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RESEARCH REPORT

ADDICTION SSA

Understanding perceived addiction to and addictiveness of electronic cigarettes among electronic cigarette users: a cross-sectional analysis of the International Tobacco Control Smoking and Vaping (ITC 4CV) England Survey

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Abstract

Background and Aims: The addictive potential of electronic cigarettes (e-cigarettes) remains to be fully understood. We identified patterns and correlates of perceived addiction to e-cigarettes and perceived addictiveness of e-cigarettes relative to tobacco cigarettes (relative addictiveness) in dual users as well as exclusive e-cigarette users.

Design, Setting and Participants: Observational study using cross-sectional survey data from England (2016) from the International Tobacco Control Project (ITC) Four Country Smoking and Vaping (4CV) survey. The study comprised 832 current e-cigarette users who had been vaping for at least 4 months.

Measurements: Perceived addiction to e-cigarettes and relative addictiveness of e-cigarettes were examined. Socio-demographic factors were age, gender and education; markers of addiction included urge to vape, time to first vape after waking and nicotine strength used; vaping and smoking characteristics included frequency and duration of e-cigarette use, intention to quit, adjustable power or temperature, enjoyment, satisfaction relative to tobacco cigarettes and tobacco cigarette smoking status.

Findings: A total of 17% of participants reported feeling very addicted to e-cigarettes, while 40% considered e-cigarettes equally/more addictive than tobacco cigarettes. Those who felt very addicted had higher odds of regarding e-cigarettes as more addictive than tobacco cigarettes (odds ratio 3.4, 95% confidence interval 2.3–5.1). All markers of addiction, daily use and enjoyment were associated with higher perceived

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addiction, whereas time to first vape after waking, daily vaping and perceiving vaping as less satisfying than smoking were associated with relative addictiveness.

Conclusions: Markers of addiction to e-cigarettes appear to correspond with perceived addiction to e-cigarettes, suggesting that self-reported perceived addiction might serve as an indicator of addiction. Prevalence both of markers of addiction and perceived addiction were comparatively low overall, suggesting a limited but relevant addictive potential of e-cigarettes. Additionally, positive and negative reinforcement, reflected here by enjoyment and relative satisfaction, might play a role in e-cigarette addiction.

KEYWORDS
E-cigarettes, electronic cigarettes, perceived addiction, reinforcement, relative addictiveness, vaping

INTRODUCTION

With more than 8 million deaths world-wide, tobacco use is the leading cause of preventable deaths [1]. With the introduction of electronic cigarettes (e-cigarettes), a potentially less harmful alternative to tobacco cigarettes is available, as e-cigarettes deliver nicotine without exposing the user to the toxicants of combusting tobacco [2–4]. While there is evidence that e-cigarettes containing nicotine increase quit rates [5], the extent of the health risks and harm potential of e-cigarettes is still debated due to the paucity of reliable long-term data.

With regard to the addictive potency of e-cigarettes, evidence has accrued that e-cigarette use is associated with symptoms of addiction, such as craving or immediate e-cigarette use after waking; however, the risk and severity of addiction is likely to be lower for e-cigarettes than for tobacco cigarettes [3, 6–8]. This is in line with studies showing that e-cigarette users consistently reported that they feel less addicted to vaping than they were previously to smoking [9–11]. The role of such self-perceptions of users is particularly emphasized in the context of cognitive theories of health behaviours, which understand behaviour as a function of the subjective value of an outcome and the expectation that a particular action will achieve that outcome: these expectations being influenced by positive and negative reinforcements [12]. In this sense, perceived addiction to vaping could, together with reinforcements, play a role in the decision to maintain or quit e-cigarette use or in switching back to smoking.

To date, addictive symptoms in e-cigarette users have been investigated largely by utilizing measures of addiction to tobacco cigarettes. The most established marker of addiction is time to first cigarette after waking [13, 14], which has been adapted analogously for e-cigarette use [15]. Another marker is craving, which is a main component in models of addiction and smoking cessation and is often measured by self-reported urges [16]. Nicotine is the key pharmacological element responsible for dependence to cigarettes through its rewarding, reinforcement and withdrawal effects [17]. Higher concentrations of nicotine have previously been associated with an increased abuse potential, particularly with respect to dependence, and might therefore be another marker of e-cigarette addiction [18].

Understanding the addictive potential of e-cigarettes is the cornerstone for developing new strategies for prevention and treatment and ultimately understanding their role from a public health perspective. However, little is known about perceived addiction and perceived addictiveness relative to tobacco cigarettes (relative addictiveness) in e-cigarette users. In this study, we used data from a survey of e-cigarette users in England to study whether (1) markers of addiction and (2) vaping and smoking characteristics were associated with perceived addiction to and relative addictiveness of e-cigarettes.

