Vapers exhibit similar subjective nicotine dependence but lower nicotine reinforcing value compared to smokers

**Abstract**

**Introduction** E-cigarette use has increased rapidly over the last 10 years, mostly among smokers and ex-smokers. Although there may be some degree of dependency on nicotine via e-cigarette use, the nature of this dependency is poorly understood. The aim of this paper is to use tasks from behavioural economics to compare the value that smokers place on tobacco cigarettes to the value that vapers place on e-cigarettes.

**Method** Exclusive currentsmokers (n=25) and vapers (n=20) attended one session where they completed the Cigarette/e-cigarette Dependence Scale, the Cigarette/e-cigarette Purchasing Task (CPT) and the Concurrent Choice Task (CCT). The CPT requires participants to indicate how many puffs of their chosen product they would purchase at increasing price points. The CCT requires participants to choose between earning a money point or a point towards a cigarette/e-cigarette after being presented with a neutral, money or cigarette/e-cigarette cue.

**Results** Overall scores on the self-report scales suggest a comparable level of dependency between smokers and vapers. The CPT revealed that vapers are more sensitive than smokers to escalating costs as consumption declined as costs increased. On the CCT, when primed with money, vapers showed a decrease in choosing e-cigarettes.

**Conclusion** These findings suggest that, on behavioural economic tasks, tobacco cigarettes have a higher relative value than e-cigarettes. Vapers appear to place a lower limit on what they will spend to access e-cigarettes and more readily choose money over e-cigarette puffs when primed by money cues.

**Keywords**

E-cigarettes, vaping, smoking, nicotine, dependence, tobacco

**Funding**

The work was supported by the MRC (G0701456: LH). JM’s contributions were supported by the Peter Boris Chair in Addictions Research. All other authors did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors for this project.

**Declarations of Interest**

None for NR and LH. JM is a principal in BEAM Diagnostics, Inc. LD provided consultancy for the pharmaceutical industry around the development of nicotine containing products in November 2017.

1. **Introduction**

The popularity of electronic cigarettes in Great Britain has increased over recent years, from around 700,000 users in 2012 to 3.6 million in 2019 (ASH, 2019). Most e-cigarette users (vapers) are current or ex-smokers (94%; ASH, 2019) and e-cigarettes are the most popular method for quitting smoking in the UK (West, Beard and Brown, 2018). Under certain conditions, vapers can obtain blood nicotine levels comparable to those achieved via cigarette smoking (Dawkins et al., 2016a; Ramôa et al. 2015) suggesting dependency potential in a population who, as ex-smokers, have a history of dependence on nicotine. Dependency on e-cigarettes is reported to be lower than dependency on tobacco based on retrospective (e.g. Dawkins et al., 2013, Etter and Eissenberg, 2015, Foulds et al., 2015, Browne and Todd, 2018) and current use self-reports (Shiffman and Sembower, 2020) although there are also reports of the converse (Johnson et al. 2018, Jankowski et al. 2019). One of these studies was conducted at an e-cigarette convention and contained a higher than expected proportion, 13.9%, of never-smokers (Johnson et al., 2018). In Jankowksi et al.’s (2019) sample, the majority used more than one device, often self-modified, as well as self-prepared e-liquids and consumed relatively high volumes (4.2ml/day) of e-liquid. This pattern of use differs from the average e-cigarette user (ASH, 2019) and suggests the participants were vaping aficionados thus questioning sample representativeness. Alongside more traditional self-report dependency scales, the aim of this study is to use measures from behavioural economics to explore the relative incentive value of e-cigarettes and tobacco cigarettes. These measures are extensions of basic operant behavioural assays of reinforcing value and abuse liability (e.g., MacKillop et al., 2019), providing complementary information to subjective dependency symptoms in terms of value preferences and choice behaviour.

Studies of e-cigarette dependency tend to adapt existing smoking dependency scale items to make them relevant to vaping. The word ‘smoke’ is replaced with ‘vape’ and ‘number of cigarettes’ replaced with ‘number of puffs/puffing episodes’. Patterns of vaping and smoking differ however, particularly in quantity and frequency (Dawkins et al., 2013; Blank et al. 2016) making it difficult to equate ‘number of puffs/puffing episodes’ to ‘number of cigarettes a day’ (Blank et al. 2016). Scoring a 10 minute puffing episode/15 puffs on an e-cigarette as directly equivalent to one cigarette may partially explain the higher levels of dependency reported amongst Polish e-cigarette users by Jankowski et al. (2019).

Three of the most reliable predictors of smoking cessation are ‘number of cigarettes smoked a day’, ‘desire to stop or cut down’ (Strong et al, 2015) and ‘time to first cigarette’ (Heatherton et al. 1991, Fagerstrom et al. 2012). Only the last item relates directly to e-cigarette use as desire to quit the considerably less harmful habit of vaping may be lower than desire to quit smoking. In a longitudinal study of self-rated dependency in smokers who had switched to vaping, Liu et al. (2017) reported lower levels of e-cigarette versus tobacco dependency after one year on all five questions used. Despite problems with measuring e-cigarette dependency based on self-report data, overall, e-cigarettes appear to be associated with lower levels of dependency than tobacco cigarettes.

