Published in final edited form as:

J Adolesc Health. 2020 January ; 66(1): 39–47. doi:10.1016/j.jadohealth.2019.08.030.

Electronic and Combustible Cigarette Use in Adolescence: Links with Adjustment, Delinquency, and Other Substance Use

Jeremy Staff, PhD^a, Jennifer Maggs, PhD^b, Christopher Seto^a, Julia Dillavou^a, Mike Vuolo, PhD^c

^aDepartment of Sociology and Criminology, Pennsylvania State University, 211 Oswald Tower, Pennsylvania State University, University Park PA

^bDepartment of Human Development and Family Studies, Pennsylvania State University

^cDepartment of Sociology, Ohio State University

Abstract

Objective: Identify proximal links between e-cigarette use and numerous indicators of adjustment, delinquency, and other substance use in adolescence, beyond prior levels and confounders.

Method: The ongoing Millennium Cohort Study is a nationally representative, intergenerational, longitudinal study of children born 2000–2001 in the United Kingdom followed from birth to age 14 (n=11,564 adolescents and their parents). A series of OLS and logistic regressions compared 14-year old e-cigarette only users to never users and to combustible/dual users on 10 measures of adjustment (school engagement, wellbeing, self-esteem), delinquency (theft, vandalism, disorderly conduct, graffitiing), and other substance use (frequent alcohol use, heavy drinking, marijuana use). Controls included each outcome variable measured at age 11 and prospectively assessed parent- and child-confounders (e.g., parent education; child externalizing and internalizing behaviors, cognitive test scores, gender, race/ethnicity).

Results: At age 14, e-cigarette only users (approximately 7% of youth) had a higher risk of adolescent adjustment problems, delinquent behavior, and substance use relative to non-users (75% of youth), but lower risk relative to combustible cigarette/dual users (18% of youth), even after controlling for a host of childhood confounders.

Conclusions: Positive links shown here between e-cigarette use and poor adjustment, delinquency, and other substance use in adolescence, coupled with accumulating evidence that e-cigarettes substantially increase youths' likelihood of combustible smoking, indicate that e-cigarettes are part of an emerging pattern of health-risk behaviors and poor adjustment for some youth.

Keywords

E-cigarettes; Combustible cigarettes; Adolescence; Adjustment; Delinquency; Alcohol; Marijuana; Millennium Cohort Study; Longitudinal studies; Intergenerational studies

INTRODUCTION

Since electronic cigarettes (“e-cigarettes”) were introduced in the mid-2000s, adolescents today are the first generation to be exposed early in life to this new nicotine delivery product. Whereas the number of youth who have ever smoked and currently smoke combustible cigarettes has declined greatly in the United States (US), United Kingdom (UK), and vast majority of European countries[1–3], the percentage of youth using e-cigarettes has risen dramatically recently[4–7].

Evidence is accumulating that e-cigarette use substantially increases youth’s likelihood of combustible smoking. For instance, an authoritative 2018 National Academies of Sciences (NAS) review[8] concluded from longitudinal studies based on teens in the US[9–12], UK[13, 14], and Canada[15] that e-cigarette use in adolescence more than triples the risk of ever smoking combustible cigarettes. Evidence that e-cigarettes can serve as a catalyst toward combustible tobacco use and dual e- and combustible cigarette use is growing [16–18].

Relative to research on e-cigarettes’ *epidemiology*, scientific knowledge is scant about *risks* posed by e-cigarettes to adolescent health and wellbeing[8]. Physically, the U.S. Surgeon General’s report on e-cigarette use among youth concluded that nicotine exposure through e-cigarettes can cause addiction and harm the developing brain[4]. Moreover, Rubinstein and colleagues[19] detected significantly higher levels of at least five carcinogenic toxicants among adolescents who had recently used e-cigarettes versus never-using youth. Behaviorally, four cross-sectional studies of teenagers showed that e-cigarette users consistently fell between non-users and combustible/dual users in terms of their relative risk of delinquency, alcohol use and heavy drinking, marijuana and other drug use, poor school performance, and truancy[20–23]. These psychosocial correlates are similar to numerous problem behaviors linked to combustible cigarette use during childhood or early adolescence[1]. However, the lack of longitudinal studies on e-cigarette use and its behavioral correlates, without consideration of shared risk factors and prior levels of these correlates, leaves open many important questions.

In fact, relatively little is known about e-cigarettes’ *etiology* (e.g., generality of previously known risk factors for combustible cigarettes[8]). No prior nationally-representative longitudinal studies have controlled for childhood risk factors when assessing links between e-cigarette use and adolescent adjustment and behavioral problems. Critics of research portraying e-cigarette use as an important new health risk for youth have argued that selection, or third variable causes such as early life risk factors, may instead be the true underlying cause of any observed ‘effects’ of e-cigarette use[24, 25, 27]. They suggest that e-cigarette users would likely have been smokers anyway. To address this very important question, data on earlier family contexts as well as parent and child behaviors are needed to disentangle potential harms of prior e-cigarette use from selection influences[8, 25–27]. Childhood factors that may distinguish e- and combustible cigarette use from non-use in adolescence include parent low socioeconomic status and smoking, as well as children’s cognitive ability, school disengagement, and problem behaviors[28–30]. Understanding the role of childhood risk factors for e- and combustible use is especially important because

combustible tobacco use among today's young people is now more strongly linked to early life disadvantages than a generation ago[1, 31, 32].