METHODS

Study population

This study is part of work package III of the EValuation of the Addictive Potential of E-cigarettes (EVAPE) project [19]. For this cross-sectional analysis, we used data from the International Tobacco Control (ITC) Four Country Smoking and Vaping (4CV) Survey [England, wave 1 (data acquired between July and September 2016)]. This survey comprises a nationally representative sample of smokers and e-cigarette users using standardized survey methods [20]. All participants were recruited into the study as current tobacco cigarette smokers who have smoked at least 100 cigarettes in their life-time, former tobacco cigarette smokers who quit within the previous 2 years or current, at least weekly, e-cigarette users [20]. For the present analysis, we only included people who were using e-cigarettes daily or weekly for at least 4 months, who could be exclusive e-cigarette users (non-smokers) or dual-users (concurrent smokers) (Figure 1).

The ITC England survey was approved by the ethics research committee at the University of Waterloo (Ontario, Canada) and the local ethics committee in England. All participants provided informed consent.

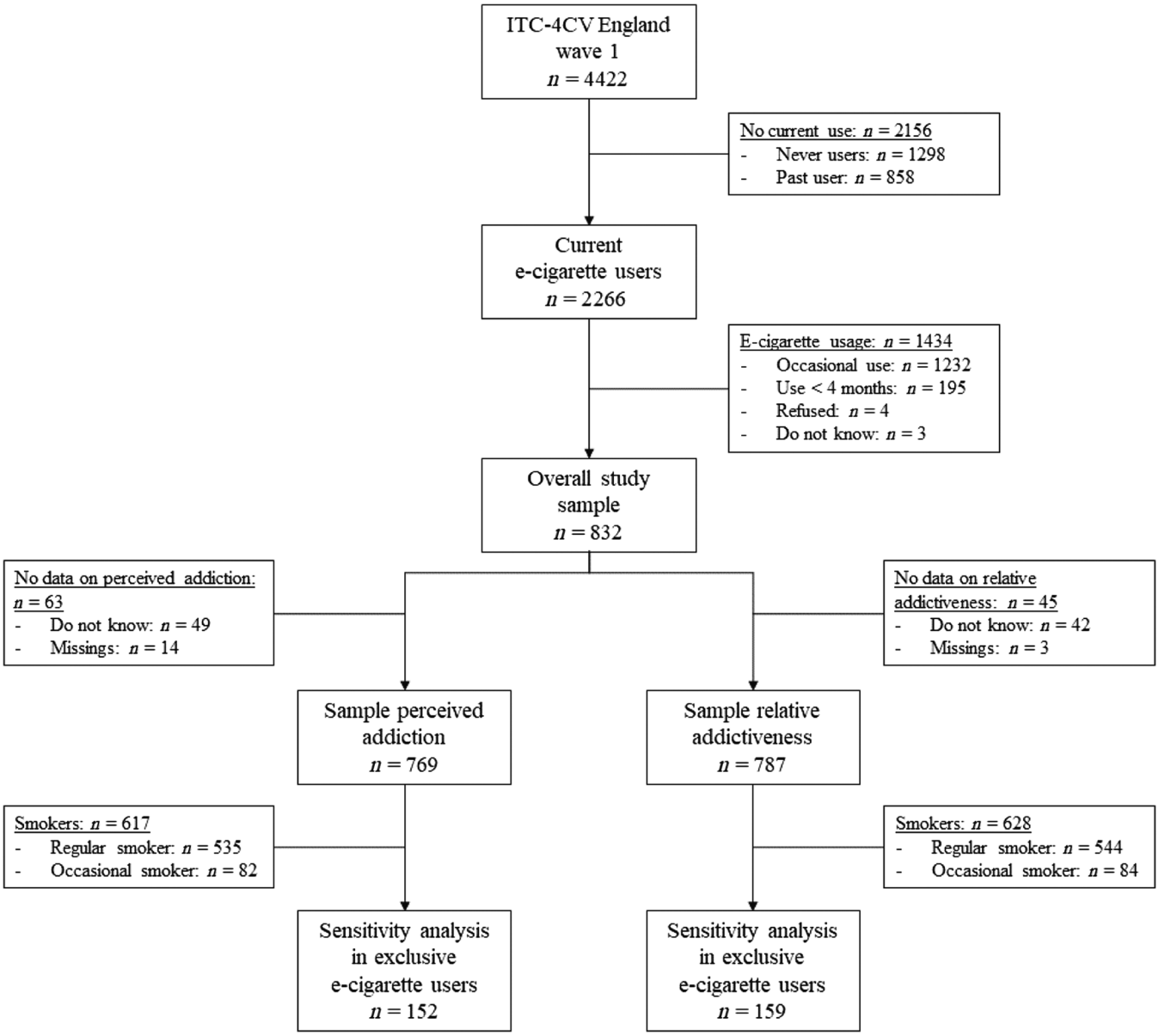

FIGURE 1 Flow-chart of the study population. This figure shows the selection of participants from the first wave of the International Tobacco Control (ITC) Four Country Smoking and Vaping (4CV) Survey (England, 2016). Data on both perceived addiction and relative addictiveness available in 737 respondents.

Outcomes

Perceived addiction

Participants reported if they considered themselves as addicted to e-cigarettes (not at all; yes, somewhat addicted; yes, very addicted). For multivariable analyses, the response options were dichotomized as very addicted versus not at all or somewhat addicted, similar to the approach used by McNeill et al. [21].