An alternative to self-report questionnaires is methods taken from behavioural economics allowing comparison of the relative value of cigarettes and e-cigarettes. Such tasks allow measurement of the reinforcing value of drugs either by quantifying the amount of effort put into obtaining them or by comparison to another reinforcer, such as food or money. Vansickel, Weaver and Eissenberg (2012) used a multiple choice procedure; smokers trained to use e-cigarettes chose 10 e-cigarette puffs over increasing amounts of money on one occasion and 10 tobacco cigarette puffs over money on another. The cross-over value (i.e. value at which money is preferred over e-cigarette/tobacco puffs) was significantly higher for tobacco puffs indicating that cigarettes were valued more highly than money, compared to e-cigarettes. Dowd and Tiffany (2018) asked dual users to indicate how much money they would pay to access one puff on an e-cigarette or a cigarette; a drink of water served as a control substance. Whilst levels of cue-elicited craving were similar for e-cigarettes and cigarettes, participants were willing to spend more to access the latter.

Here we report findings from two tasks that use behavioural economic measures and cue-priming effects to establish the relative reward value of e-cigarettes and tobacco cigarettes. The Cigarette Purchase Task (CPT; Jacobs & Bickel, 1999; MacKillop et al., 2008) is an adaptation of an operant progressive-ratio schedule into a decision making task and provides a number of indices of the reinforcing value of cigarettes. Indices from the CPT have been shown to be associated with nicotine dependence (Chase, Mackillop and Hogarth, 2013), concurrently and prospectively (MacKillop et al. 2016), and sensitive to the presence of cues and induction of withdrawal (MacKillop et al. 2012). The purchase task methodology more generally has been validated as a strategy for characterizing abuse liability (MacKillop et al. 2019) and allows researchers to quantify how sensitive demand for a substance is to escalating costs.

The Concurrent Choice Task (CCT, Hogarth et al. 2012, 2015a) requires smokers to choose between a response that earns points exchangeable for cigarettes and a response that earns points for money. The proportion of tobacco choices indexes the relative value ascribed to the drug versus money. Furthermore, in the Pavlovian-instrumental transfer test phase, cues for each reward are presented, which increase choice of the congruous response. This method could thus be used to test the relative value of e-cigarettes and cigarettes, and whether responding for these two rewards is differentially sensitive to cue priming effects. This task has been demonstrated as sensitive to smoking status and level of craving for tobacco (Hogarth et al., 2012), the type of cigarette cue used (Hogarth et al. 2015a) and mood state of the smoker (Hogarth et al. 2015b).

The aim of the current study was to compare dependency on cigarettes in current smokers to dependency on e-cigarettes in current vapers. The Cigarette Dependence Scale (Etter, Houezec & Perneger, 2003) was used as a self-report measure of nicotine dependence. Given that the relevance to vaping of items on this scale vary, analysis was conducted on each item separately as well as the total score. The CPT and CCT were used as indicators of the relative value of tobacco cigarettes and e-cigarettes, and sensitivity to cue priming effects. In order to control for current levels of craving or withdrawal from nicotine, all participants were also asked to complete the Mood and Physical Symptoms Scale (West and Hajek, 2004).

**2. Methods**

**2.1 Participants**

Participants were smokers (n=25) and vapers (n=21) recruited via advertisements around the University of East London (UEL), an East London e-cigarette café and by word of mouth. Inclusion criteria were current daily exclusive use of either tobacco cigarettes for at least six months or electronic cigarettes and, for vapers, exclusive e-cigarette use for at least 3 months, use of e-liquid that contains nicotine and daily use of tobacco prior to vaping. Dual users were excluded to enable a more direct comparison of dependency to nicotine and reinforcement value amongst users of e-cigarettes and tobacco cigarettes. Three months of exclusive use of e-cigarettes was required to ensure all participants had made a successful and relatively stable switch from smoking to vaping.

**2.2 Materials and Methods**

*Demographic and smoking/vaping related info*

Smokers were asked to report number of cigarettes smoked per day and years of smoking. Vapers reported this information retrospectively and also reported type of e-cigarette used, length of time vaping, nicotine concentration used and ml of liquid used per day.

*Cigarette Dependence Scale (CDS-12) / e-Cigarette Dependence Scale (CDS-12)*

The CDS-12 and e-CDS-12 (Etter, Houezec & Perneger, 2003) is a twelve-item self-report scale based on definitions of dependence from the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) and the International Classification of Diseases (ICD-10). Each individual item of the scale is scored from 1-5, and total scores range from 12 (low dependence) to 60 (high dependence). For ‘cigarettes per day’ (CPD) and ‘puffs per day’ the scale ranged from 1 = 1-5 cigarettes or 0-20 puffs and 5 = 30+ cigarettes or 201+ puffs.

*Mood and Physical Symptoms Scale (MPSS)*

The MPSS (West & Hajeck, 2004) was used to measure the extent of six common nicotine withdrawal symptoms. Total scores can range from 0 to 24; higher scores represent increased experience of symptoms. For vapers, current urge to smoke was replaced with urge to vape measured from 1 (not at all strong) to 7 (very strong).

