**Short title:** *Combustible and e-cigarette use over time in binge drinking young adults*

**Is e-cigarette use associated with persistence or discontinuation of combustible cigarettes?**

**A 24-month longitudinal investigation in young adult binge drinkers**

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**ABSTRACT**

**Introduction:** It remains unclear whether electronic cigarette (e-cigarette) use promotes persistent combustible tobacco use or smoking discontinuation over time. Alcohol use is associated with greater risk of adverse health effects of tobacco, and higher likelihood of e-cigarette use, making drinkers a high priority subpopulation. This study examined longitudinal patterns of combustible tobacco and e-cigarette use over 24-months in young adult binge drinkers.

**Method:** A pooled dataset of 1,002 (58.5% female; *M* age = 22.14) binge drinkers from the United States (60%) and Canada (40%) was used. The primary outcomes were past month combustible tobacco and e-cigarette use. Nicotine dependence was measured using the Fagerström Test of Cigarette Dependence. Alcohol severity was measured using the Young Adult Alcohol Consequences Questionnaire. Latent transition analysis (LTA) was used to identify patterns of cigarette smoking and e-cigarette use over 24 months.

**Results:** The LTA yielded a four-class solution: 1) e-cigarettes-only users (prevalence over time: 7.75-10.10%), 2) dual-product users (2.61-9.89%), 3) combustible-only smokers (8.12-20.70%) and 4) non-users (61.66-80.06%). Dual-product users predominantly transitioned to complete abstinence or exclusively e-cigarette use. In combustible-only smokers, the most common transition was to abstinence, followed by persistence of combustible-only status. At 24-months, 63% of e-cigarettes-only users transitioned to abstinence, with 37% continuing e-cigarettes-only use and 0% transitioning to dual or combustible cigarette use.

**Conclusions:** Dual-product use in young adult binge drinkers was associated with discontinuation of combustible tobacco over time, and e-cigarette-only use was not associated with subsequent combustible tobacco use.

**Implications:** These findings suggest that concurrent or exclusive e-cigarette use is not a risk factor for persistence or development of combustible tobacco use in this subpopulation, with dual-product use reflecting a transitional pattern away from combustible use, toward discontinuation.

**Keywords:** cigarette smoking, e-cigarette, vaping, dual use, young adults, smoking discontinuation

**INTRODUCTION**

The growing use of electronic cigarettes (e-cigarettes) may represent both a challenge and a benefit to public health 1,2,3. On one hand, increased availability and targeted advertising have increased e-cigarettes use in youth in the US and Canada 4,5. This is important as nicotine dependence in e-cigarette users is associated with younger age at onset 6 and e-cigarette use has been associated with unique dependence symptoms in young adults 7. On the other hand, approximately 40% of adult e-cigarette users in the US are also combustible cigarette smokers8, with the primary motivation being to quit smoking 9. The effectiveness of e-cigarettes for aiding quitting remains an ongoing debate 10,11, and the risks of dual use are not well understood.

In dual-users, some studies also reported higher overall levels of dependence compared to combustible cigarette-only 12,13 and respiratory symptoms 14, as well as evidence of delayed intentions to quit 15, shifts to exclusive combustible cigarette smoking 16,17 and decreases in the likelihood of discontinuation 18. In addition, up to 80% adult smokers randomly assigned to behavioral support + e-cigarettes (compared to behavioral support + nicotine replacement therapy, NRT) reported still using e-cigarettes after 52 weeks compared to 9% who were still using NRT 19 and, in adolescents, 31.4% of dual users reported being exclusive e-cigarettes uses after 12 months,20 suggesting a sustained behavioral pattern.

Young adulthood is a high-priority population because smoking and e-cigarettes use are typically initiated between adolescence and this developmental period, 21,22 and young adult behaviors can forecast longstanding smoking and e-cigarette behavior 23,24. Moreover, binge drinking is of particular relevance because it is highly prevalent in young adults 25 and is associated with both combustible cigarette smoking 26,27 and e-cigarette use 27,28. Higher prevalence of binge drinking has also been reported in dual and exclusive e-cigarette users, compared to cigarette smokers and non-users 3. Finally, because alcohol and tobacco are synergistic in terms of carcinogenicity and other harms 29, discontinuation/progression trajectories among binge-drinking young adults may have interactive health significance across the lifespan. Thus, binge drinking young adults constitute a particularly important subgroup in understanding patterns of e-cigarettes and combustible tobacco use.