Relative addictiveness

All participants indicated how addictive they considered vaping e-cigarettes relative to smoking tobacco cigarettes (much less, somewhat less, equally, somewhat more, much more addictive). For multivariable analyses, the response options were dichotomized as e-cigarettes being equally or somewhat or much more addictive versus them being somewhat or much less addictive than tobacco cigarettes. This dichotomization was chosen to ensure sufficient cases for analysis.

Socio-demographic characteristics

Socio-demographic characteristics included age (18–24, 25–39, 40–54 and 55+ years), gender (men, women, other) and highest level of education attained (low: pre-vocational secondary education; moderate: secondary vocational, senior general secondary and pre-university education; high: higher professional or a university degree).

Markers of addiction

We categorized time to first vape after waking into '5 minutes or less', '6–30 minutes', '31–60 minutes' and 'more than 60 minutes'. Urge to vape in the past 24 hours was assessed only among e-cigarette users who did not simultaneously smoke tobacco cigarettes daily. Response options were collapsed into three categories to allow for sufficient cases for analysis: low (none, slight urge), moderate and strong urge to vape (strong, very strong, extremely strong urge). Nicotine strength was divided into four categories (none/low: no nicotine, 1–4 mg/ml; medium: 5–8 mg/ml; high: 9–14 mg/ml; very high: 15 mg/ml or more).

Vaping and smoking characteristics

We defined tobacco cigarette smoking status as 'non-smoker' [non-smoker, recent quitter (quit in last 24 months), long-term quitter (quit more than 24 months ago)], 'occasional smoker' (current monthly or less than monthly smoker) or 'regular smoker' (current daily or weekly smoker) and frequency of e-cigarette use as 'daily vaper' or 'weekly vaper'. Respondents further reported on the duration of e-cigarette use (4–6 months, 7–12 months, 1–2 years, 2–3 years, 3–5 years, more than 5 years), if their e-cigarette had adjustable power or temperature (no, yes, but I do not change it; yes, I change it occasionally; yes, I change it regularly), and if they had an intention to quit vaping (no intention to quit, undecided, intention to quit within 1–6 months, intention to quit after more than 6 months). Participants also indicated how much they enjoy vaping (not/slightly, moderately, very much, extremely) and how satisfying vaping is relative to smoking (relative satisfaction; much less, less, equally, more, much more than smoking).

Data analysis

First, we examined correlations among the markers of addiction and vaping and smoking characteristics using Pearson correlations. Then, we examined associations of (1) socio-demographic factors, (2) markers of addiction and (3) vaping and smoking characteristics with perceived addiction and relative addictiveness using logistic regression. All models were adjusted for age, gender, education and tobacco cigarette smoking status. Respondents identifying their gender as 'other' were excluded from the analysis due to low numbers (n = 4).

To rule out confounding by tobacco smoking and concomitant addiction to smoking, we performed a sensitivity analysis in exclusive e-cigarette users (non-smokers) using the same models as described above without adjustment for smoking status.

Respondents had the option to answer 'prefer not to answer' to any question, which was coded as 'refusal'. Refusals were treated as missing values [enjoyment: 3 (0.4%); nicotine strength: 4 (0.5%); relative satisfaction: 4 (0.5%)]. Whenever a respondent skipped a question and did not answer it, this was coded as 'missing value' [relative addictiveness: 3 (0.4%); perceived addiction: 14 (1.7%)]. Missing values were excluded from the analysis.

'Do not know' answers were also treated as missing values in the main analysis [urge to vape: 2 (0.2%); enjoyment: 6 (0.7%); relative satisfaction: 10 (1.2%); education: 13 (1.6%); adjustment of power or temperature: 28 (3.4%); relative addictiveness: 42 (5.0%); perceived addiction: 49 (5.9%)].

To ensure that the dichotomization used for the outcome variables did not lead to any bias, we ran a sensitivity analysis utilizing multinomial regression, including the same models as described above. Here, we were able to include all answer options for perceived addiction (not at all, somewhat, very addicted, do not know) but still had to group relative addictiveness to ensure sufficient cases for analysis (less, equally, more addictive than smoking, do not know).

Additionally, we explored distributions of markers of addiction in relation to perceived addiction and relative addictiveness throughout further European countries who had implemented ITC surveys with similar methodology and survey instruments available (Germany, Greece, Hungary, Poland, Romania, Spain and the Netherlands (6E and NL); see Supporting information, Figure S1 [22]). Due to the low frequency of e-cigarette users in 6E and NL, we pooled them for the descriptive comparison with England and could not perform any multivariable statistical analyses.

All analyses were performed in R version 4.1.3 [23]. P-values less than 0.05 were considered statistically significant, and we corrected for multiple comparisons by using false discovery rate (FDR) correction (Benjamini & Hochberg approach [24]). The analysis plan was not pre-registered, and the results should therefore be considered exploratory.