Based on a developmental epidemiological approach, we use longitudinal data from the ongoing Millennium Cohort Study (MCS), a nationally representative birth cohort study of children born in the UK in 2001, to test for acute links of e-cigarette use with school disengagement, poor mental health, delinquency, and alcohol and marijuana use. Unlike prior large-sample work with adolescent-only data collection[8], the MCS includes parent and child data from infancy through age 14 (N=11,564 children and their parents), allowing us to control in our regression models for many theoretically driven shared childhood factors predictive of e-and combustible cigarette use and for adolescent adjustment and health.

METHOD

Sample

The data source is the ongoing, nationally representative, longitudinal Millennium Cohort Study (MCS), which collects multi-method, multi-informant data from UK children and their parents; schools; health professionals; and investigator-assessed cognitive ability tests. The MCS targeted 9-month-olds in a random sample of electoral wards[33] born September 2000 through January 2002, oversampling areas with high child poverty, and (in England) areas with high numbers of Asian and Black families based on census data. In total, 18,552 nine-month-olds participated (91% of target; 52% female, 18% racial/ethnic minority[34]). At age 3, 1,389 new families who met sampling criteria were added. With parental consent and child assent, interviewers conducted follow-ups and cognitive tests during in-home visits to cohort members and parents at ages 3, 5, 7, 11, and 14 (in 2004, 2006, 2008, 2012, and 2015, respectively). Ethics committees approved each wave of data collection.

At ages 11 and 14 years, 13,287 and 11,726 productive interviews with children and parents/guardians were completed, respectively, representing 81% and 76% of eligible children who had not died, emigrated, or permanently withdrawn[35]. By age 14, sample attrition was more likely among boys, Whites, and youth from more economically disadvantaged family backgrounds[35]. All analyses are weighted to adjust for this nonrandom sample attrition, as well as MCS families having unequal probabilities of sample inclusion in infancy (due to stratified design and non-response).

We used data from 11,564 youth who completed the survey at age 14 and had a valid statistical weight, along with data from their parents. The percentage of item missing data on these cases averaged about 5%, ranging from 0% (for gender and race/ethnicity) to 12% (for childhood internalizing and externalizing behaviors). In Stata 15, we used the “mi” command to impute 20 datasets using chained regressions, and the “mi estimate” command to combine results across datasets and adjust test statistics.

Measures

Our analyses include 10 self-reported measures of adjustment, delinquency, and substance use that were assessed at ages 11 and 14, as well as parent reports of child externalizing and internalizing behaviors at age 11; parent educational attainment and smoking; investigator-

assessed measures of child test scores; and child's gender and race/ethnicity. Descriptions of these measures, their coding, and scale reliability, are presented in Table 1, along with weighted descriptive statistics for the overall sample and by age 14 cigarette use.

Age 14 Outcome Measures: Adjustment, Delinquency, and Substance Use—

Ten summary indicators of adjustment, delinquency, and substance use were assessed at age 14. *School engagement* is based on the average of five items such as how often the respondent finds school interesting, and tries their best at school. *Wellbeing* is based on the average score of six items, for example, how happy they felt about the way they look, their family, friends, school, and so on. *Self-esteem* is the average of five items such as the extent to which they are satisfied with themselves, and are a person of value. Four types of past year delinquent behavior were assessed: *Theft*, *Vandalism*, *Disorderly conduct*, and *Graffitiing*. Finally, youth were asked about their alcohol and marijuana use, with outcomes assessed for *Frequent alcohol use*, *Heavy drinking*, and *Marijuana use*.

Focal Predictor Variable: E-cigarette and Combustible Cigarette Use—At ages 11 and 14, MCS children reported whether they had ever smoked a cigarette[31]. At age 14, youth also indicated whether they: 1) had never used or tried electronic cigarettes (e-cigarettes); 2) have used e-cigarettes but do not at all now; 3) now smoke e-cigarettes occasionally but not every day; or 4) smoke e-cigarettes every day. Youth who reported using an e-cigarette by age 14, but not smoking combustible cigarettes at age 11 or age 14, were coded as “e-cigarettes only”. Children who reported “no” to smoking at both ages and “no” to e-cigarette use were coded as “never users”. Children who reported smoking a combustible cigarette at age 11 or age 14 were coded as “combustible or dual use”. Note that this latter category includes respondents who smoked *only* combustible cigarettes as well as respondents who smoked *both* combustible and e-cigarettes. Combining the combustible only and dual users provides a conservative test of whether e-cigarette use is indeed risky, as past studies show dual use to be most strongly associated with risk indicators, whereas the evidence is mixed distinguishing e-cigarette use and combustible use [20–23, 36].

Predictor Variables: Sociodemographic Background and Age 11 Confounders

—Sociodemographics include the child's *gender*, *race/ethnicity*, and age at the time of the most recent survey. We also included *parent(s') highest educational level* and whether parents had smoked since pregnancy. These measures are based on parent reports in all waves (i.e., when the child was an infant and at ages 3, 5, 7, 11, and 14 years).