Despite these issues, few studies have explored patterns of changes over time, in general or in high-risk subpopulations. Coleman et al 30 analyzed transitions between combustible cigarette and e-cigarettes use in young adults and found that nearly half of exclusive e-cigarette users discontinued their use after one year, only 5% of dual users transitioned to exclusive e-cigarettes use, and 7% transitioned to complete abstinence. However, the authors did not consider conditional probabilities of transition and the study assessed a single one-year period. To overcome this limitation, Hair et al 24 analyzed transitions from baseline to several assessments over increasing intervals. However, this study did not examine changes between those intervals and the study sample included mainly adolescents (i.e., 15-21 years old). Additionally, as authors combined cigarettes, cigars and hookah into a single category of “combustible use”, and e-cigarettes and e-hookah into “ENDS” (electronic nicotine delivery systems), it was not possible to isolate the most common form of dual use (i.e., combustible cigarettes+e-cigarettes). Finally, Clendennen et al 31 used a latent transition analysis (LTA) to explore patterns of use and transitions using separate indicators among individuals aged 18-29. The authors found four classes of users and a non-use group but no evidence of transition from dual (“poly-cigarette use”) to any other use during the 1.5-year period analyzed. Interestingly, those having experimented with e-cigarettes and hookah (“e-cigarette & hookah experimenters”) only transitioned to either the “poly-cigarette use” or the “poly-experimental use” classes. Notwithstanding these interesting results, all but one class represented experimental use of different tobacco products, which limits their generalization to regular or current users.

To address these questions about patterns of e-cig and combustible cigarette use over time, the current study examined longitudinal patterns in two samples of binge drinking young adults from the US and Canada. Considering the association between binge drinking and e-cig use, the present sample represents a unique opportunity to explore natural transitions between patterns of e-cig and combustible cigarette use. Patterns present in this sample are both of public health relevance for this high-risk cohort and may potentially inform problematic trajectories in the broader population. Specifically, this study sought to: 1) characterize distinct subpopulations based on their pattern of use across four assessments during a 24-month period; 2) examine the most probable transitions between patterns over time; and 3) examine differences between subpopulations in sociodemographic and alcohol severity variables. We predicted that four classes would emerge (non-smokers, exclusive combustible cigarette smokers, exclusive e-cig users and dual users). Although there are conflicting findings in the literature, we hypothesized that dual use would have a deleterious role on combustible tobacco use, but exclusive e-cig use would be associated with positive trajectories.

**METHODS**

**Participants and Procedure**

 The study sample included participants in two independent studies comprising young adult binge drinkers from Memphis, Tennessee, USA (*N* = 602) and Hamilton, Ontario, Canada (*N* = 400). The samples were recruited from the community by means of print, bus, and online advertising. Potential candidates had 1) to be aged 21-24.9 in the US sample (differences are due to differences in legal drinking ages, 19 vs 21) and 19.5 to 23 years old in the Canadian sample, and 2) to report binge drinking (i.e., >3/4 standard drinks of 14g of alcohol per episode for females/males, respectively) at least 2-3 times per month. Data from participants completing the baseline assessment and three in-person follow-ups (8-months, 16-months, and 24-months) were used (additional details are in supplemental materials). Data were collected between December 2017 and July 2020. Both samples were similar in terms of sociodemographic and substance use characteristics, although the US sample was slightly older (22.64 vs 21.39, *p* < .001) and had a greater percentage of Black/African participants (41.5% vs 2.3%, *p* < .001). The Canadian sample had a greater proportion of white (71.3% vs 47%) and Asian (16% vs 3.3%) participants (see S2 in supplemental material). Ethics review boards at the University of Memphis and McMaster University approved all procedures, and all participants underwent informed consent, signing a written informed consent form. The present study follows the STROBE reporting standard for observational study and raw data are available under demand.

In the Canadian study, the eligibility criteria also permitted one binge drinking episode per month among those reporting at least monthly cannabis use (8% of participants). As the samples were made up of young adults, who are characterized by an increased likelihood of moving, a briefer online version of the assessments was available. In the Canadian study, the briefer online version did not include e-cigarette assessments, so to ensure high quality data and reliable results, only participants with in-person data in two of the three follow-up assessments were included (*n* = 400 of N = 730 in the overall study). This approach ensures the robustness of the analysis performed when dealing with missing data and allows retaining enough participants (see S1 for a further report of rates of in-person and online assessments in both samples).

 Of the 1,002 participants included in the present study, 901 (89.92%) were retained at 8-months, 895 (89.32%) at 16-months and 730 (72.85%) at 24-months. Sample characteristics are in Table 1. Participants with missing data in any of the assessments were slightly older and those with missing data at 16-months presented slightly higher nicotine dependence at the study entry (*t*(455.57) = 2.063, *p* = .040, *d* = 0.15). Also, participants with missing data at 8- (χ2 (1) = 4.14, *p* = .042; *ϕ* = .068), 16- (χ2 (1) = 6.25, *p* = .012; *ϕ* = .082), and 24-months (χ2 (1) = 4.65, *p* = .031; *ϕ* = .071) were more likely to smoke cigarettes. Missing participants at 24-months were also more likely to report using e-cigarettes at baseline (χ2 (1) = 7.75, *p* = .005; *ϕ* = .091). Participants with missing data at 16- (χ2 (1) = 10.73, *p* = .001; *ϕ* = .107) and 24-months (χ2 (1) = 8.97, *p* = .003; *ϕ* = .097) were more likely to be males. Participants with missing data at 24-months also were more likely to be white (χ2 (1) = 26.29, *p* < .001; *ϕ* = .164). Lastly, participants who no longer lived locally were given an option of an Internet-based assessment at 8- (χ2 (1) = 4.49, *p* = .034, *ϕ* = .12) and 24-months (χ2 (1) = 17.06, *p* < .001, *ϕ* = .217) were more likely to be females (see supplemental material for further information). Effect sizes suggest a limited impact on the sample composition.