*Cigarette Purchase Task (CPT) / e-Cigarette Purchase Task (eCPT)*

The CPT (MacKillop et al. 2008) is a behavioural economic assessment used to measure motivation for tobacco use. It has been validated for concurrent validity (MacKillop et al. 2008; Murphy et al., 2009), discriminant validity (Chase et al. 2013) and temporal reliability (Few et al, 2012). The eCPT is an adaptation of the CPT for e-cigarettes. This revised version asked participants to think in terms of puffs per day instead of whole cigarettes in order to make the data comparable between smokers and vapers. Participants were asked to imagine a typical day in which they smoked or vaped and to estimate how many puffs they would take if each puff cost a certain amount of money. Price per puff varied from 0 pence to 235 pence (US$2.93). Indices from the CPT are: Intensity (puffs consumed when price is zero), Omax (maximum expenditure on puffs), Pmax (price at which demand transitions from inelasticity to elasticity, when smokers/vapers become sensitive to costs and disproportionately reduce the number of puffs purchased) and breakpoint (price that suppresses consumption entirely).

*Concurrent Choice Task (CCT)*

Two versions of the CCT (adapted from Hogarth et al. 2015a) assessed the relative value of cigarettes or e-cigarettes versus money and sensitivity to cue-elicited drug choice. In the smokers version, participants were asked to press either the D or H key on a keyboard to earn either cigarette or money points. A packet of cigarettes or six one pound coins were placed on the corresponding side of the desk to remind participants of the response-outcome contigencies. Choosing a key earned either the cigarette outcome: ‘You earn one cigarette point’ plus a cigarette image (two cigarettes on a white background) or the money outcome: ‘You earn one money point’ plus a money image (a small pile of pound coins on a white background). Participants were aware that the points were hypothetical and no cigarettes or money would be earned. Percent choice of cigarette over money points over 48 trials indexed the relative value of cigarettes compared to money.

The cue-priming test examined the ability of the cigarette and money cues presented during baseline to prime choice of the corresponding key. In these trials, the choice prompt ‘D or H key?’ was presented as before, but accompanied by the cigarette image, money image or no image on a random third of trials each. Responding produced no outcome (i.e. no money or cigarette points earned) in this stage (nominal extinction) so we could evaluate the impact of cues on response choice in the absence of feedback from outcomes. Percent choice of the cigarette over money keys in the three cue priming conditions was the dependent variable, indexing sensitivity to cue provoked choice.

In the e-cigarette version of this task, the cigarettes were replaced with an e-Go style, the most popular device in use at the time of data collection second generation e-cigarette containing 1.0ml e-liquid. The words ‘cigarette(s)’ and ‘smoke’ were replaced with the words ‘e-cigarette’ and ‘vape’ respectively. The cigarette image was replaced by an e-cigarette image (three second generation ‘eGo’ type e-cigarettes on a white background).

**2.3 Procedure**

All participants attended one session and were asked to abstain from smoking or vaping for at least one hour before the study. All participants completed tasks in the same fixed order as presented above. Participants were then debriefed and reimbursed with a £7 love to shop voucher for their time. The study was approved by UEL’s research ethics committee.

**2.4 Data Analysis**

Unrelated t-tests were used to identify differences between smokers and vapers on single items from the CDS and for choice of cigarettes/e-cigarettes over money during the baseline training stage in the CCT. Bayes factors (Dienes and Mclatchie, 2018); calculated using the online calculator available here: <http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/bayes_factor.swf> were used to confirm whether non-significant results were uninformative (Bayes factors between 1/3 and 3) regarding differences between vapers and smokers or whether such results indicated no difference exists (scores below 1/3).

The following variables were computed on the CPT (MacKillop et al, 2008): intensity (number of puffs taken when price was zero), Omax (maximum expenditure per day), Pmax (price at which consumption becomes elastic) and breakpoint (the price at which participants chose to stop buying puffs). An observed values approach was used for all measures. Where no breakpoint was recorded by the participant (indicating they were still purchasing puffs at 235 pence per puff), 235 pence was taken as their breakpoint. This applied to 7 cigarette smokers. Inspection of histograms confirmed that data were not normally distributed. Log10 transformations significantly improved the distributions. One-way ANCOVAs were performed on log transformed data to compare smokers and vapers with age, number of cigarettes smoked per day and years of smoking cigarettes entered as covariates.

Data from the cue-priming stage of the CCT were also not normally distributed and Log10 transformations improved the distribution. The log transformed data were analysed using a 2 (group: smoker vs. vaper) x 3 (no cue, cigarette/e-cig cue, money cue) mixed ANCOVA with the same covariates. Data from the baseline training stage were normally distributed and analysed with a between-subjects t-test.

For all inferential tests, p<0.05 was the cut-off for statistical significance.

1. **Results**

**3.1 Demographics and Smoking Characteristics**

Unrelated t-tests revealed that vapers were older, smoked more cigarettes per day and for more years (prior to switching to e-cigarettes) than current cigarette smokers. See table 1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Smokers | Vapers | t (df = 44) | p  |
| Age in years | 31.00 (7.59) | 39.81 (8.98) | -3.198 | 0.003 |
| CPD | 10.28 (6.42) | 14.90 (7.02) | -2.332 | 0.024 |
| No. of years smoked | 13.04 (7.34) | 19.00 (8.68) | -2.497 | 0.016 |
| Last use of nicotine (minutes) | 318.25 (317.71) | 205.62 (226.51) | 1.301\* | 0.202 |

\* Levene’s test significant (p<0.001) df = 34.22

Table 1. Mean (S.D.), t-values and p-values for demographic and smoking characteristics in smokers (n=25) and vapers (n=21). CPD = cigarettes per day. For vapers, CPD and years smoked are based on retrospective reporting.