At age 11, parents described child behavior in the prior six months using the Strengths and Difficulties (SDQ) Questionnaire[37]. Ten items capturing conduct problems and hyperactivity/inattention were used to create a scale of *externalizing behaviors*, and 10 items assessing emotional symptoms and peer problems were used for the scale of *internalizing behaviors*. Higher scores correspond to a higher number of problem behaviors and symptoms. Given their high skewness, scores were log-transformed (after adding a value of 1 to each score). *Test scores* at age 11 were assessed using a developmentally-appropriate investigator-assessed cognitive test of verbal ability[38]. These scores adjust for both item difficulty and age at time of assessment, and were standardized (mean=0, sd=1).

The outcome measures described above were also assessed at age 11, with the exception of marijuana use, and are used as predictors in models for the same age 14 outcome. Including prior levels of each outcome allows us to assess whether e-cigarette only users and combustible only or dual users evidenced different levels of the 10 outcome variables at age 14, independent of the level predictable by the assessed childhood risk factors and their expected levels of the outcome as predicted by age 11.

Analytic Strategy

We first discuss the weighted descriptive statistics for the overall sample. To highlight variation in the childhood precursors of e- and combustible cigarette use in adolescence, we also show mean differences in the age 11 confounders by age 14 cigarette use. We then used a series of OLS and logistic regression models to assess how e-cigarette use relates to 10 concurrent measures of adjustment, delinquency, and other substance use, controlling for age 11 confounders.

RESULTS

As shown in Table 1, by age 14, 74.3% of teenagers had never used an e-cigarette or smoked a combustible cigarette, 7.3% had used only e-cigarettes, and 18.3% had smoked combustible cigarettes or were dual users. Approximately 52.5% of the analysis sample were boys, 80.9% were White British, 7.1% were Asian British, 4.1% were Black British, and 7.9% were Other British, and 76.8% were ages 14 and older. On average, parent(s') highest educational level was some postsecondary education (mean=2.8) and 58.1% of youth had a least one parent who had smoked at some time since pregnancy.

Though our primary focus is on proximal links, we first assessed how prior levels of adjustment, delinquency, and other substance use are linked to age 14 cigarette use. The bottom right section of Table 1 provides descriptive statistics for the age 11 confounders separately for youth who had never smoked, used e-cigarettes only, or engaged in combustible/dual use by age 14. The table presents a consistent pattern, wherein the children who never used either product by age 14 had the lowest mean values on age 11 externalizing and internalizing behaviors, delinquency measures, and substance use, and on average scored the highest on school engagement, happiness, and self-esteem. Conversely, combustible/dual users at age 14 had reported the least positive adjustment and the most delinquency and substance use at age 11. Children who have used only e-cigarettes by age 14 typically had a mean score between the non-smokers and the combustible/dual users. Exceptions to this pattern occurred for internalizing behavior and self-esteem: on these variables the e-cigarette users have similar means to the non-users. Overall, e-cigarette users are not similar in childhood adjustment or behavior to combustible/dual users, which further motivates the need to adjust for these existing differences in our regression models.

Adjustment at Age 14

Table 2 displays estimates from OLS regressions of school engagement, wellbeing, and self-esteem on e- and combustible cigarette use, with adjustments for age 11 levels of the outcome variable and childhood confounders. Never users served as the reference group. In

the text, we concentrate on this focal predictor, referring the reader to the table for the effects of the age 11 predictors. Teens who had used only e-cigarettes, relative to those who had never used, had significantly lower levels of school engagement by 0.115 units ($p < .001$), wellbeing by 0.371 units ($p < .001$), and self-esteem by 0.112 units ($p < .001$), even after controlling for corresponding measures of these behaviors at age 11, parent-reported externalizing and internalizing behaviors, cognitive scores, and sociodemographic characteristics. Teens who smoked combustibles or were dual users had significantly lower levels of school engagement ($b = -0.169$ units; $p < .001$), wellbeing ($b = -0.539$; $p < .001$), and self-esteem ($b = -0.181$; $p < .001$) relative to youth who never used. Importantly, the differences in the outcomes between the combustible/dual users and the e-cigarette users were about half the magnitude of the differences between the e-cigarette only users and the never smokers.

Delinquency at Age 14

Table 3 shows odds ratios and 95% confidence intervals from a series of logistic regressions predicting age 14 theft, vandalism, disorderly conduct, and graffitiing, contrasting e- and combustible/dual cigarette users with never users. For all four outcomes, the odds of delinquency were higher for combustible/dual users relative to never users, ranging from odds 5.7 times as great ($p < .001$) for acting disorderly in public to 11.9 times as great ($p < .001$) for vandalism. The odds of delinquency were significantly higher for e-cigarette only users compared to never users. These differences ranged from odds 3.9 times as great ($p < .001$) for acting disorderly in public to 6 times as great ($p < .001$) for vandalism.

Other Substance Use at Age 14

Finally, Table 4 displays odds ratios and 95% confidence intervals from three logistic regressions predicting frequent alcohol use, heavy drinking, and marijuana use. Relative to never users, combustible/dual users had odds 7.4 times as great for frequently drinking alcohol, 16.2 times as great for drinking heavily, and over 100 times as great for using marijuana. The odds of substance use were also higher for e-cigarette only users compared to never users, ranging from odds 4.3 times as great for frequently drinking alcohol to 9.6 times as great for marijuana use.

The consistent pattern in which e-cigarette users fell between never users and combustible/dual users across the 10 outcome variables is illustrated in Figure 1. The top panel shows expected values for adjustment (based on Table 2 estimates), and the middle and bottom panels show predicted probabilities for delinquency and substance use (based on estimates from Tables 3 and 4, respectively). While combustible/dual users clearly evidenced the least positive adjustment and highest levels of delinquency and substance use, even users of e-cigarettes only were still significantly different on these age 14 outcomes than never users.