**Measures**

Participants completed a battery of demographic and cigarette-related questions including frequency of combustible and e-cigarettes use (none, monthly, weekly, daily and multiple times daily). Those reporting smoking combustible cigarettes were asked to complete the Fagerström Test of Cigarette Dependence 32*.* Alcohol-related problems were assessed using the Young Adult Alcohol Consequences Questionnaire (YAACQ) 33. Participants’ total score (0-48) was dichotomized into low/moderate-high alcohol severity according to sex-related cut-offs (males ≥ 8; females ≥ 10) 34.

**Statistical Analysis**

 Sample characteristics were explored through descriptive analyses. Due to the relatively low frequency of cigarette smoking and e-cigarette use (see Table S3), past month use of combustible cigarettes and e-cigarettes was dichotomized (none=1, monthly or more frequently=2). This strategy was followed to avoid an elevated number of reduced cell sizes, which complicate the interpretation of the results and reduce their generalization. Nonetheless, when adopting an alternative approach (i.e., based on 3-level responses: non-use, monthly and at least weekly) interpretations and conclusions remain unalterable (see supplemental materials, Tables S5a-6b). A LTA was performed to obtain subgroups of participants engaging in different patterns of combustible cigarette smoking and e-cigarettes use across four assessment waves using SAS 9.4. Based on participants’ responses, the LTA uses the probability of being part of each exclusive subgroup to assign participants to one of such groups or latent classes. As an extension of the latent class analysis, this procedure also allows participants to move dynamically between groups and to estimate the probability of between-classes transitions (tau parameter) in addition to of class membership (delta parameter) and of item-response probability (rho parameter). Parameters were estimated by the maximum likelihood method using the expectation maximization procedure 35. The LTA handles missing data by calculating the equation using the product over the non-missing values of those individuals under the assumption of missing at random (for the mathematical expression see equation 4 in Lanza et al. 35. Besides, the likelihood test suggests that data is missing completely at random (G2 = 300.89, df = 633, *p* = .999), despite differences between completers and dropouts. Measurement invariance between assessments (i.e., the same latent classes are presented in each assessment) was tested using a likelihood ratio test between de constraint and unconstraint model. Based on the result suggesting measurement invariance (Δ*G2*= 15.03, Δdf = 24, *p* = .920), the rhoparameters were constrained across time.

Performance of the tested models was assessed through multiple indicators to identify an optimal model. The number of latent classes was selected based on 1) the likelihood-ratio statistics (G2 and log-likelihood or LL), and 2) the incremental model fit statistics (the Akaike’s Information Criteria or AIC, and the Bayesian Information Criterion or SABIC). Considering class sample size and interpretability of each class,a smaller G2, LL, AIC, BIC suggest a better model fit and parsimony. Measurement invariance between both samples was explored using a likelihood ratio test (Canada = 1; US = 2), suggesting the presence of the same latent classes in both samples (Δ*G2*= 1.92, Δdf = 8, *p* = .983), thus not requiring separate analysis for each sample. Despite the presence of same subpopulations of cigarette smokers and e-cigarette users, demographic characteristics and alcohol severity levels between classes were compared cross-sectionally using chi-squared analyses and Cramer’s *V* as the effect size.

**RESULTS**

**Identification of Latent Group Structure**

 The model with more adequate fit and interpretability suggested the presence of four latent classes (G2 = 150.88, LL = -2,362.93, AIC = 244.88, BIC = 475.64): 1) exclusive e-cigarette users (probability per assessment in %: 7.75, 8.13, 10.10, 8.93), dual users (%: 9.89, 6.39, 5.34, 2.61), non-users (%: 61.66, 72.28, 76.44, 80.06), and exclusive combustible cigarette smokers (%: 20.70, 13.20, 8.12, 8.40). Latent class solutions greater than four did not converge. Table 2 shows the item-response probability for each indicator across classes and their prevalence over time (see Table S4, in supplemental material, for the distribution of participants across classes over time).

All four classes showed high homogeneity, but groups’ sizes changed across assessments, except in the e-cigarettes only group (see Table 2 and S3, in supplemental material). Although the same latent classes were found in both samples, some significant differences in their distribution existed. Specifically, at 16-months, dual use was more likely in the Canadian sample (55.3% vs 44.7%) while non-use was higher in the US sample (61.7% vs 38.3%; *χ*2(3) = 8.51, *p* = .037, *V* = .092). These differences remained at 24-months (*χ*2(3) = 8.58, *p* = .035, *V* = .093) for both dual (58.1% vs 41.9%) and non-use (61.8% vs 38.2%).