Vapers used a wide variety of devices including cigalikes (n=7), vape pens (n=5), box mods (n=5) and more than one type (n=4). They had been using e-cigarettes for a mean of 1.16 (SD = 0.78) years. E-liquid nicotine concentration ranged from 6 mg/ml to 18 mg/ml (mean=14.33; SD=3.54). Millilitres of e-liquid used a day ranged from 0.4-8ml (mean=2.93; SD=2.18).

**3.2 Cigarette Dependence Scale (CDS), Urge to Smoke and Mood and Physical Symptoms Scale (MPSS)**

Smokers and vapers did not differ on current urge to smoke or vape, levels of nicotine withdrawal symptoms and overall CDS scores. See table 2. Cronbach’s alpha indicated acceptable internal reliability for the CDS in both smokers (α = 0.914) and vapers (α = 0.749).

Analysis of CDS individual items revealed that vapers take more puffs per day whilst smokers report higher levels of ‘dropping everything to use’. Bayes factors indicate that vapers may report higher levels of stress if they do not have their device and may smoke sooner after waking and feel like they smoke too much. See table 2.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Smokers | Vapers | t (df=44) | p  | Bayes |
| Current urge to smoke/vape | 3.12 (1.48) | 3.57 (1.36) | -1.068 | 0.292 | 0.03 |
| MPSS total  | 4.00 (4.64) | 4.05 (4.14) | -0.038 | 0.970 | 0.08 |
| Cigarettes/Puffs per day | 2.20 (0.96) | 3.62 (1.24) | -4.272\* | <0.001 | n/a |
| How soon after waking | 2.32 (1.25) | 3.10 (1.41) | -1.977 | 0.054 | 0.50 |
| Difficulty stopping | 3.28 (0.68) | 3.38 (0.92) | -0.428 | 0.671 | 0.00 |
| Self-rated addiction | 3.28 (1.24) | 3.52 (1.08) | -0.704 | 0.485 | 0.00 |
| Urge to smoke/vape | 3.60 (1.23) | 3.76 (1.26) | -0.441 | 0.662 | 0.00 |
| Not having causes stress | 3.08 (1.38) | 3.86 (1.24) | -1.992 | 0.053 | 0.51 |
| Always take out with me | 4.36 (1.19) | 4.76 (0.54) | -1.432 | 0.159 | 0.01 |
| Prisoner of cigs/e-cigs | 2.92 (1.44) | 2.67 (1.20) | 0.641 | 0.525 | 0.01 |
| Smoke too much | 3.68 (1.41) | 2.86 (1.39) | 1.988 | 0.053 | 0.62 |
| Drop everything to use | 2.96 (1.49) | 1.76 (0.94) | 3.314\*\* | 0.002 | n/a |
| Smoke/vape all the time | 3.00 (1.50) | 2.90 (1.04) | 0.245 | 0.808 | 0.00 |
| Use despite health risks | 4.48 (1.00) | 3.10 (1.30) | 4.073 | <0.001 | n/a |
| CDS Total score | 38.63 (10.65) | 38.73 (7.47) | -0.046 | 0.964 | 0.01 |

**\***Levene’s test significant (p=0.029), df = 37.18

\*\* Levene’s test significant (p=0.003), df = 41.91

Table 2. Mean (SD), t-values and p-values for ‘current urge to smoke’, MPSS total and CDS in smokers (n=25) and vapers (n=21).

**3.3 Cigarette Purchase Task**

Data reported here are from 20 smokers and 14 vapers; 12 participants (5 smokers and 7 vapers) were excluded due to reversals (increased number of puffs purchased as price point increases) on the CPT task suggesting inattention or intentionally low effort. When consumption was free (intensity), smokers and vapers did not differ in number of puffs consumed. Smokers spent considerably more, as measured by Omax (maximum spend in one day), exhibited lower price sensitivity Pmax (highest price point reached) and had a significantly higher breakpoint. See table 3.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Smokers | Vapers | F (df = 1,29) | p  | ηp2 |
| Intensity | 2.31 (0.08) | 2.14 (0.09) | 1.593 | 0.217 | 0.052 |
| Omax | 3.54 (0.12) | 2.93 (0.16) | 7.440 | 0.011 | 0.210 |
| Pmax | 1.65 (0.14) | 0.94 (0.18) | 8.449 | 0.007 | 0.233 |
| Breakpoint | 1.77 (0.13) | 1.23 (0.17) | 5.129 | 0.031 | 0.150 |

Table 3. Mean (SD), F-values and p-values for performance in the Cigarette Purchasing Task for smokers (n=20) and vapers (n=14).

**3.4 Concurrent Choice Task**

There was no difference between smokers (mean = 33.67, SD = 28.68) and vapers (mean = 36.51, SD = 22.19) in percentage of trials where cigarettes/e-cigarettes were chosen over money during baseline training, t=-0.370, df = 44, p=0.713, Bayes = 0.13

A 2 (group: smokers vs. vapers) x 3 (cue type: no cue vs. cigarette/e-cig cue vs. money cue) ANCOVA revealed no significant main effect of cue type F(2,44) = 1.703, p=0.194, ηp2 = 0.072. The main effect of group was also not significant, F(1,22) = 1.070 p = 0.312, ηp2 = 0.046. The 2-way interaction between group and cue type was significant F(2,44) = 3.234, p = 0.049, ηp2 = 0.128. Post-hoc one way ANCOVAs comparing smokers to vapers at each level of cue shows that this was due to no difference between smokers and vapers in percentage choice of cigarettes/e-cigarettes when the neutral cue, F(1,34) = 1.730, p=0.197, ηp2 = 0.048 and cigarette/e-cigarette cue, F(1,35) = 1.774, p=0.596, ηp2 = 0.008 were presented. When, however, the money cue was presented, vapers were less likely to choose an e-cigarette, F(1,23) = 6.309, p=0.019, ηp2 = 0.215; see figure 1.