RESULTS

Characteristics of the study population

The overall sample consisted of 832 current e-cigarette users, who had data on either outcome. Figure 1 and Table 1 show the selection and characteristics of the study population. Overall, 17% (n = 137) considered themselves very addicted to e-cigarettes, and 40% (n = 333) considered e-cigarettes equally or more addictive relative to tobacco cigarettes (Table 1). Sixty-six per cent (n = 90) of the respondents who considered themselves very addicted also considered e-cigarettes equally or more addictive than tobacco cigarettes, whereas 60% (n = 382) of the respondents who considered themselves not/somewhat addicted to e-cigarettes also considered e-cigarettes less addictive relative to tobacco cigarettes.

Correlations among markers of addiction and vaping and smoking characteristics

Pearson correlation results revealed strong correlations between higher enjoyment and higher relative satisfaction; and moderate correlations between a shorter time to first vape after waking and increased urge to vape and more frequent e-cigarette use and increased urge to vape (Figure 2).

TABLE 1 Characteristics of the study sample.

Characteristics [*n* (%)]		*n* = 832
Age (years)	18–24	234 (28.1)
	25–39	228 (27.4)
	40–54	158 (19.0)
	55+s	212 (25.5)
Gender	Women	297 (35.7)
	Men	531 (63.8)
	Other	4 (0.5)
Education level	Low	170 (20.4)
	Moderate	340 (40.9)
	High	309 (37.1)
	Do not know	13 (1.6)
Tobacco cigarette smoking status	Non-smoker	165 (19.8)
	Occasional smoker	86 (10.3)
	Regular smoker	581 (69.9)
Frequency of e-cigarette use	Daily use	534 (64.2)
	Weekly use	298 (35.8)
Perceived addiction[a]	Not at all addicted	289 (35.3)
	Somewhat addicted	343 (41.9)
	Very addicted	137 (16.7)
	Do not know	49 (6.0)
Relative addictiveness[a]	Much less addictive	127 (15.3)
	Somewhat less addictive	327 (39.9)
	Equally addictive	286 (34.5)
	Somewhat more addictive	29 (3.5)
	Much more addictive	18 (2.2)
	Do not know	42 (5.1)

[a]Participants with missing data: perceived addiction: *n* = 14 (1.7%); relative addictiveness: *n* = 3 (0.4%).

Correlates of perceived addiction

Overall, 815 respondents had provided answers for both outcomes, 737 after excluding 'do not know' answers. Among these respondents, feeling very addicted to e-cigarettes was associated with increased odds of rating e-cigarettes equally or more addictive than tobacco cigarettes [odds ratio (OR) = 3.4, 95% confidence interval (CI) = 2.3–5.1], even after correction for multiple comparisons. Table 2 gives an overview of the results of the logistic regression models for each outcome.

Socio-demographic characteristics

Socio-demographic factors were not associated with perceived addiction.

Markers of addiction

Participants who had their first vape in the morning within 5 minutes or 6–30 minutes after waking had higher odds of feeling addicted compared to participants who first vaped more than an hour after waking (OR = 4.0, CI = 2.1–7.7; OR = 2.7, CI = 1.6–4.5, respectively). A very high compared to low nicotine strength was associated with increased perceived addiction (very high: OR = 3.7, CI = 1.9–7.7). In the subsample of e-cigarette users who did not simultaneously smoke tobacco cigarettes daily, a strong compared to moderate urge to vape was associated with higher odds of feeling addicted (OR = 6.5, CI = 3.3–13.6).

Vaping and smoking characteristics

Daily vaping compared to weekly vaping and extreme compared to moderate enjoyment of vaping increased the odds of feeling addicted (OR = 3.1, CI = 1.9–5.1; OR = 8.8, CI = 5.1–15.5; respectively; Table 2).

Correlates of relative addictiveness

Socio-demographic characteristics

Socio-demographic factors were not associated with relative addictiveness (Table 2).

Markers of addiction

Participants who vaped within 5 minutes after waking compared to more than 1 hour after waking had increased odds of regarding e-cigarettes as equally or more addictive than tobacco cigarettes (OR = 2.4, CI = 1.5–4.2).

Vaping and smoking characteristics

E-cigarette users who experienced vaping as much less (OR = 0.3, CI = 0.2–0.6) and somewhat less satisfying (OR = 0.5, CI = 0.3–0.7) than smoking tobacco cigarettes were less likely to perceive e-cigarettes as equally or more addictive than tobacco cigarettes compared to e-cigarette users who perceived e-cigarettes as equally satisfying as tobacco cigarettes (Table 2).