**Latent Transition Analysis of Patterns of Use**

 Figure 1 shows the 24-month status of participants belonging to the three classes of users of nicotine-products at baseline; a complete 24-month follow-up disposition is in Figure S1. Figure 2 shows the proportion of usage status transitions among those reporting any use in the whole sample over the 24 months.

 The mean stability parameters suggest the non-use class as the most stable and the dual use class as the most dynamic across time (see Table 2). Of dual users, 31.6-48.5% remained in their class over time, with most transitioning to exclusive e-cigarettes use. One in four dual users moved toward exclusive combustible cigarette smoking between the first assessments and the same proportion (23.4%) moved toward non-use between the last two. Thus, most dual users at baseline reported being either non-users or exclusive e-cigarette users at 24-months.

 Between 52-79.6% exclusive cigarette smokers maintained their pattern of use. Nonetheless, 29.6-32.4% quit across time (see Table 2). At 24-months most exclusive combustible cigarette smokers at baseline reported being non-users, followed by those still smoking combustible cigarettes exclusively (see Figure 1).

 Although virtually all (92.4%) exclusive e-cigarette users remained in their class between 8- and 16-months, those moving between the first and last assessments transitioned mostly to non-use (see Figure 1). Only 5.6% of non-users changed their status, with most of them transiting to either exclusive e-cigarette use (2.4%) or exclusive combustible cigarette smoking (1.3%) (see Table 2).

**Group Differences in Alcohol Severity and Demographics**

Alcohol severity also differed significantly between classes at baseline (*χ*2(3) = 31.63, *p* < .001, *V* = .178), 8- (*χ*2(3) = 28.20, *p* < .001, *V* = .168), 16- (*χ*2(3) = 20.76, *p* < .001, *V* = .144) and 24-months (*χ*2(3) = 11.65, *p* = .009, *V* = .108). Individuals with moderate/high alcohol severity from baseline to 16-months were more likely to be exclusive combustible cigarette (63.7%, 66.4% and 70.1%) users compared to those with low alcohol severity (36.3%, 33.6% and 29.9%, respectively). At baseline, individuals with moderate/high alcohol severity were also more likely to be dual users (74.7% vs 25.3%). However, at 8- to 24-months they were more likely to be exclusive e-cigarette users (76.1%, 71.1% and 67.1%) compared to those with low alcohol severity (23.9%, 28.9% and 32.9%). However, except for baseline differences, all significant differences were small in magnitude.

There were also statistically significant differences in the proportion of males and females between classes at baseline (*χ*2(3) = 16.59, *p* = .001, *V* = .129), 8- (*χ*2(3) = 25.75, *p* < .001, *V* = .160), 16- (*χ*2(3) = 19.17, *p* < .001, *V* = .138) and 24-months (*χ*2(3) = 17.82, *p* < .001, *V* = .133), although with low effect sizes. Specifically, males were more likely to be exclusive e-cigarette users (58.9-70.1% vs 29.9-41.1%) and females more likely to be non-users (59-61.4% vs 38.6-41%) in all assessments. At baseline, males were also more likely than females to be dual users (52.6% vs 47.4%). Ethnicity also differed significantly at baseline (*χ*2(3) = 15.52, *p* = .001, *V* = .125), 8- (*χ*2(3) = 29.80, *p* < .001, *V* = .173), 16- (*χ*2(3) = 28.09, *p* < .001, *V* = .168) and 24-months (*χ*2(3) = 25.10, *p* < .001, *V* = .158), ranging from low to moderate effect sizes. Non-white participants were more likely to be non-users over time, despite being less prevalent (46.2-47.6% vs 52.4-53.8%). White participants were more likely to be combustible cigarette smokers (66.3–70.1% vs 29.9-33.3%), except at 24-months. Regarding exclusive e-cigarette use, white participants were more prevalent in assessments from 8- to 24-months (75.6–81.1% vs 18.9–24.4%). White participants were also more likely to be dual users at 16-months, compared to non-white (72.3% vs 27.7%).

**DISCUSSION**

Given the ongoing discussion on the effectiveness of e-cigarettes for quitting, their effect on discontinuation of use and their potential role as a gateway for combustible cigarette smoking, the current study examined patterns of combustible cigarette and e-cigarettes use over two years in young adult binge drinkers from US and Canada. The present study adds to prior evidence in several meaningful ways. Consistent with both our *a priori* hypothesis and epidemiological data 30, we found a four-class solution comprising non-users, exclusive e-cigarette users, exclusive combustible cigarettes smokers and dual users. These four patterns are present in both US and Canadian samples. As this study focused on current use defined as monthly or more frequent use, results offer a more fine-grained description of regular patterns of use than the only previous longitudinal study to use LTA in ever-tobacco users 31. Although most participants were classified as non-users, 56.5% of e-cigarette users at the baseline were classified as dual users. This prevalence aligns with the evidence indicating that dual users are overrepresented in the population of e-cigarette users in the US and Canada 16,24,36,37, although the prevalence appears to be higher among adults than young adults 30. In fact, while some studies found that among individuals aged 15-24, exclusive e-cigarette users were more prevalent than dual users 36,37 other found the opposite 24.