Alternative Specifications

We performed several alternative model specifications to assess the robustness of our findings (available upon request). In separate models that: 1) used current use instead of ever use; 2) included age 14 confounders instead of age 11 confounders; and 3) included age 11 measures of all the outcomes assessed, we found consistent results to those presented. In

supplemental analyses we also classified combustible and dual users separately, which confirmed the significant differences between all use categories and never users.

DISCUSSION

Recent authoritative reviews have called for nationally representative samples with prospective prediction of the precursors, correlates, and consequences of e-cigarette use from childhood to adolescence[8]. Such high-quality longitudinal data on links between e-cigarette use and adolescent health and wellbeing is essential fundamental knowledge on which to justify, build, and strategically target tobacco control and prevention efforts. Using the MCS's prospective design, we identified acute correlates of e-cigarette use with adolescent adjustment, delinquency, and substance use, addressing an important gap in the existing literature. Consistent with some earlier, cross-sectional investigations[20–23], we found that youth who use only e-cigarettes have a higher likelihood of delinquency, alcohol, and marijuana use at age 14 than non-users, but a lower likelihood than dual users and to some extent to youth who only smoke combustible cigarettes. This gradient is reversed for age 14 adjustment, as school interest, wellbeing, and self-esteem are highest for non-using youth, followed by e-cigarette users and dual/combustible users.

Are e-cigarette users simply high-risk adolescents who would have smoked combustible cigarettes anyway? Our findings do not support the argument that e-cigarette users, either prior to use or afterwards, are identical in adjustment or behavior to combustible/dual users. First, we found that youth who had used only e-cigarettes by age 14 typically fell between the non-smokers and the combustible/dual users in their mean values on age 11 adjustment and behavioral problems, similar to limited prior research [27]. Second, observed links showing less healthy psychosocial and behavioral adjustment at age 14 for e-cigarette users relative to non-users did not disappear despite numerous tests, including a rigorous set of controls comprised of child- and parent-risk factors prospectively assessed across childhood and age 11 levels of each risk indicator individually. These results consistently showed e-cigarette users to have less positive adjustment, more delinquent behaviors, and more alcohol and other substance use than never users.

An important question is whether e-cigarettes are attractive to teens who otherwise might not use tobacco products[20, 36]. As argued by common liability models, complex biobehavioral antecedents for substance use and addiction are expressed within norms of reaction bounded, in part, by social norms, legality, and availability of specific substances [e.g., 25]. As a novel product, e-cigarettes benefit from persuasive social marketing, are widely accessible to youth, and are viewed as innovative, clean, and safe [4,27]. E-cigarettes expose users to nicotine and numerous carcinogens [4,8,19], predict increased likelihood of combustible use[8–18], and are linked with poorer adjustment and greater delinquency and other substance use contemporaneously[20–23]. Evidence is accumulating that e-cigarette use in adolescence both reflects a general higher liability for substance use[25] and may increase risk for immediate and sustained risks to lifelong health and wellbeing[8]. Given the somewhat-elevated risk profile of early adolescent e-cigarette users, it seems quite plausible that some adolescents will try this new product and that some will become

addicted to nicotine who may not otherwise have done so. However, direct answers to the question about increased risk for nicotine dependence awaits further research.

The following limitations are present: First, although we control for prospectively assessed (age 11) measures of our outcome variables at age 14, as well as numerous childhood antecedent variables, the directionality of the associations is not certain, and there are other unobserved genetic, developmental, or social factors that may confound the observed relationships shown here [25, 27]. Second, we rely solely on self-reports of e-cigarette and combustible cigarette use. Self-report is generally accepted as reliable and valid for smoking data[39] and concerns regarding social desirability bias are reduced by the fact that the child surveys are confidential and self-completed privately away from parents and interviewers. Third, the measures of e-cigarette and cigarette use do not assess nicotine strength or capture the high variability in e-cigarette flavoring[40]. Fourth, although a strength of this sample for addressing these questions is the assessment of e-cigarette use at an early age (14 years) and early historic period in terms of this new product (i.e., 2015), in our primary analyses we primarily focused on *ever* use of e- and combustible cigarettes due to low overall prevalence, similar to most research to date [4]. Supplemental analyses (not shown but available upon request) comparing non-users, current e-cigarette users and current combustible/dual users, however, found the same pattern of associations despite lower prevalence. Finally, attrition is present, as in all longitudinal studies, but analyses utilized weights and adjusted for missing data and attrition.

In conclusion, scientific evidence to support prevention, regulation, and control of e-cigarettes rests on critical tests of whether existing factors account for observed links between e-and combustible cigarette use and adolescent health and wellbeing[9]. This study shows that e-cigarette use in adolescence is associated with numerous indicators of poor adjustment, delinquency, and substance use, even when antecedent variables are controlled. The intermediate position of e-cigarette only users between non-users and combustible/dual users in terms of psychosocial correlates supports concerns that e-cigarettes are part of an emerging pattern of health-risk behaviors and poor adjustment for some youth. Control efforts to limit access to new, highly appealing products, combined with universal prevention (e.g., school-based) and screening (e.g., medical providers), are needed. Overall, the results provide evidence consistent with the urgent call for increased e-cigarette regulation to protect the health and wellbeing of current and future generations of youth.