Sensitivity analysis using multinomial models

Supporting information, Tables S1 and S2 present associations of socio-demographic factors, markers of addiction and vaping and smoking characteristics with all categories of perceived addiction and relative addictiveness, respectively, including participants with 'do not

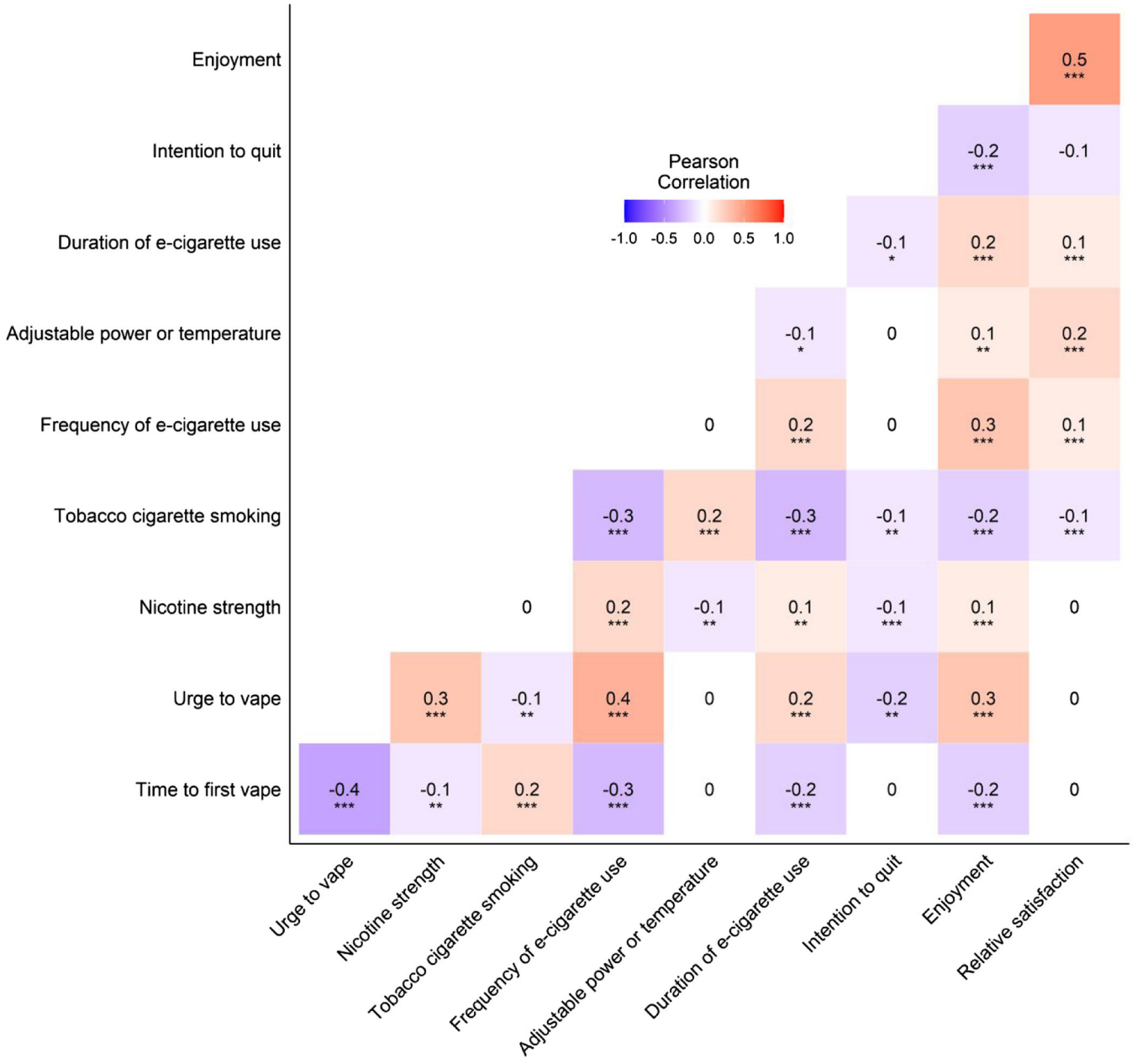

FIGURE 2 Correlations among markers of addiction and vaping and smoking characteristics in the England sample. Asterisks indicate *P*-value level: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.005$.

know' answers. Overall, the results suggested a dose–response pattern when looking across effect estimates of perceived addiction and relative addictiveness, but effect estimates were imprecise due to the small groups and supported our approach dichotomizing the outcome variables in the main analyses.

Sensitivity analysis in exclusive e-cigarette users

Of the 165 exclusive e-cigarette users, % (n = 35) considered themselves very addicted, and 35% (n = 56) considered e-cigarettes equally or more addictive than tobacco cigarettes. The sensitivity analysis revealed similar trends compared to the results described above (Supporting information, Table S3). However, only the associations between time to first vape in the morning within 5 minutes (OR = 55.7, CI = 8.8–1114.4) and extreme pleasure (OR = 11.1, CI = 3.3–46.6) with perceived addiction were significant, but effect estimates were imprecise, probably due to the small sample size.

Comparison of markers of addiction with perceived addiction and relative addictiveness throughout further European countries

The 6E and NL sample was comprised of 163 current e-cigarette users. Generally, patterns regarding markers of addiction across

TABLE 2 Results of the logistic regression model examining associations of socio-demographic factors, markers of addiction and vaping and smoking characteristics with perceived addiction to (n = 769) and perceived relative addictiveness of (n = 787) e-cigarettes.