Present findings also support our hypothesis on transitions in the case of exclusive e-cig use. The prevalence of each class varied significantly over time, with the “dual users” class the most dynamic, as shown in adults 16. The only exception was the “exclusive e-cigarette users” class. This stability may be a response to the continued transition from exclusive e-cigarettes use to non-use, in parallel to changes from dual to exclusive e-cigarettes use. Of note, individuals using any nicotine products drop in 24 months from 38.34% to 19.94%. Indeed, the prevalence of the “exclusive e-cigarette users” class increased by 3% between 8- and 16-months, the period without transition between “exclusive e-cigarette users” and “non-users” classes. As shown in a previous study on trajectories of tobacco use among young adults 38, the present study highlights this period (i.e., baseline to 8-months, that is, between 22 and 23 years old) as critical for transiting from e-cigarettes use to non-use, as most exclusive e-cigarette users (63.9%) reported being only monthly users. This is of special interest considering the “stagnation” of transitions between 8- and 16-months, and the general stabilization reported previously 24. Furthermore, this high rate of transition contrasts with the stability of exclusive combustible cigarette smokers.

 The hypothesis of a deleterious role of dual use was not supported. In parallel with the transition of e-cigarette users to non-use, around 1/3 dual users transitioned to exclusive e-cigarettes use during the same period (i.e., baseline to 16-months). This change is important because the vast majority of e-cigarette users in the present study move from either dual use to exclusive e-cigarettes use or from exclusive e-cigarettes use to non-use. Despite the mixed evidence on the likelihood of discontinuing e-cigs among cigarette smokers 39,40, the present study shows greater transitions from dual to exclusive e-cigarettes use. In line with previous studies, this suggests that, for several young adults, dual use does not jeopardize desistance attempts 24,30. Data on adult dual users suggest that perceived relative harm of e-cigarettes compared to combustible cigarettes is associated with transitions to exclusive e-cigarette use and with reductions in smoking frequency, thus facilitating prospect transitions 41. Factors promoting change from dual to exclusive e-cigarettes use and non-use are to date unknown, and warrant investigation toward interventions to promote change in young adults.

 This study indicates that those who remain using e-cigarettes exclusively were more likely to be white, male and to present higher alcohol severity at baseline. Previous epidemiological data and systematic reviews have also reported these associations regarding sex and ethnicity 42,43, strongly supporting these individuals as risk populations in relation to regular e-cigarettes use. Results regarding alcohol severity aligns with evidence showing increased risk of endorsing DSM-5 AUD criteria in e-cigarette users, especially among less frequent users 44. Nonetheless, the association between e-cig use and hazardous drinking is far from clear, with studies suggesting that alcohol increases the rewarding effects of both combustible cigarettes and e-cigs and hence increasing their concurrent use 45, and others finding e-cigarette use to predict alcohol use but not vice versa 46. Whatever the association between alcohol and e-cigarette use is, the present study suggests a generalized reduction in dual use even for high-risk young adults, such as binge drinkers. Some studies have suggested the influence of specific transdiagnostic variables in the co-occurrence of binge drinking and smoking or e-cig use. Higher levels of lack of premeditation have been shown to play a major effect in developmental trajectories of impulsivity in relation to high-risk patterns of substance use, and particularly hazardous drinking 47. Mental health conditions are also related to ever e-cig use, which was also associated to alcohol use and binge drinking 48. Future studies are warranted to test potential covariates associated to specific patterns of change based on aforementioned factors. Also, further investigation is warranted on e-cig characteristics associations with persistence and the effect of environmental preventive interventions.

 This study has a number of limitations that should be considered when interpreting results. These samples were young adult binge drinkers and, therefore, the results might not be generalizable either to adult binge drinkers or to the general population. Secondly, latent statuses were explored based only on combustible and e-cigarettes, which may have prevented the identification of other potential statuses including other tobacco-related products. Nonetheless, the aim of this research focused on the relationship between cigarettes and e-cigarettes irrespective of the potential use of other tobacco products. In addition, we consider as “dual users” participants reporting at least past month use of both products, independently of their frequency of use. Thus, participants within this class can vary considerably, which may affect transitional pathways. Missing participants differed slightly from those retained. Lack of data on nicotine levels in e-cigarettes precluded furthering examining characteristics of e-cig users more precisely. Also, the final assessment window overlapped with the COVID-19 pandemic in a subset of participants, but any possible role of the pandemic could not be meaningfully undertaken. Finally, smoking status was self-reported and severity of addiction was examined via the FTCD, which is psychometrically suboptimal in lighter smokers 49.

 Acknowledging these considerations, the present study nonetheless provides novel and informative perspectives on patterns of cigarettes smoking and e-cigarettes use in high-risk young adults. Considering the active debate on whether dual use is a natural mid-state between combustible use and non-use or a risk pattern for persistent use, the present results support the former trajectory, as dual-users generally followed the pathway away from dual use to exclusive e-cigarettes use and from there to non-use. Nonetheless, this was not the case for all users and further characterization of patterns of combustible smoking and e-cigarettes use over time remain of high priority.