Acknowledgements.

This research is based on analysis of data from the UK Millennium Cohort Study (MCS), which receives core funding from the Economic and Social Research Council UK (ESRC) and a consortium of UK government departments. Measures of alcohol use at age 11 in the MCS were supported by grant AA019606 from the National Institute on Alcohol Abuse and Alcoholism. The study sponsors played no role in the study design; collection, analysis and interpretation of data; the writing of the report; or the decision to submit the manuscript for publication.

REFERENCES

- [1]. U.S. Department of Health and Human Services. Preventing Tobacco Use Among Youth and Young Adults: A Report of the Surgeon General. Atlanta, GA: U.S. Dept of Health and Human

Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2012.

- [2]. Kraus L, Guttormsson U, Leifman H, et al. ESPAD Report 2015 Results From the European School Survey Project on Alcohol and Other Drugs. Lisbon: EMCDDA/ESPAD; 2015.
- [3]. Scholes S, Mindell J, Neave A. Health Survey for England 2015: Children's Smoking and Exposure to Other People's Smoke. London: Health and Social Information Centre; 2016.
- [4]. U.S. Department of Health and Human Services. E-cigarette Use Among Youth and Young Adults. A Report of the Surgeon General. Atlanta, GA: U.S. Dept of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2016.
- [5]. Miech R, Johnston L, O'Malley PM, et al. Adolescent vaping and nicotine use in 2017– 2018 — U.S. national estimates. *N Engl J Med*. 2019;380(2):192. [PubMed: 30554549]
- [6]. Cullen KA, Ambrose BK, Gentzke AS, et al. Notes from the field: Use of electronic cigarettes and any tobacco product among middle and high school students—United States, 2011–2018. *MMWR Morb Mortal Wkly Rep*. 2018;67:1276–7. [PubMed: 30439875]
- [7]. National Health Statistics Digital. Smoking, drinking and drug use among young people in England – 2016. Available at: <https://www.gov.uk/government/statistics/smoking-drinking-and-drug-use-among-young-people-in-england-2016>. Accessed April 24, 2018.
- [8]. National Academies of Sciences, Engineering and Medicine. Public Health Consequences of E-cigarettes. Washington, DC: National Academies Press; 2018.
- [9]. Barrington-Trimis JL, Urman R, Berhane K, et al. E-cigarettes and future cigarette use. *Pediatrics*. 2016;138:e20160379. [PubMed: 27296866]
- [10]. Leventhal AM, Strong DR, Kirkpatrick MG, et al. Association of electronic cigarette use with initiation of combustible tobacco product smoking in early adolescence. *JAMA*. 2015;314:700–7. [PubMed: 26284721]
- [11]. Miech R, Patrick ME, O'Malley PM, Johnston LD. E-cigarette use as a predictor of cigarette smoking: Results from a 1-year follow-up of a national sample of 12th grade students. *Tob Control*. 2017;26:e106–11. [PubMed: 28167683]
- [12]. Wills TA, Knight R, Sargent JD, et al. Longitudinal study of e-cigarette use and onset of cigarette smoking among high school students in Hawaii. *Tob Control*. 2017;26:34–9. [PubMed: 26811353]
- [13]. Best C, Haseen F, Currie D, et al. Relationship between trying an electronic cigarette and subsequent cigarette experimentation in Scottish adolescents: A cohort study. *Tob Control*. 2018;27:373–8.
- [14]. Conner M, Grogan S, Simms-Ellis R, et al. Do electronic cigarettes increase cigarette smoking in UK adolescents? Evidence from a 12-month prospective study. *Tob Control*. 2018;27:365–72.
- [15]. Hammond D, Reid JL, Cole AG, Leatherdale ST. Electronic cigarette use and smoking initiation among youth: A longitudinal cohort study. *CMAJ*. 2017;189:e1328–36. [PubMed: 29084759]
- [16]. Bold KW, Kong G, Camenga DR, et al. Trajectories of e-cigarette and conventional cigarette use among youth. *Pediatrics*. 2017;141:e20171832. [PubMed: 29203523]
- [17]. Soneji S, Barrington-Trimis JL, Wills TA, et al. Association between initial use of e-cigarettes and subsequent cigarette smoking among adolescents and young adults: a systematic review and meta-analysis. *JAMA Pediatr*. 2017;171:788–97. [PubMed: 28654986]
- [18]. Watkins SL, Glantz SA, Chaffee BW. Association of noncigarette tobacco product use with future cigarette smoking among youth in the population assessment of tobacco and health (PATH) study, 2013–2015. *JAMA Pediatr*. 2018;172:181–7. [PubMed: 29297010]
- [19]. Rubinstein ML, Delucchi K, Benowitz NL, Ramo DE. Adolescent exposure to toxic volatile organic chemicals from e-cigarettes. *Pediatrics*. 2018;141(4):e20173557. [PubMed: 29507165]
- [20]. Wills TA, Knight R, Williams RJ, et al. Risk factors for exclusive e-cigarette use and dual e-cigarette use and tobacco use in adolescents. *Pediatrics*. 2015;135:e43–51 [PubMed: 25511118]
- [21]. Demissie Z, Everett Jones S, Clayton HB, King BA. Adolescent risk behaviors and use of electronic vapor products and cigarettes. *Pediatrics*. 2017;139:e20162921. [PubMed: 28115539]
- [22]. Azagba S E-cigarette use, dual use of e-cigarettes and tobacco cigarettes, and frequency of cannabis use among high school students. *Addict Behav*. 2018;79:166–70. [PubMed: 29291507]