Fig. 1. Lg10 transformed data for percentage choice of cigarettes/e-cigarettes for smokers (n=25) and vapers (n=20) on the CCT.

**4. Discussion**

This experiment used two behavioural economic tasks alongside self-report questionnaires to explore dependency to nicotine amongst daily cigarette smokers and vapers. Whilst levels of self-reported dependency were similar, nicotine may have higher reinforcing value for smokers than vapers as smokers were willing to pay more for cigarettes than vapers were for e-cigarettes. This was the case despite the heavier cigarette smoking history amongst vapers, which could be indicative of higher levels of cigarette dependency prior to switching to e-cigarette use. Whilst there are higher costs associated with smoking, and similar findings were reported by Dowd & Tiffany (2018), the higher breakpoint amongst smokers indicated a willingness to spend more money to obtain tobacco. Previous studies have suggested that purchase task indices represent two underlying latent categories, reflecting amplitude of demand (how much a person wants, measured primarily by intensity) and persistence of demand (how sensitive a person is to escalating costs, measured by Omax, Pmax and breakpoint) (Mackillop et al 2009, Bidwell et al. 2012, Aston et al. 2017, Epstein et al. 2018). Vapers may differ from smokers on the latter; they were more sensitive to costs on the CPT and showed a reduction in e-cigarette choice when primed with money cues on the CCT. Whilst both tasks are sensitive to satiety and withdrawal (Hogarth and Chase, 2011, MacKillop et al. 2012), these findings are unlikely to be influenced by differences in current level of desire for nicotine. There were no group differences in withdrawal symptoms or desire to smoke or vape at the start of the session, nor on choice of tobacco/e-cigarette in the baseline stage of the CCT.

Our findings, however, need to be interpreted in light of the changes made to the CPT task and the fact that nearly one-third of the data were removed from the analysis. The original task (MacKillop et al, 2008, Jacobs and Bickel, 1999) asked smokers to answer in number of cigarettes, our participants were asked to answer in number of puffs. Puffs was chosen in order to use a comparable measure that applied to both smoking and vaping as well as all types of device used. Cassidy et al. (2017) established that whilst vapers do find it difficult to conceptualise use in terms of number of puffs, the preferred measure of quantity used varied across device type. For example, users of cigalikes preferred number of cartridges, users of tanks preferred volume of liquid (Cassidy et al., 2017). Price per puff has also been used in a marijuana purchase task (Aston, Metrik and Mackillop, 2015) and intensity, Omax and elasticity were robustly associated with patterns of marijuana use and levels of subjective craving. It may, however, be more meaningful to marijuana users, who used a wide range of methods of administration (e.g. bongs, vaporisers), to conceptualise use in number of puffs. Smokers and vapers may find this measure difficult but this limitation applies equally to both groups.

Analysis of individual CDS/eCDS items revealed some differences between smokers and vapers although level of dependency may not be the best explanation for them. Number of ‘puffs per day’ reported by vapers was higher than ‘cigarettes per day’ reported by smokers. Given the difficulties in establishing equivalencies between patterns of use of cigarettes and e-cigarettes (Blank et al., 2016), this probably reflects measurement bias in this item which equated one cigarette with approximately six-to-seven e-cigarette puffs – likely an underestimate (Dawkins et al., 2013; 2018). Given that vaping puff number also depends on device used, nicotine concentration, flavour, power and atomiser resistance (Dawkins et al., 2016b; 2018; St. Helen, 2018), determining parity in measurement between smoking and vaping may not be fruitful and could even be misleading. Number of cigarettes a day is a widely accepted indication of level of use for tobacco cigarettes, vapers tend to prefer other measures (Cassidy et al. 2017) particularly so on purchase tasks (Cassidy, Long, Tidey and Colby, 2020). Use of the same measure for e-cigarettes requires all participants to use the same device which was not the case in this study.

Smokers reported higher levels of ‘dropping everything to use’ and ‘smoking despite health risks’ which could indicate higher levels of dependence, but, in the latter case, could also reflect effective public health messaging. These items, however, may be of little relevance to vapers who have switched from smoking to vaping. The putatively relatively low health risks of vaping (PHE, 2018) would suggest that ‘vaping despite health risks’ is not a reliable indicator of e-cigarette dependence, especially as all vapers in this study were ex-smokers. This measure raises questions about the extent to which dependency on e-cigarettes, a product for which there is increasing evidence for lower harm than from cigarettes, should be considered problematic (Cox and Jakes 2017). Whilst the data presented here suggest lower levels of dependency on vaping than smoking, how problematic this dependency is was not explored. For many of the other CDS/eCDS items, our data did not identify differences between smokers and vapers. Differences between subjective and behavioural indices of dependency are commonly reported in the literature (e.g. Lamb et al 1991, Ligouri et al. 1999) and may be indicative of dual-process theories of addiction (Tiffany 1990). Such differences could, however, also be explained by different thresholds for responding for explicit and implicit measures.