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**Declaration of competing interest**

JM is a principal in a private company, BEAM Diagnostics, Inc., but no commercial products fall within the scope of the study. No other authors have declarations.

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**REFERENCES**

1. Action on Smoking and Health. *Fact Sheet: Use of e-cigarettes (vapes) among adults in Great Britain.* 2020.

2. Cullen KA, Gentzke AS, Sawdey MD, et al. e-Cigarette Use Among Youth in the United States, 2019. *Jama.* 2019.

3. Pham T, Williams, J.V.A., Bhattarai, A., Dores, A.K., Isherwood, L.J., & Patten, S.B. Electronic cigarette use and mental health: A Canadian populaton-based study. *J Affect Disord.* 2020;260:646-652.

4. D'Angelo H, Patel M, Rose SW. Convenience Store Access and E-cigarette Advertising Exposure Is Associated With Future E-cigarette Initiation Among Tobacco-Naive Youth in the PATH Study (2013-2016). *J Adolesc Health.* 2021;68(4):794-800.

5. Hammond D, Reid JL, Burkhalter R, Rynard VL. E-cigarette Marketing Regulations and Youth Vaping: Cross-Sectional Surveys, 2017-2019. *Pediatrics.* 2020;146(1).

6. Vogel EA, Ramo DE, Rubinstein ML. Prevalence and correlates of adolescents' e-cigarette use frequency and dependence. *Drug Alcohol Depend.* 2018;188:109-112.

7. Simpson KA, Kechter A, Schiff SJ, et al. Characterizing symptoms of e-cigarette dependence: a qualitative study of young adults. *BMC Public Health.* 2021;21(1):959.

8. Owusu D, Huang J, Weaver SR, et al. Patterns and trends of dual use of e-cigarettes and cigarettes among U.S. adults, 2015-2018. *Prev Med Rep.* 2019;16:101009.

9. Glasser AM, Collins L, Pearson JL, et al. Overview of Electronic Nicotine Delivery Systems: A Systematic Review. *Am J Prev Med.* 2017;52(2):e33-e66.

10. Bafunno D, Catino A, Lamorgese V, et al. Impact of tobacco control interventions on smoking initiation, cessation, and prevalence: a systematic review. *J Thorac Dis.* 2020;12(7):3844-3856.

11. Hartmann-Boyce J, McRobbie H, Bullen C, Begh R, Stead LF, Hajek P. Electronic cigarettes for smoking cessation. *Cochrane Database Syst Rev.* 2016;9:CD010216.

12. Jankowski M, Krzystanek M, Zejda JE, et al. E-Cigarettes are More Addictive than Traditional Cigarettes-A Study in Highly Educated Young People. *Int J Environ Res Public Health.* 2019;16(13).

13. Martinez U, Martinez-Loredo V, Simmons VN, et al. How Does Smoking and Nicotine Dependence Change After Onset of Vaping? A Retrospective Analysis of Dual Users. *Nicotine Tob Res.* 2020;22(5):764-770.

14. Cassidy RN, Tidey JW, Colby SM. Exclusive e-cigarette users report lower levels of respiratory symptoms relative to dual e-cigarette and cigarette users. *Nicotine Tob Res.* 2020;22(S1):S54-S60.

15. Piper ME, Baker TB, Benowitz NL, Kobinsky KH, Jorenby DE. Dual Users Compared to Smokers: Demographics, Dependence, and Biomarkers. *Nicotine Tob Res.* 2019;21(9):1279-1284.

16. Piper ME, Baker TB, Benowitz NL, Jorenby DE. Changes in Use Patterns Over 1 Year Among Smokers and Dual Users of Combustible and Electronic Cigarettes. *Nicotine Tob Res.* 2020;22(5):672-680.

17. Khouja JN, Suddell SF, Peters SE, Taylor AE, Munafo MR. Is e-cigarette use in non-smoking young adults associated with later smoking? A systematic review and meta-analysis. *Tob Control.* 2020.

18. Flacco ME, Ferrante M, Fiore M, et al. Cohort study of electronic cigarette use: safety and effectiveness after 4 years of follow-up. *Eur Rev Med Pharmacol Sci.* 2019;23(1):402-412.

19. Hajek P, Phillips-Waller A, Przulj D, et al. A Randomized Trial of E-Cigarettes versus Nicotine-Replacement Therapy. *N Eng J Med.* 2019;380(7):629-637.

20. Vogel EA, Prochaska JJ, Ramo DE, Andres J, Rubinstein ML. Adolescents' E-Cigarette Use: Increases in Frequency, Dependence, and Nicotine Exposure Over 12 Months. *J Adolesc Health.* 2019;64(6):770-775.

21. Johnston LD, Miech, R. A., O’Malley, P. M., Bachman, J. G., Schulenberg, J. E., & Patrick, . *Monitoring the Future national survey results on drug use 1975-2020: Overview, key findings on adolescent drug use.* M. E. Ann Arbor:: Institute for Social Research, University of Michigan.;2021.

