 min (%)			7 (20.6%)	7 (33.3%)				
More than 60 min (%)			9 (26.5%)	8 (38.1%)				
FTND (SD) [min to max]		4.30 (2.54) [0, 11]	1.85 (1.86) [0, 7]			5.265	< 0.001	1.071
eFTND (SD) [min to max]			3.72 (2.60) [0, 9]	5.15 (2.16) [2, 9]		-2.111	0.039	0.071

Differences in AB Between Groups

Smoking Cues Versus Neutral Cues

Mean differences in AB towards smoking-related cues between smoking status groups are presented in Table 2. A one-way ANOVA revealed significant group differences in AB towards smoking-related cues ($F = 15.126$, $p < 0.001$). Cigarette smokers (0.101 ± 0.110), dual users (0.097 ± 0.120), and full-switchers (0.086 ± 0.086) showed a significantly greater AB towards smoking-related cues compared to non-using

controls (-0.011 ± 0.081) ($p \leq 0.001$) and former smokers (-0.005 ± 0.129) ($p \leq 0.004$). AB towards smoking-related cues among former smokers did not significantly differ from non-using controls ($p = 0.998$) (Fig. 1).

Table 2
Mean differences (SE) in AB towards smoking-related cues between smoking status groups. Each cell represents the AB of the row group (I) minus the AB of the column group (J). Positive values indicate greater AB for the row group (I). * $p < 0.05$; ** $p < 0.001$.

Smoking Status (I)	***Smoking Status (J)***				
	Cigarette Smokers	**Dual Users**	**Full-Switchers**	**Former Smokers**	**Non-using Controls**
Cigarette Smokers		0.004 (0.218)	0.015 (0.026)	0.106 (0.020)**	0.112 (0.019)**
Dual Users	-0.004 (0.218)		0.011 (0.027)	0.102 (0.026)**	0.108 (0.022)**
Full-Switchers	-0.015 (0.026)	-0.011 (0.027)		0.091 (0.253)*	0.097 (0.025)*
Former Smokers	-0.106 (0.020)**	-0.102 (0.026)**	-0.091 (0.253)*		0.006 (0.019)
Non-using Controls	-0.112 (0.019)**	-0.108 (0.022)**	-0.097 (0.025)*	-0.006 (0.019)	

Association between Baseline Smoking Craving (QSU Scores) and AB

This linear regression model examined whether the association between baseline smoking craving and AB towards smoking-related cues differed between cigarette smokers and dual users. The overall model was significant ($F(3, 96) = 11.82$, $p < 0.001$), explaining 27.0% of the variance in AB ($R^2=0.270$).

There was a significant main effect of baseline smoking craving ($B = 0.005$, 95% CI [0.003, 0.007], $p < 0.001$, $\eta p^2 = 0.257$), indicating that higher smoking craving was associated with greater AB. The main effect of smoking status was not significant ($B = 0.089$, 95% CI [-0.012, 0.190], $p = 0.084$, $\eta p^2=0.031$).

The smoking status × smoking craving interaction was significant ($B=-0.003$, 95% CI [-0.006, 0.000], $p = 0.025$, $\eta p^2=0.051$), indicating that the association between smoking craving and AB was significantly stronger among cigarette smokers than dual users.

Association between Baseline Vaping Craving (QVC Scores) and AB

This linear regression model examined whether the association between vaping craving and AB towards smoking-related cues differed between dual users and full-switchers. The overall model was significant ($F(3, 56) = 2.90$, $p = 0.043$), explaining 13.4% of the variance in AB ($R^2=0.134$).

Neither the main effect of baseline vaping craving (B < 0.001, 95% CI [-0.003, 0.004], p = 0.925, ηp^2=0.046), nor the smoking status × vaping craving interaction (B = 0.003, 95% CI [-0.001, 0.007], p = 0.145, ηp^2=0.038) was significant. The main effect of smoking status was also non-significant (B=-0.126, 95% CI [-0.327, 0.074], p = 0.213, ηp^2=0.028).

Discussion

Cigarette smokers, e-cigarette users who use cigarettes daily or occasionally (dual users), and e-cigarette users who no longer use cigarettes (full-switchers) exhibited significantly greater AB towards smoking-related cues relative to non-using controls and former smokers who no longer used nicotine products. Contrary to our initial hypothesis, dual users and full-switchers exhibited levels of AB comparable to those in cigarette smokers. Smoking craving showed a stronger positive association with AB among cigarette smokers and a weaker association among dual users. In contrast, baseline vaping craving was not meaningfully associated with AB towards smoking-related cues in either dual users or full-switchers.