- [23]. McCabe SE, West BT, Veliz P, Boyd CJ. E-cigarette use, cigarette smoking, dual use, and problem behaviors among U.S. adolescents: Results from a national survey. *J Adolesc Health*. 2017;61:155–62. [PubMed: 28391965]
- [24]. Glasser A, Abudayyeh H, Cantrell J, Niaura R. Patterns of e-cigarette use among youth and young adults: Review of the impact of e-cigarettes on cigarette smoking. *Nicotine Tob Res*. nty103, 10.1093/ntr/nty103
- [25]. Vanyukov MM, Tarter RE, Kirillova GP, et al. Common liability to addiction and “gateway hypothesis”: Theoretical, empirical and evolutionary perspective. *Drug Alcohol Depend*. 2012;123:S3–17. [PubMed: 22261179]
- [26]. Royal College of Physicians. *Nicotine Without Smoke. Tobacco Harm Reduction*. London: RCP; 2016.
- [27]. Wills TA. E-cigarettes and adolescents’ risk status. *Pediatrics*. 2017;139:e20163736. [PubMed: 28115538]
- [28]. Chassin L, Hussong A, Beltran I. Adolescent substance use. In: Lerner RM, Steinberg L, eds.. *Handbook of Adolescent Psychology: Vol 1. Individual Bases of Adolescent Development*, Third Edition, New York: Wiley; 2009:723–63.
- [29]. Wills TA, Yaeger AM. Family factors and adolescent substance use: Models and mechanisms. *Curr Dir Psychol Sci*. 2011;12:222–6.
- [30]. Vuolo M, Staff J. Parent and child cigarette use: A longitudinal, multigenerational study. *Pediatrics*. 2013;132:e568–77. [PubMed: 23918887]
- [31]. Staff J, Maggs JL, Ploubidis GB, Bonell C. Risk factors associated with early smoking onset in two large birth cohorts. *Addict Behav*. 2018;87:283–9. [PubMed: 29935736]
- [32]. Wellman RJ, Dugas EN, Dutczak H, et al. Predictors of the onset of cigarette smoking: A systematic review of longitudinal population-based studies in youth. *Am J Prev Med*. 2016;51:767–78. [PubMed: 27180028]
- [33]. Dex S, Joshi H, eds. *Children of the 21st Century: From Birth to Nine Months*. Bristol, UK: The Policy Press; 2005.
- [34]. Plewis I *The Millennium Cohort Study: Technical Report on Sampling* (4th ed.). London: Centre for Longitudinal Studies, Institute of Education; 2007.
- [35]. Mostafa T, Ploubidis G. *Millennium Cohort Study, Sixth Survey 2015–2016: Technical Report on Response*. London: Centre for Longitudinal Studies: Institute for Education; 2017.
- [36]. Dutra LM, Glantz SA. E-cigarettes and national adolescent cigarette use: 2004–2014. *Pediatrics*. 2017;139(2):e20162450. [PubMed: 28115540]
- [37]. Goodman R Psychometric properties of the Strengths and Difficulties Questionnaire (SDQ). *J Am Acad Child Adolesc Psychiatry*. 2001;40:1337–45. [PubMed: 11699809]
- [38]. Connelly R *Millennium Cohort Study Data Note 2013/1: Interpreting Test Scores*. London: Centre for Longitudinal Studies: Institute for Education; 2013.
- [39]. Henriksen L, Jackson C. Reliability of children’s self-reported cigarette smoking. *Addict Behav*. 1999;24:271–7. [PubMed: 10336108]
- [40]. Krüsemann EJZ, Boesveldt S, de Graaf K, Talhout R. An e-liquid flavor wheel: A shared vocabulary based on systematically reviewing e-liquid flavor classifications in literature. *Nicotine Tob Res*. 2018: nty101, 10.1093/ntr/nty101.

Implications and Contribution:

E-cigarette users who do not smoke combustible cigarettes have less positive adolescent adjustment, and greater delinquency and other substance use, relative to teens who have never used combustible or e-cigarettes. Thus, even e-cigarette use alone during adolescence is linked with less positive health and wellbeing.

Figure 1. Predicted Values and Probabilities of Age 14 Adjustment, Delinquency, and Substance Use Contrasting Never Users with E-Cigarette Users and Dual or Combustible Only Users Among Youth in the UK Millennium Cohort Study (N=11,564)

Note. ¹ School Engagement coded 1 “Never”, 2 “Some of the time”, 3 “Most of the time”, 4 “All the time”; ² Wellbeing ranges on a seven-point scale from 1 “Not at all happy” to 7 “Completely happy”; ³ Self esteem is coded 1 “Strongly disagree”, 2 “Disagree”, 3 “Agree”, 4 “Strongly agree”.