22. Schulenberg JE, Johnston, L. D., O’Malley, P. M., Bachman, J. G., Miech, R. A. & Patrick, M. E. *Monitoring the Future national survey results on drug use, 1975–2019: Volume II, College students and adults ages 19–60.* Ann Arbor: Institute for Social Research, The University of Michigan;2020.

23. Doran N, Brikmanis K, Petersen A, et al. Does e-cigarette use predict cigarette escalation? A longitudinal study of young adult non-daily smokers. *Prev Med.* 2017;100:279-284.

24. Hair EC, Romberg AR, Niaura R, et al. Longitudinal Tobacco Use Transitions Among Adolescents and Young Adults: 2014-2016. *Nicotine Tob Res.* 2019;21(4):458-468.

25. Substance Abuse and Mental Health Services Administration. *Key substance use and mental health indicators in the United States: Results from the 2018 National Survey on Drug Use and Health.* Rockville, MD: Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration;2019.

26. Gubner NR, Delucchi KL, Ramo DE. Associations between binge drinking frequency and tobacco use among young adults. *Addict Behav.* 2016;60:191-196.

27. Wang Q. High-intensity binge drinking is associated with cigarette smoking and e-cigarette use among US adults aged 40-64 years: Findings from the 2017 BRFSS survey. *Tob Induc Dis*. 2020;18:54.

28. Rothrock AN, Andris H, Swetland SB, et al. Association of E-cigarettes with adolescent alcohol use and binge drinking-drunkenness: A systematic review and meta-analysis. *Am J Drug Alcohol Abuse.* 2020;46(6):684-698.

29. Pelucchi C, Gallus S, Garavello W, Bosetti C, La Vecchia C. Cancer risk associated with alcohol and tobacco use: focus on upper aero-digestive tract and liver. *Alcohol Res Health.* 2006;29(3):193-198.

30. Coleman B, Rostron B, Johnson SE, et al. Transitions in electronic cigarette use among adults in the Population Assessment of Tobacco and Health (PATH) Study, Waves 1 and 2 (2013-2015). *Tob Control.* 2019;28(1):50-59.

31. Clendennen SL, Loukas A, Creamer MR, Pasch KE, Perry CL. Longitudinal Patterns of Multiple Tobacco and Nicotine Product Use Among Texas College Students: a Latent Transition Analysis. *Prev Sci.* 2019;20(7):1031-1042.

32. Heatherton TF, Kozlowski LT, Frecker RC, Fagerstrom KO. The Fagerstrom Test for Nicotine Dependence: a revision of the Fagerstrom Tolerance Questionnaire. *Br J Addict.* 1991;86(9):1119-1127.

33. Read JP, Kahler CW, Strong DR, Colder CR. Development and preliminary validation of the young adult alcohol consequences questionnaire. *J Stud Alcohol.* 2006;67(1):169-177.

34. Read JP, Haas AL, Radomski S, Wickham RE, Borish SE. Identification of hazardous drinking with the Young Adult Alcohol Consequences Questionnaire: Relative operating characteristics as a function of gender. *Psychol Assess.* 2016;28(10):1276-1289.

35. Lanza ST, Dziak, J. J., Huang, L., Wagner, A. T., & Collins, L. M. Proc LCA & Proc LTA users' guide (Version 1.3.2). In: The Methodology Center, Penn State: University Park; 2015: methodology.psu.edu.

36. Johnson AL, Collins LK, Villanti AC, Pearson JL, Niaura RS. Patterns of Nicotine and Tobacco Product Use in Youth and Young Adults in the United States, 2011-2015. *Nicotine Tob Res.* 2018;20 suppl 1:S48-S54.

37. Oakly A, Martin G. Dual use of electronic cigarettes and tobacco in New Zealand from a nationally representative sample. *Aust N Z J Public Health.* 2019;43(2):103-107.

38. Berg CJ, Haardorfer R, Lanier A, et al. Tobacco Use Trajectories in Young Adults: Analyses of Predictors Across Systems Levels. *Nicotine Tob Res.* 2020;22(11):2075-2084.

39. Benmarhnia T, Pierce JP, Leas E, et al. Can E-Cigarettes and Pharmaceutical Aids Increase Smoking Cessation and Reduce Cigarette Consumption? Findings From a Nationally Representative Cohort of American Smokers. *Am J Epidemiol.* 2018;187(11):2397-2404.

40. Zhu SH, Zhuang YL, Wong S, Cummins SE, Tedeschi GJ. E-cigarette use and associated changes in population smoking cessation: evidence from US current population surveys. *BMJ.* 2017;358:j3262.

41. Persoskie A, O'Brien EK, Poonai K. Perceived relative harm of using e-cigarettes predicts future product switching among US adult cigarette and e-cigarette dual users. *Addiction.* 2019;114(12):2197-2205.

42. Harlow AF, Stokes A, Brooks DR. Socioeconomic and Racial/Ethnic Differences in E-Cigarette Uptake Among Cigarette Smokers: Longitudinal Analysis of the Population Assessment of Tobacco and Health (PATH) Study. *Nicotine Tob Res.* 2019;21(10):1385-1393.