Overall, the results from the self-report measure (CDS/eCDS) were uninformative in relation to whether smokers and vapers differ in levels of dependency. However, in line with previous studies (Dawkins et al. 2013 Foulds et al, 2015, Dowd and Tiffany, 2018), the higher demand amongst smokers is indicative of higher levels of dependency amongst smokers than vapers. Vaping, appears to share similar features to smoking such as automaticity and cue elicitation but may be more sensitive to increasing costs. Whilst there are some similarities between levels of dependency on e-cigarettes and tobacco cigarettes, the lower health risks associated with e-cigarettes combined with the greater sensitivity to costs suggest they make a viable harm-reduction alternative to smoking tobacco. Indeed, if e-cigarettes caused no dependency at all, it is unlikely that smokers would be able to successfully switch from tobacco use to vaping. Future research using behavioural economic tasks would benefit from including dual users of cigarettes and e-cigarettes. Whilst lower levels of self-reported dependency to e-cigarettes have now been reported in dual users (Shiffman and Sembower, 2020), the difficulties of establishing equivalent self-report measures are still evident, especially in regard to ‘time to use after waking’ amongst this population. Dual users, therefore, could provide valuable insight into the relative value of both products, especially during the transition from cigarette smoking to e-cigarette use.

**Acknowledgements**

The authors give their thanks to Maya Campbell and Maria Lee for their help with data collection**.**

**References**

ASH (2019) Use of e-cigarettes (vaporisers) among adults in Great Britain. Action on Smoking and Health factsheet. Downloaded from <https://ash.org.uk/wp-content/uploads/2019/09/Use-of-e-cigarettes-among-adults-2019.pdf> Accessed 24/4/20

Aston, E. R., Farris, S. G., MacKillop, J., & Metrik, J. (2017). Latent factor structure of a behavioral economic marijuana demand curve. *Psychopharmacology*, *234*(16), 2421-2429. <http://doi:10.1007/s00213-017-4633-6>

Aston, E. R., Metrik, J., & MacKillop, J. (2015). Further validation of a marijuana purchase task. *Drug and alcohol dependence*, *152*, 32-38. <http://dx.doi.org/10.1016/j.drugalcdep.2015.04.025>

Bidwell, L. C., MacKillop, J., Murphy, J. G., Tidey, J. W., & Colby, S. M. (2012). Latent factor structure of a behavioral economic cigarette demand curve in adolescent smokers. *Addictive behaviors*, *37*(11), 1257-1263. <http://doi:10.1016/j.addbeh.2012.06.009>.

Blank, M.D., Breland, A.B., Cobb, C.O., Spindle, T., Ramôa, C. and Eissengerg, T. (2016) Clinical laboratory evaluation of electronic cigarettes. Methodological challenges. Tobacco Regulatory Science, 2(4), 426-439 <http://dx.doi.org/10.18001/TRS.2.4.12>

Browne, M. and Todd, D.G. (2018) Then and now: Consumption and dependence in e-cigarette users who formerly smoked cigarettes. Addictive Behaviors 76, 112-121 <http://dx.doi.org/10.1016/j.addbeh.2017.07.034>

Cassidy, R. N., Long, V., Tidey, J. W., & Colby, S. M. (2020). Validation of an E-cigarette Purchase Task in Advanced Generation Device Users. *Nicotine & Tobacco Research*.

Cassidy, R. N., Tidey, J. W., Colby, S. M., Long, V., & Higgins, S. T. (2017). Initial development of an e-cigarette purchase task: A mixed methods study. *Tobacco regulatory science*, *3*(2), 139-150. <https://doi.org/10.18001/TRS.3.2.2>

Chase, H. W., MacKillop, J., & Hogarth, L. (2013). Isolating behavioural economic indices of demand in relation to nicotine dependence. *Psychopharmacology*, *226*(2), 371-380. <https://doi.org/10.1007/s00213-012-2911-x>

Cox, S. and Jakes, S. (2017) Nicotine and e-cigarettes: Rethinking addiction in the context of reduced harm. International Journal of Drug Policy 44, 84-85. <https://dx.doi.org/10.1016/j.drugpo.2017.03.009>

Dawkins, L., Turner, J., Roberts, A. and Soar, K. (2013) ‘Vaping’ profiles and preferences: an online survey of electronic cigarete users. Addiction, 108(6), 1115-1125. <https://doi.org/10.1111/ass.12150>

Dawkins, L, Kimber, C.F., Doig, M., Feyerabend, C. and Corcoran, O. (2016a) Self-titration by experienced e-cigarette users: blood nicotine delivery and subjective effects. Psychopharmacology, 233 (15-16), 2933-2941  [https://doi.org/10.1007/s00213-016-4338-2](https://psycnet.apa.org/doi/10.1007/s00213-016-4338-2)

Dawkins, L., Munafo, M., Christoforou, G., Olumegbon, N. and Soar, K. (2016b) The effects of e-cigarette visual appearance on craving and withdrawal symptoms in abstinent smokers. Psychology of Addictive Behaviours, 30 (1), 101-105 [https://doi.org/10.1037/adb0000112](https://psycnet.apa.org/doi/10.1037/adb0000112)

Dawkins, L. Cox, S., Goniewicz, M., McRobbie, H., Kimber, C., Doig, M. and Kosmider, L. (2018) ‘Real-world’ compensatory behaviour with low nicotine concentration e-liquid: subjective effects and nicotine, acrolein and formaldehyde exposure. Addiction <https://doi.org/10.1111/add.14271>

Dienes, Z. and Mclatchie, N. (2018) Four reasons to prefer Bayesian analysis over significance testing. Psychonomic Bulletin Review, 25, 201-128 <https://doi.org/10.3758/s13423-017-1266-z>

Dowd, A.N. and Tiffany, S.T. (2018) Comparison of tobacco and electroinic cigarete reward value measured during a cue-reactivity task: An extension of the Choice-Behavior-Under-Cued-Conditions (CBUCC) procedure. Nicotine and Tobacco Research, <https://doi.org/10.1093/ntr/nty143>.