Although dual users displayed elevated AB towards smoking-related cues comparable to cigarette smokers, the relationship between smoking craving and AB was significantly weaker among dual users. This finding suggests that concurrent e-cigarette use may alter the relationship between smoking motivation and attentional processing of smoking-related cues. Nevertheless, persistent AB among dual users suggests that ongoing cigarette smoking may maintain conditioned responses to smoking-related cues, contributing to continued smoking. This interpretation aligns with a recent systematic review that found dual users of tobacco cigarettes and nicotine e-cigarettes to be less likely to reach complete smoking cessation than exclusive cigarette smokers and exclusive e-cigarette users (Hamoud et al., 2025).

Contrary to our hypothesis, full-switchers also exhibited smoking-related AB comparable to cigarette smokers despite no longer smoking cigarettes. Elevated AB among full-switchers may reflect transfer of cue salience between cigarettes and e-cigarettes due to shared behavioural and sensory characteristics, or persistent conditioned responding acquired during prior cigarette smoking (Iturralde et al., 2025). The absence of a meaningful association between vaping craving and AB suggests that elevated smoking cue reactivity may not reflect current vaping motivation. Taken together with our AB findings in former smokers, continued e-cigarette use may be associated with the maintenance of smoking cue salience following smoking abstinence. As higher levels of AB have been associated with an increased risk of relapse, full-switchers may remain vulnerable to returning to smoking. This interpretation is supported by a 2021 meta-analysis which found that the risk of relapse was double for former smokers who were current e-cigarette users compared to former smokers with no e-cigarette use (Barufaldi et al., 2021). Despite this, continued e-cigarette use may represent a preferable harm reduction strategy for individuals at an elevated risk of relapse to tobacco cigarettes.

Former smokers who had been abstinent for at least 1 year with no nicotine product use did not exhibit a heightened level of AB towards smoking-related cues and instead had AB comparable to that of non-using controls. To our knowledge, this is the first study to utilize eye-tracking technology to directly assess AB

towards smoking-related cues in long-term former smokers. Previous findings for AB in former smokers are mixed, likely reflecting differences in abstinence duration and the use of indirect reaction-time measures. Our findings are consistent with those of Munafò et al. (2003), who found no differences in processing bias for smoking-related cues between ex-smokers who had been abstinent for at least 6 months and never-smokers using a modified Stroop Task. Together, these results provide convergent evidence across eye-tracking and Stroop Task measures that the incentive salience attributed to smoking-related cues in tobacco use disorder can be substantially diminished. This supports the possibility that neuroadaptations in dopaminergic reward pathways are not necessarily permanent, and may partially reverse following sustained abstinence from cigarette smoking and nicotine use (Franken, 2003). However, it is important to note that AB is known to fluctuate with motivational state, and may re-emerge during “high-risk” situations for relapse.

The elevated AB observed among cigarette smokers and its positive association with smoking craving are consistent with previous research and incentive-sensitization models of addiction, which propose a mutual excitatory relationship between craving and AB (Field & Cox, 2008; Franken, 2003; Rahmani et al., 2024). Similar association have also been reported across other substance use disorders (Creswell & Skrzynski, 2021; Field et al., 2009; Huang et al., 2025; Mogg & Bradley, 2002; Mogg et al., 2003).

This study has several limitations. First, this study relied solely on mean relative fixation times (mRFTs) as a measure of AB, which captures maintained attention but does not assess early attention processes such as initial orienting biases. However, prior research suggests that smoking-related AB may depend more on maintained attention than on early attentional shifts. Secondly, smoking craving in full-switchers and former smokers was not comprehensively assessed, limiting our ability to directly evaluate whether the heightened AB observed among our full-switchers reflects a residual craving for cigarette smoking. Thirdly, as e-cigarettes are still a relatively new nicotine product, no minimum abstinence duration was required for full-switchers, although the mean duration of smoking abstinence among full-switchers was 1.17 years. Finally, the cross-sectional design precludes conclusions regarding the directionality of nicotine use behaviours and whether dual use or complete switching represent transitional stages toward nicotine abstinence.