43. Hartwell G, Thomas S, Egan M, Gilmore A, Petticrew M. E-cigarettes and equity: a systematic review of differences in awareness and use between sociodemographic groups. *Tob Control.* 2017;26(e2):e85-e91.

44. Roberts W, Moore KE, Peltier MR, et al. Electronic Cigarette Use and Risk of Harmful Alcohol Consumption in the U.S. Population. *Alcohol Clin Exp Res.* 2018;42(12):2385-2393.

45. Thrul J, Gubner NR, Tice CL, Lisha NE, Ling PM. Young adults report increased pleasure from using e-cigarettes and smoking tobacco cigarettes when drinking alcohol. *Addict Behav.* 2019;93:135-140.

46. Dunbar MS, Davis JP, Rodriguez A, Tucker JS, Seelam R, D'Amico EJ. Disentangling Within- and Between-Person Effects of Shared Risk Factors on E-cigarette and Cigarette Use Trajectories From Late Adolescence to Young Adulthood. *Nicotine Tob Res.* 2019;21(10):1414-1422.

47. Martinez-Loredo V, Fernandez-Hermida JR, De La Torre-Luque A, Fernandez-Artamendi S. Trajectories of impulsivity by sex predict substance use and heavy drinking. *Addictive behaviors*. 2018;85:164-72.

48. Hefner KR, Sollazzo A, Mullaney S, Coker KL, Sofuoglu M. E-cigarettes, alcohol use, and mental health: Use and perceptions of e-cigarettes among college students, by alcohol use and mental health status. *Addictive behaviors.* 2019;91:12-20.

49. Etter JF, Duc TV, Perneger TV. Validity of the Fagerstrom test for nicotine dependence and of the Heaviness of Smoking Index among relatively light smokers. *Addiction.* 1999;94 2:269-281.

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| Table 1*Descriptive statistics* |
|  | Baseline(n = 1,002) | 8-months(n = 901) | 16-months(n = 895) | 24-months(n = 730) |
| Sexa (female) | 572 (57.1) | 520 (57.7) | 517 (59.2) | 433 (60.1) |
| Ethnicitya (White) | 572 (57.1) | 521 (57.9) | 508 (58.1) | 448 (62.2) |
| Ageb | 22.14 (1.26) | 22.79 (1.32) | 23.40 (1.48) | 24.02 (1.79) |
| Cigarette useaNoneMonthly or more | 712 (71.2)288 (28.8) | 749 (83.1)152 (16.9) | 761 (87.0)114 (13) | 640 (88.9)80 (11.2) |
| FTCDb | 2.93 (1.70)† | 2.56 (1.62)† | 2.84 (1.47)† | 2.85 (1.46)† |
| E-cigarette useaNoneMonthly or more | 833 (83.3)167 (16.7) | 759 (86.2)122 (13.8) | 740 (85.6)124 (14.4) | 524 (89.3)63 (10.7) |
| *Notes.*a n (%) b *M* (*SD*)FTCD: Fagerström Test of Cigarette Dependence† combustible smokers, *n* = 287 (Baseline), 167 (8-months), 114 (16-months) and 80 (24-months)  |

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| Table 2*Item-response probabilities and class membership probabilities across time and tau estimates (transition probabilities)* |
|  | Class 1(exclusive e-cig users) | Class 2(dual users) | Class 3(non users) | Class 4(exclusive cigarette users) |
| Cigarette useNoYes | **.976**.024 | .000**1.000** | **.981**.019 | .163**.837** |
| E-cigarettes useNoYes | .219**.781** | .055**.945** | **.978**.022 | **.999**.001 |
|  |  |  |  |  |
| Baseline | 7.75 % | 9.89 % | 61.66 % | 20.70 % |
| 8-Months | 8.13 % | 6.39 % | 72.28 % | 13.20 % |
| 16-Months | 10.10 % | 5.34 % | 76.44 % | 8.12 % |
| 24-Months | 8.93 % | 2.61 % | 80.06 % | 8.40 % |
| Time 1 / Time 3 |  |  |  |  |
| Class 1 | **.456** | .000 | .544 | .000 |
| Class 2 | .283 | **.316** | .155 | .246 |
| Class 3 | .024 | .006 | **.970** | .000 |
| Class 4 | .015 | .141 | .324 | **.520** |
| Time 3 / Time 5 |  |  |  |  |
| Class 1 | **.924** | .037 | .040 | .000 |
| Class 2 | .307 | **.485** | .078 | .130 |
| Class 3 | .000 | .005 | **.992** | .003 |
| Class 4 | .048 | .119 | .296 | **.538** |
| Time 5 / Time 7 |  |  |  |  |
| Class 1 | **.625** | .033 | .342 | .000 |
| Class 2 | .244 | **.343** | .234 | .179 |
| Class 3 | .004 | .001 | **.982** | .013 |
| Class 4 | .124 | .047 | .033 | **.796** |
| *Note.*Cells in **bold** within the lower part of the table denotes stability parameters of class membership across time.  |