Epstein, L. H., Stein, J. S., Paluch, R. A., MacKillop, J., & Bickel, W. K. (2018). Binary components of food reinforcement: Amplitude and persistence. *Appetite*, *120*, 67-74. <https://doi.org/10.1016/j.appet.2017.08.023>.

Etter, J.F., Le Houezec, J. and Perneger, T.V. (2003). A self-administered questionnaire to measure dependence on cigarettes: the cigarette dependence scale. Neuropsychopharmacology, 28(2), 359-370. <https://doi.org/10.1038/sj.npp.1300030>

Etter, J. F., & Eissenberg, T. (2015). Dependence levels in users of electronic cigarettes, nicotine gums and tobacco cigarettes. *Drug and alcohol dependence*, *147*, 68-75. <https://doi.org/10.1016/j.drugalcdep.2014.12.007>

Fagerström K-O, Russ C, Yu CR, Yunis C, Foulds J. (2012) The Fagerström Test for Nicotine Dependence as a predictor of smoking abstinence: a pooled analysis of Varenicline Clinical Trial Data. Nicotine and Tobacco Research, 14(12), 1467-1473. <https://doi.org/10.1093/ntr/nts018>

Few, L.R., Acker, J., Murphy, C., & MacKillop, J. (2012). Temporal stability of a cigarette purchase task. Nicotine & Tobacco Research, 14(6), 761-765. <https://doi.org/10.1093/ntr/ntr222>

Foulds, J., Veldheer, S., Yingst, J., Hrabovsky, S., Wilson, S.J., Nichols, T.T. and Eissenberg, T. (2015) Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking e-cigarette users. Nicotine and Tobacco Research, 17 (2), 186-192 <https://doi.org/10.1093/ntr/ntu204>

Heatherton TF, Kozlowski LT, Frecker RC and Fagerström K-O. (1991) The Fagerström Test for Nicotine Dependence: a revision of the Fagerström Tolerance Questionnaire. British Journal of Addiction, 86(9), 1119–1127.  [**https://doi.org/10.1111/j.1360-0443.1991.tb01879.x**](https://doi.org/10.1111/j.1360-0443.1991.tb01879.x)

Hogarth, L. and Chase, H.W. (2012) Evaluating psychological markers for human nicotine dependence: Tobacco choice, extinction and Pavlovian-to-instrumental transfer. Experimental and Clinical Psychopharmacology, 20(3), 213-224 [https://doi.org/10.1037/a0027203](https://psycnet.apa.org/doi/10.1037/a0027203)

Hogarth, L., Maynard, O. M., & Munafò, M. R. (2015a). Plain cigarette packs do not exert Pavlovian to instrumental transfer of control over tobacco-seeking. Addiction, 110(1), 174-182. <https://doi.org/10.1111/add.12756>

Hogarth, L., He. Z., Chase, H.W., Wills, A., Troisi, J., Leventhal, A.M., Mathew, A.R. and Hitsman, B. (2015b) Negative mood reverses devalution of goal-directed drug-seeking favouring an incentive learning account of drug dependence. Psychopharmacology, 232 (17), 323-3247 [10.1007/s00213-015-3977-z](https://dx.doi.org/10.1007/s00213-015-3977-z)

Jacobs, E. A., & Bickel, W. K. (1999). Modeling drug consumption in the clinic using simulation procedures: demand for heroin and cigarettes in opioid-dependent outpatients. *Experimental and clinical psychopharmacology*, *7*(4), 412. [https://doi.org/10.1037/1064-1297.7.4.412](https://psycnet.apa.org/doi/10.1037/1064-1297.7.4.412)

Jankowski, M., Krzystanek, M., Zejda, J. E., Majek, P., Lubanski, J., Lawson, J. A., & Brozek, G. (2019). E-cigarettes are more addictive than traditional cigarettes—a study in highly educated young people. *International journal of environmental research and public health*, *16*(13), 2279. [**https://doi.org/10.3390/ijerph16132279**](https://doi.org/10.3390/ijerph16132279)

Johnson, J. M., Muilenburg, J. L., Rathbun, S. L., Yu, X., Naeher, L. P., & Wang, J. S. (2018). Elevated nicotine dependence scores among electronic cigarette users at an electronic cigarette convention. *Journal of community health*, *43*(1), 164-174. <https://doi.org/10.1007/s10900-017-0399-3>

Lamb, R.J., Preston, K.L., Schindler, C.W., Meisch, R.A., Davis, F., Katz, J.L., Henningfield, J.E. and Goldberg, S.R. (1991). The reinforcing and subjective effects of morphine in post-addicts: A dose-response study. Journal of Pharmacology and Experimental Therapeutics, 259 (3), 1165-73 PMID: 1672068