	Perceived addiction			Relative addictiveness		
	Adjusted OR (95% CI)	P	P_{FDR}	Adjusted OR (95% CI)	P	P_{FDR}
Outcomes[a]						
Perceived addiction (reference: not/somewhat addicted)				3.4 (2.3–5.1)	< 0.001	< 0.001
Relative addictiveness (reference: less addictive)	3.4 (2.3–5.2)	< 0.001	< 0.001			
Socio-demographic factors						
Age (reference: 18–24 years)						
25–39 years	0.9 (0.6–1.5)	0.801	1.000	1.0 (0.7–1.5)	0.918	1.000
40–54 years	0.4 (0.2–0.7)	0.004	0.073	0.8 (0.5–1.2)	0.304	1.000
55+ years	0.7 (0.4–1.2)	0.162	1.000	0.7 (0.4–1.0)	0.074	1.000
Men (reference: women)	1.1 (0.7–1.6)	0.759	1.000	1.1 (0.8–1.5)	0.471	1.000
Education (reference: low)						
Moderate	0.9 (0.5–1.5)	0.717	1.000	0.9 (0.6–1.3)	0.471	1.000
High	1.0 (0.6–1.7)	0.992	1.000	1.1 (0.7–1.6)	0.753	1.000
Markers of addiction						
Urge to vape (reference: moderate)[b]						
Low[c]	–	–	–	0.6 (0.3–1.2)	0.137	0.775
Strong	6.5 (3.3–13.6)	< 0.001	< 0.001	2.2 (1.3–3.7)	0.003	0.088
Time to first vape (reference: more than 60 min)						
5 min or less	4.0 (2.1–7.7)	< 0.001	0.001	2.4 (1.5–4.2)	0.001	0.021
6–30 min	2.7 (1.6–4.5)	< 0.001	0.002	1.6 (1.1–2.3)	0.011	0.130
31–60 min	1.5 (0.8–2.9)	0.188	1.000	1.1 (0.7–1.7)	0.710	1.000
Nicotine strength (reference: none/low)						
Medium	2.3 (1.2–4.9)	0.021	0.124	1.0 (0.6–1.6)	0.966	1.000
High	2.4 (1.2–5.0)	0.020	0.124	1.4 (0.9–2.2)	0.171	1.000
Very high	3.7 (1.9–7.7)	< 0.001	0.008	1.5 (0.9–2.3)	0.088	0.747
Vaping and smoking characteristics						
Current daily use (reference: weekly)	3.1 (1.9–5.1)	< 0.001	0.000	1.4 (1.0–2.0)	0.026	0.367
Status smoking (reference: non-smoker)						
Occasional smoker	1.3 (0.7–2.4)	0.427	1.000	2.1 (1.2–3.6)	0.013	0.432
Regular smoker	0.5 (0.3–0.8)	0.004	0.073	1.2 (0.8–1.7)	0.489	1.000
Duration e-cigarette use (reference: 1–2 years)						
4–6 months	0.8 (0.5–1.5)	0.530	1.000	0.7 (0.5–1.1)	0.140	1.000
7–12 months	1.3 (0.8–2.3)	0.265	1.000	1.0 (0.7–1.5)	0.853	1.000
2–3 years	2.3 (1.2–4.1)	0.008	0.120	1.2 (0.7–2.0)	0.492	1.000
3–5 years	2.6 (1.1–5.8)	0.026	0.189	1.3 (0.7–2.7)	0.419	1.000
More than 5 years[c]	–	–	–	2.2 (0.6–7.7)	0.213	1.000
Adjustment of power or temperature (reference: not possible)						
No change	1.2 (0.7–2.2)	0.488	1.000	1.1 (0.7–1.7)	0.650	1.000
Occasional change	1.4 (0.8–2.3)	0.241	1.000	1.3 (0.9–2.0)	0.160	1.000
Regular change	2.6 (1.2–5.7)	0.014	0.163	1.7 (0.9–3.3)	0.117	1.000
Enjoyment (reference: moderate)						
None/slight	0.8 (0.3–1.7)	0.576	1.000	0.8 (0.5–1.2)	0.255	1.000
Very much	1.8 (1.0–3.0)	0.035	0.310	1.3 (0.9–1.9)	0.117	1.000
Extreme	8.8 (5.1–15.5)	< 0.001	< 0.001	1.6 (1.0–2.4)	0.048	0.543

(Continues)

TABLE 2 (Continued)

	Perceived addiction			Relative addictiveness		
	Adjusted OR (95% CI)	*P*	P_{FDR}	Adjusted OR (95% CI)	*P*	P_{FDR}
Relative satisfaction (reference: equally satisfying)						
Much less satisfying than smoking	0.3 (0.1–0.9)	0.044	0.258	0.3 (0.2–0.6)	< 0.001	0.004
Somewhat less satisfying than smoking	0.9 (0.6–1.5)	0.706	1.000	0.5 (0.3–0.7)	< 0.001	0.004
Somewhat more satisfying than smoking	2.2 (1.2–3.8)	0.006	0.092	0.6 (0.4–1.0)	0.034	0.291
Much more satisfying than smoking	2.0 (1.0–3.6)	0.034	0.258	0.8 (0.5–1.4)	0.429	1.000
Intention to quit (reference: no intention)						
Within 1–6 months	0.2 (0.1–0.7)	0.024	0.285	0.8 (0.4–1.5)	0.426	1.000
After > 6 months	1.0 (0.3–2.3)	0.916	1.000	0.7 (0.3–1.5)	0.386	1.000
Undecided	1.0 (0.6–1.6)	0.885	1.000	1.6 (1.1–2.4)	0.022	0.378