Conclusion

E-cigarette users who use cigarettes concurrently (dual users), and those who have transitioned fully to e-cigarettes (full-switchers) show levels of AB towards smoking-related cues comparable to cigarette smokers, and significantly greater than non-using controls and former smokers who no longer use any nicotine product. Further, the association between baseline smoking craving and AB was significantly stronger among cigarette smokers than dual users, suggesting that concurrent e-cigarette use may attenuate the relationship between smoking craving and AB towards smoking-related cues. In contrast, baseline vaping craving was not reliably associated with AB towards smoking-related cues in either dual users or full-switchers. These findings suggest that continued nicotine use through e-cigarettes may be associated with the maintenance of smoking cue salience, even following smoking cessation. In contrast, complete abstinence from all nicotine products was associated with substantially lower smoking cue

salience. Future longitudinal studies are needed to clarify the mechanisms underlying persistent AB towards smoking-related cues among e-cigarette users and determine whether this sustained smoking cue salience contributes to increased smoking relapse risk, or whether continued use of e-cigarettes plays a role in preventing relapse to smoking.

Declarations

Ethics Declarations

Ethics Approval

All procedures were performed in accordance with the principles of the 1964 Declaration of Helsinki and its later amendments. Ethical approval was obtained from the Centre for Addiction and Mental Health (CAMH) Research Ethics Board (Protocol #030–2019).

Consent to Participate

Written informed consent was obtained from all individual participants included in the study.

Competing Interests

PS receives research support from the Department of Family and Community Medicine at the University of Toronto and the INTREPID lab at the Centre for Addiction and Mental Health. PS is the vice-chair, research, and is the Giblon Professor in Family Medicine Research, a university named professorship at the University of Toronto. All other authors declare no competing interests.

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Not Applicable

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Author Contribution

Conceptualization: KI, LZ; Methodology: KI, LZ, SV; Formal analysis and investigation: KI; Writing – original draft: KI; Writing – review & editing: KI, LZ, PS, SV; Funding acquisition: LZ; Resources: LZ, PS; Supervision: LZ, PS; Project administration: LZ.

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Data Availability

The data of this study is available from the corresponding author upon reasonable request.

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Figures

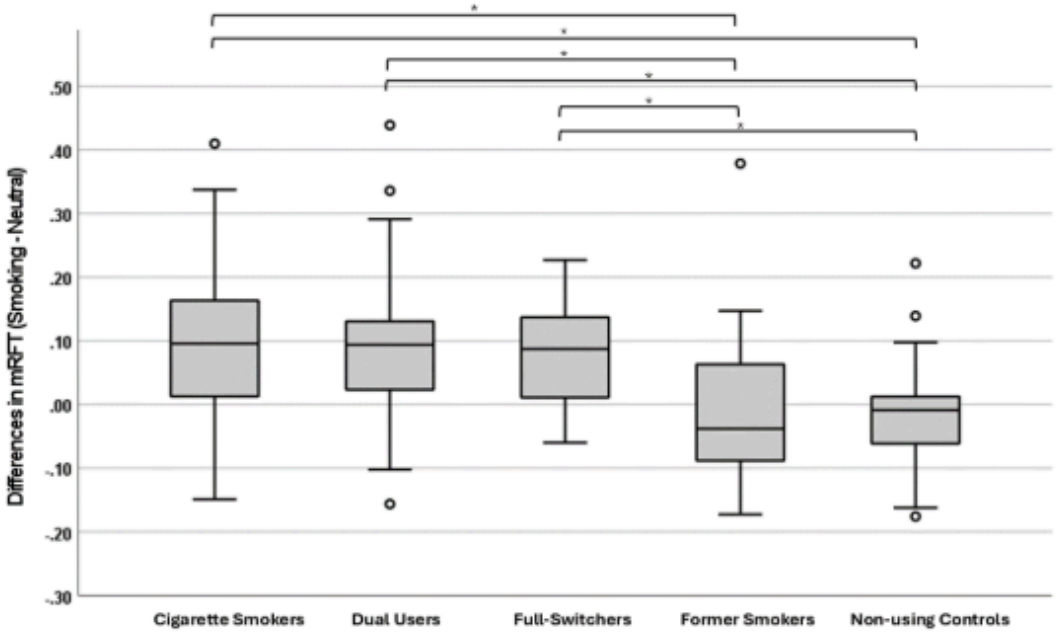


Figure 1

Differences in mean relative fixation times (mRFT) to smoking-related cues between cigarette smokers, dual users, full-switchers, former smokers and non-using controls. Cigarette smokers ($p<0.001$), dual users ($p<0.001$) and full-switchers ($p=0.001$) displayed significantly higher mRFTs towards smoking-related cues than former smokers and non-using controls.