Ligouri, A., D’Agostino Jr, R.B., Dworkin, S.I., Edwards, D. and Robinson, J.H. (1999). Alcohol effects on mood, equilibrium and simulated driving. Alcoholism, Clinical and Experimental Research, 23 (5), 815-21 [**https://doi.org/10.1111/j.1530-0277.1999.tb04188.x**](https://doi.org/10.1111/j.1530-0277.1999.tb04188.x)

Liu, G., Wasserman, E., Kong, L. and Foulds, J. (2017) A comparison of nicotine dependence among exclusive e-cigarette and cigarette users in the PATH study. Preventative Medicine, 104, 86-91 <https://doi.org/10.1016/j.ypmed.2017.04.001>

MacKillop, J., Murphy, J.G., Ray, L.A., Eisenberg, D.T.A., Lisman, S.A., Lum, J.K., & Wilson, D.S. (2008). Further validation of a cigarette purchase task for assessing the relative reinforcing efficacy of nicotine in college smokers. Experimental and Clinical Psychopharmacology, 16(1), 57-65. [https://doi.org/10.1037/1064-1297.16.1.57](https://psycnet.apa.org/doi/10.1037/1064-1297.16.1.57)

Murphy, J. G., MacKillop, J., Skidmore, J. R., & Pederson, A. A. (2009). Reliability and validity of a demand curve measure of alcohol reinforcement. *Experimental and clinical psychopharmacology*, *17*(6), 396. <https://doi.org/10.1037/a0017684>

MacKillop, J., Murphy, C. M., Martin, R. A., Stojek, M., Tidey, J. W., Colby, S. M., & Rohsenow, D. J. (2016). Predictive validity of a cigarette purchase task in a randomized controlled trial of contingent vouchers for smoking in individuals with substance use disorders. *Nicotine & Tobacco Research*, *18*(5), 531-537. <https://doi.org/10.1093/ntr/ntv233>

MacKillop, J., Brown, C. L., Stojek, M. K., Murphy, C. M., Sweet, L., & Niaura, R. S. (2012). Behavioral economic analysis of withdrawal-and cue-elicited craving for tobacco: an initial investigation. *Nicotine & Tobacco Research*, *14*(12), 1426-1434. <https://doi.org/10.1093/ntr/nts006>

MacKillop, J., Goldenson, N. I., Kirkpatrick, M. G., & Leventhal, A. M. (2019). Validation of a behavioral economic purchase task for assessing drug abuse liability. *Addiction biology*, *24*(2), 303-314. <https://doi.org/10.1111/adb.12592>

MacKillop, J., Murphy, J. G., Tidey, J. W., Kahler, C. W., Ray, L. A., & Bickel, W. K. (2009). Latent structure of facets of alcohol reinforcement from a behavioral economic demand curve. *Psychopharmacology*, *203*(1), 33-40. <https://doi.org/10.1007/s00213-008-1367-5>

PHE (2018) Public Health England independent expert e-cigarettes evidence review. <https://www.gov.uk/government/news/phe-publishes-independent-expert-e-cigarettes-evidence-review>. Accessed on 14th May 2018

Ramôa, C. P., Hiler, M. M., Spindle, T. R., Lopez, A. A., Karaoghlanian, N., Lipato, T., Eissenberg, T. (2015). Electronic cigarette nicotine delivery can exceed that of combustible cigarettes: a preliminary report. Tobacco Control. <http://doi.org/10.1136/tobaccocontrol-2015-052447>

St. Helen, G., Shahid, M., Chu, S. and Benowitz. N.L. (2018) Impact of e-liquid flavours on e-cigarette vaping behaviour. Drug and Alcohol dependence, 189(1), 42-48 <https://doi.org/10.1016/j.drugalcdep.2018.04.032>

Strong, D.R., Messer, K., Hartman, S.J., Conway, K.P., Hoffman, A.C., Pharris-Ciurej, N., White, M., Green, V.R., Compton, W.M. and Pierce, J. (2015) Measurement of multiple nicotine dependence domains among cigarette, non-cigarette and poly-tobacco users: Insights from item response theory. Drug and Alcohol Dependence 152, 185-193 <https://doi.org/10.1016/j.drugalcdep.2015.03.040>

Tiffany, S.T. (1990). A cognitive model of drug urges and drug-use behaviour: Role of automatic and non-automatic processes. Psychological Review, 97 (2), 147-168 PMID 2186423

Vansickel, A.R., Weaver, M.F. and Eissenberg, T. (2012) Clinical laboratory assessment of the abuse liability of an electronic cigarettes. Addction, 107(8), 1493-1500 [**https://doi.org/10.1111/j.1360-0443.2012.03791.x**](https://doi.org/10.1111/j.1360-0443.2012.03791.x)

West, R., & Hajek, P. (2004). Evaluation of the mood and physical symptoms scale (MPSS) to assess cigarette withdrawal. *Psychopharmacology*, *177*(1-2), 195-199. <https://doi.org/10.1007/s00213-004-1923->

West, R., Beard, E. & Brown, J. (2018). Smoking Toolkit Study: Electronic Cigarettes in England – Latest Trends. STS140122. <http://www.smokinginengland.info/latest-statistics/> Downloaded on 14th May 2018