All models were adjusted for age, gender, education and smoking status.
P_{FDR}, false discovery rate (FDR)-adjusted *P*-value.
[a]Data on both perceived addiction and relative addictiveness available in $n = 737$.
[b]Urge to vape was only assessed in e-cigarettes users who did not simultaneously smoke tobacco cigarettes daily ($n = 368$).
[c]No analysis performed for perceived addiction: all participants with other gender ($n = 4$) and low urge to vape ($n = 78$) regarded themselves as not/somewhat addicted; there were no e-cigarette users who had been vaping for more than 5 years.

countries appeared comparable, with only a small minority of e-cigarette users vaping within 5 minutes after waking, and more than 40% having their first vape more than 60 minutes after waking (Supporting information, Table S4). A greater proportion of e-cigarette users in England, however, used high nicotine strengths ≥ 15 mg/ml (31% in England versus 16% in E6 and NL), while using zero nicotine was more prevalent in the other European countries (23% in 6E and NL versus 3% in England). Overall, the distributions throughout countries in relation to perceived addiction were quite similar, except that there were more e-cigarette users who reported feeling very addicted to e-cigarettes in England (Supporting information, Figure S2a). Figure S2b displays the patterns of relative addictiveness in relation to markers of addiction, which were also quite similar across countries.

DISCUSSION

This study investigated perceived addiction to and relative addictiveness of e-cigarettes and their associations with markers of addiction and vaping and smoking characteristics. We found that (1) fewer than one in five respondents considered themselves very addicted to e-cigarettes and fewer than one in 10 respondents thinks that vaping is more addictive than tobacco cigarette smoking; (2) participants who considered themselves very addicted to e-cigarettes were more likely to consider e-cigarettes equally or more addictive than tobacco cigarettes; (3) markers of addiction corresponded with perceived addiction to e-cigarettes, but only partly with relative addictiveness; and (4) daily use of e-cigarettes and feeling extreme enjoyment from vaping was related to higher perceived addiction, whereas low satisfaction relative to smoking was associated with lower odds of perceiving e-cigarettes as addictive.

That the majority of e-cigarette users considered themselves not or only somewhat addicted to e-cigarettes and that more than half considered e-cigarettes to be less addictive than tobacco cigarettes confirms previous studies showing a low prevalence of e-cigarette users feeling very addicted [3, 6–8]. E-cigarettes and tobacco cigarettes are very similar with respect to their handling, nicotine delivery and social aspects, including smoking breaks [19]. Perceived addiction and relative addictiveness hence need not necessarily be due to nicotine dependence, but may also be rooted in these psychosocial habits, especially among former smokers or dual users. Future studies are needed to disentangle the effect of psychosocial behaviours on e-cigarette addiction.

We demonstrated that markers of addiction, including immediate e-cigarette use after waking, a strong urge to vape and a very high nicotine strength, corresponded with elevated levels of perceived addiction. Tolerance, craving and time to first vape have been described as main components of e-cigarette addiction [25, 26]. Higher levels of nicotine strength might indicate a higher tolerance towards nicotine. Studies on perceived addiction of e-cigarettes in youth and young adults (16–25 years) reported that those who vaped daily, used higher strengths of nicotine and had started vaping more than a year ago considered themselves more addicted to e-cigarettes [27]. Previous epidemiological studies found associations of craving and use within 30 minutes after waking with dependence symptoms in e-cigarette users [6, 8]. Our findings expand these findings by linking such markers of addiction to perceived addiction to and relative addictiveness of e-cigarettes in adult users.

There were slight differences in the distribution of perceived addiction and relative addictiveness between the whole sample of e-cigarette users and the subsample of exclusive e-cigarette users. Exclusive e-cigarette users reported feeling addicted to e-cigarettes more often compared to all e-cigarette users (23 versus 17%),

whereas fewer exclusive e-cigarette users regarded the product equally or more addictive than tobacco cigarettes (35 versus 40%). The latter might seem counter-intuitive at first, but could be due to the fact that almost all exclusive e-cigarette users were former smokers who might have used e-cigarettes as cessation aid to quit smoking. As we only included e-cigarette users who had been vaping for at least 4 months, former smokers who use e-cigarettes as a long-term harm reduction and relapse prevention tool might have been over-represented, and these long-term users might generally be more susceptible to nicotine addiction and more aware of the high addictive potential of tobacco cigarettes. In line with this, use of very high nicotine strength was more prevalent among exclusive e-cigarette users than among the overall sample of e-cigarette users (42 versus 31%; data not shown).