Description		Mean or %		
Age 14 Outcomes^a	Overall			
School Engagement	How often tries best at school, finds school interesting, etc (average, 5 items [$\alpha=.70$], 1=never to 4=all of the time)	2.6		
Wellbeing	How happy with family, friends, life overall, etc (average, 6 items [$\alpha=.86$], 1=not at all to 7=completely)	5.4		
Self-Esteem	Feel they are person of value, has good qualities, etc (average, 5 items [$\alpha=.90$], 1=strongly disagree to 4=strongly agree)	3.1		
Theft	Took item from shop without paying in last year (1=yes; 0=no)	3.8%		
Vandalism	Purposely damaged something in public place not belonging to them in last year (1=yes; 0=no)	3.8%		
Disorderly conduct	Noisy or rude in a public place so that people complained or got youth into trouble in last year (1=yes; 0=no)	14.0%		
Graffitiing	Wrote things or spray painted on a building, fence, or train in last year (1=yes; 0=no)	3.0%		
Frequent alcohol use	Consumed alcohol on at least six occasions in past year (1=yes; 0=no)	23.1%		
Heavy drinking	Ever consumed 5 or more alcoholic drinks at a time (1=yes; 0=no)	10.1%		
Marijuana use	Ever tried cannabis (1=yes; 0=no)	5.8%		
Focal Predictor: E- and Combustible Cigarette Use by Age 14^a				
Never used	Never smoked combustible cigarette or used e-cigarette	74.3%		
E-cigarette only	Used e-cigarette but never smoked combustible cigarette	7.3%		
Combustible/dual use	Smoked only combustibles or both combustibles & e-cigarettes	18.3%		
Age 11 Predictors	By E- and Combustible Cigarette Use by Age 14			
	Never used	E-cigarette only	Combustible/dual use	
Externalizing behaviors ^b	Child conduct problems and hyperactivity/inattention (natural logarithm of summary of 10 items [$\alpha=.81$], 0=not at all true to 2=certainly true)	1.5	1.6	1.8
Internalizing behaviors ^b	Child emotional symptoms and peer problems (natural logarithm of summary of 10 items [$\alpha=.77$], 0=not at all true to 2=certainly true)	1.2	1.2	1.3
Test scores ^c	Test of verbal ability (standardized)	0.0	-0.1	-0.2
School Engagement ^a	Same measure as age 14 [$\alpha=.71$]	3.2	3.1	3.0
Wellbeing ^a	" " [$\alpha=.83$]	5.9	5.8	5.7
Self-Esteem ^a	" " [$\alpha=.74$]	3.4	3.4	3.3

	Description	Mean or %			
Theft ^a	Same questions as age 14; “ever” instead of “past year”	5.5%	3.4%	6.9%	13.5%
Vandalism ^a	“	3.2%	1.8%	4.6%	8.5%
Disorderly conduct ^a	“	19.1%	15.4%	21.9%	33.2%
Graffitiing ^a	“	3.0%	1.7%	4.8%	7.8%
Frequent alcohol use ^a	“	3.0%	1.8%	3.8%	7.4%
Heavy drinking ^a	“	0.6%	0.3%	0.0%	2.1%
Sociodemographic Predictors^b					
Gender of child	1=male; 0=female	52.5%	52.2%	60.9%	50.3%
Race/ethnicity of child	White British	80.9%	79.6%	82.3%	85.5%
	Asian British	7.1%	8.0%	5.7%	3.7%
	Black British	4.1%	4.4%	4.9%	2.7%
	Other British	7.9%	8.0%	7.2%	8.2%
Age 14+	Age of child at survey (1=age 14+; 0=age 13 or younger)	76.8%	75.5%	78.9%	81.2%
Parent highest education	Parent highest educational attainment, 0=no diploma to 4= postsecondary diploma	2.8	2.9	2.8	2.5
Parent smoked since pregnancy	Whether mother smoked during pregnancy or either parent smoked since child was born (1=yes)	58.1%	52.7%	66.9%	76.8%

Note. N=11,564 (20 imputed datasets).

^aChild self-reports.

^bParent reports.

^cInvestigator-assessed. For MSC user guides with further description of age 11 and 14 measures, see: Johnson J, Atkinson M, Rosenberg R. Millennium Cohort Study: Psychological, Developmental and Health Inventories. London: Centre for Longitudinal Studies: Institute for Education; 2015; Connelly R. *Millennium Cohort Study Data Note 2013/1: Interpreting Test Scores*. London: Centre for Longitudinal Studies: Institute for Education; 2013.

Table 2.

OLS Regressions Predicting Age 14 Adjustment

	School Engagement		Wellbeing		Self Esteem	
	beta	SE	beta	SE	beta	SE
<i>Cigarette Use (Ref: Never used)</i>						
E-cigarette only	-.115 ***	(.018)	-.371 ***	(.059)	-.112 ***	(.028)
Combustible/dual use	-.169 ***	(.012)	-.539 ***	(.041)	-.181 ***	(.02)
<i>Age 11 Confounders</i>						
Externalizing behaviors	-.023 **	(.007)	-.100 ***	(.022)	-.016	(.012)
Internalizing behaviors	-.001	(.007)	-.125 ***	(.021)	-.045 ***	(.01)
Test scores	-.004	(.005)	-.026	(.016)	-.016	(.008)
School engagement	.205 ***	(.011)				
Wellbeing			.210 ***	(.014)		
Self-esteem					.331 ***	(.017)
<i>Sociodemographic Background</i>						
Male	.090 ***	(.01)	.422 ***	(.025)	.315 ***	(.013)
Age 14+	-.018	(.011)	-.033	(.032)	.002	(.014)
<i>Race/ethnicity (Ref: white British)</i>						
Asian British	.085 ***	(.016)	.159 ***	(.045)	.094 **	(.027)
Black British	.010	(.027)	-.041	(.072)	.138 ***	(.033)
Other British	.027	(.018)	-.088	(.053)	.001	(.026)
Parent highest education	.013 **	(.004)	-.001	(.012)	.001	(.007)
Parent smoked since pregnancy	-.020 *	(.008)	-.073 **	(.024)	-.043 **	(.013)

Note. SE=Robust standard errors; N=11,564 (20 imputed datasets);***
 $p < .001$;**
 $p < .01$;*
 $p < .05$

Table 3.