We demonstrated that a dose above 15 mg/ml nicotine is associated with increased levels of perceived addiction. This is in alignment with previous studies reporting that higher nicotine concentrations were related to increased dependence symptoms and longer use of e-cigarettes [18]. Approximately one-third of the English participants used high nicotine levels, i.e. more than 15 mg/ml, and approximately 10% of the sample were using a nicotine dose of more than 20 mg/ml (data not shown). While the European Union introduced new regulations in May 2016 according to which nicotine levels are not allowed to exceed a dose of more than 20 mg/ml [28], baseline data were acquired between July and September 2016, and e-cigarette users might still have had liquid containers with higher nicotine levels stored at home, or might have mixed their own liquids.

Moreover, our analysis revealed that the degree of perceived addiction and relative addictiveness was associated with enjoyment and relative satisfaction, respectively, which might be due to the release of dopamine by stimulating nicotinic acetylcholine receptors [29]. Enjoyment and relative satisfaction might reflect positive and negative reinforcement, thereby leading to more frequent e-cigarette use. This is in line with common theories of positive reinforcement in addiction [30–33]. Through its rewarding effect, e-cigarettes might appear as an attractive alternative to tobacco cigarettes, especially when being used as harm reduction tool. However, the addictive potential needs to be carefully considered, as e-cigarettes might prolong dependence upon nicotine products, on one hand, but also prevent relapse to tobacco smoking on the other hand.

Our descriptive cross-country comparison suggested that patterns of perceived addiction and relative addictiveness with respect to markers of addiction were quite similar throughout countries. While these countries have similar regulation of e-cigarettes, given that all countries had implemented the European Tobacco Products Directive (2014/40/EU) by May 2016 [28], they differed in their public health approach to the use of e-cigarettes as a smoking cessation aid. In contrast to the rest of Europe, public health agencies in England recommend e-cigarettes as smoking cessation and harm reduction tool. That descriptive patterns were relatively comparable across both samples suggests that our findings relating to the England sample might be generalizable to other European countries with different public health approaches to e-cigarettes.

There are some limitations to our study. Due to our sampling strategy and inclusion criteria, most e-cigarette users in our study were current or former smokers, and the level of perceived addiction could reflect nicotine addiction from (previous) long-term use of tobacco cigarettes. Hence, we cannot clarify if e-cigarette use alone leads to the development of addiction. Future studies would be required to investigate addiction in regular vapers who never smoked tobacco cigarettes. However, the prevalence of exclusive e-cigarette users who never smoked is low. Also, the England sample was taken from 2016 and products have evolved rapidly since that time, so our findings might not reflect the addictive potential of newer products. Data were based on self-report, which might lead to bias, including social desirability bias. Finally, as our sample was highly selective, we cannot generalize our results to the general population.

Further studies in the context of the EVAPE project aim to shed light on the addictive potential of e-cigarettes by examining their reward value and dependence symptoms from neurobiological and sociological perspectives [19, 34].

CONCLUSIONS

In this cross-sectional study, we showed that markers of addiction corresponded with perceived addiction of e-cigarette users, implying that self-reported measures of perceived addiction might be an indicator of addiction. Prevalence both of perceived addiction and markers of addiction were comparatively low overall, supporting the research indicating that an addictive potential of e-cigarettes is present, and the high endorsement of their lower relative addictiveness is consistent with research suggesting that this addictive potential is lower than that of tobacco cigarettes. Moreover, our data imply that positive and negative reinforcement, expressed by enjoyment and relative satisfaction, plays a role in perceived addiction to and relative addictiveness of e-cigarettes. Further studies are warranted to investigate these associations longitudinally.

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DECLARATION OF INTERESTS

G.T.F. has served as an expert witness or a consultant for governments defending their country's policies or regulations in litigation. All other authors have no conflicts of interest.

AUTHOR CONTRIBUTIONS

Valerie Lohner: Conceptualization (equal); formal analysis (equal); methodology (equal); writing—original draft (equal). **Ann McNeill:** Data curation (equal); funding acquisition (equal); writing—review and editing (equal). **Sven Schneider:** Conceptualization (equal); funding acquisition (equal); writing—review and editing (equal). **Sabine Vollstaedt-Klein:** Conceptualization (equal); funding acquisition (equal); writing—review and editing (equal). **Marike Andreas:** Conceptualization (equal);

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ETHICS STATEMENT

The survey protocols and all materials, including the survey questionnaires, were cleared for ethics by the Review Ethics Board at the Office of Research Ethics, University of Waterloo, Canada (REB#20803/30570 for England, REB#21262/30709 for 6E, REB#41704 for the Netherlands); internal review boards at: King's College London (IRB RESCM-17/18-2240); Romania Iuliu Hatieganu University of Medicine and Pharmacy (IRB155), Spain Hospital Universitari de Bellvitge (IRB PR100/16), Poland State College of Higher Vocational Education (IRB 1/2016), Greece Medical School, University of Athens (IRB 1516023880), Hungary Medical Research Council (IRB 46344-2/2017/EKU) and Medical Faculty Heidelberg (IRB 196/2016); ethics clearance from the University of Maastricht, the Netherlands, was waived due to minimal risks.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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