Multiple Logistic Regressions Predicting Age 14 Delinquency

	Theft		Vandalism		Disorderly Conduct		Graffitiing	
	AOR	95% CI	AOR	95% CI	AOR	95% CI	AOR	95% CI
<i>Cigarette Use (Ref: Never used)</i>								
E-cigarette only	4.53	[2.80,7.33]	6.04	[3.62,10.07]	3.86	[2.91,5.12]	4.31	[2.49,7.48]
Combustible/dual use	11.70	[8.19,16.71]	11.95	[8.04,17.78]	5.69	[4.73,6.85]	11.15	[7.65,16.25]
<i>Age 11 Confounders</i>								
Externalizing behaviors	.98	[.77,1.25]	1.34	[1.01,1.79]	1.10	[.97,1.25]	1.08	[.80,1.47]
Internalizing behaviors	1.13	[.92,1.39]	.98	[.77,1.26]	.90	[.79,1.02]	1.20	[.93,1.55]
Test scores	1.24	[1.02,1.50]	.98	[.83,1.14]	1.15	[1.05,1.26]	1.24	[1.03,1.48]
Theft	2.99	[2.00,4.48]						
Vandalism			2.49	[1.43,4.33]				
Disorderly conduct					1.84	[1.54,2.20]		
Graffitiing							4.09	[2.34,7.15]
<i>Sociodemographic Background</i>								
Male	1.66	[1.23,2.25]	1.69	[1.24,2.31]	1.18	[1.01,1.38]	1.34	[.98,1.83]
Age 14+	.95	[.65,1.40]	1.29	[.89,1.87]	1.28	[1.04,1.57]	1.18	[.78,1.77]
Race/ethnicity (Ref: white British)								
Asian British	.41	[.18,.96]	.76	[.42,1.38]	.66	[.47,.93]	1.06	[.56,2.03]
Black British	1.18	[.60,2.31]	.51	[.18,1.43]	1.15	[.78,1.69]	.53	[.19,1.43]
Other British	1.51	[.97,2.35]	1.10	[.64,1.90]	1.20	[.87,1.65]	.99	[.58,1.67]
Parent highest education	1.01	[.88,1.14]	1.06	[.92,1.21]	1.02	[.95,1.10]	.95	[.82,1.09]
Parent smoked since pregnancy	.98	[.69,1.38]	1.57	[1.10,2.23]	1.12	[.95,1.32]	.93	[.68,1.27]

Note. AOR=Adjusted odds ratio, CI=Confidence Intervals; N=1,564 (20 imputed datasets);

p < .001;

**
p < .01;

*
p < .05

Table 4.

Multiple Logistic Regressions Predicting Age 14 Substance Use

	Frequent alcohol use		Heavy drinking		Marijuana Use	
	AOR	95% CI	AOR	95% CI	AOR	95% CI
<i>Cigarette Use (Ref: Never used)</i>						
E-cigarette only	4.33 ***	[3.48,5.40]	6.72 ***	[4.96,9.12]	9.61 ***	[4.68,19.74]
Combustible/dual use	7.36 ***	[6.17,8.78]	16.21 ***	[12.88,20.39]	102.04 ***	[63.35,164.35]
<i>Age 11 Confounders</i>						
Externalizing behaviors	1.04	[.93,1.17]	1.08	[.90,1.29]	1.27 *	[1.01,1.60]
Internalizing behaviors	.79 ***	[.71,.88]	.86 *	[.74,.99]	1.00	[.79,1.26]
Test scores	1.24 ***	[1.14,1.34]	1.12 *	[1.01,1.23]	1.16	[.99,1.35]
Frequent alcohol use	2.65 ***	[1.81,3.87]				
Heavy drinking			1.71	[.58,5.03]		
<i>Sociodemographic Background</i>						
Male	1.06	[.93,1.20]	.94	[.77,1.14]	1.15	[.89,1.50]
Age 14+	1.64 ***	[1.36,1.98]	1.51 **	[1.20,1.91]	1.28	[.88,1.87]
Race/ethnicity (Ref: white British)						
Asian British	.11 ***	[.06,.19]	.11 ***	[.05,.27]	.50 *	[.25,.99]
Black British	.51 *	[.28,.92]	.38 *	[.18,.81]	2.01	[.79,5.14]
Other British	.66 **	[.50,.87]	.68 *	[.47,.98]	1.51	[.97,2.34]
Parent highest education	1.16 ***	[1.08,1.24]	1.08	[.99,1.18]	1.04	[.93,1.16]
Parent smoked since pregnancy	1.18 *	[1.02,1.36]	1.28 *	[1.05,1.57]	1.53 **	[1.14,2.04]

Note. Marijuana use not assessed at age 11; AOR=Adjusted odds ratio, CI=Confidence Intervals; N=11,564 (20 imputed datasets);

p < .001;

**
p < .01;

*
p < .05