Electronic cigarette use and risk of harmful alcohol consumption in the US population

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Abstract

Background: Electronic cigarette (e-cigarette) use is an increasingly common method of nicotine delivery in the general population. It is well-established that tobacco users are at increased risk to engage in hazardous drinking and meet criteria for alcohol use disorder (AUD) relative to nonusers. Less is known, however, about risk of harmful alcohol use among people who use e-cigarettes. The current study reports on the association between e-cigarette and alcohol use in the United States population using a nationally representative sample.

Methods: Data from 36,309 adults who participated in the National Epidemiologic Survey on Alcohol and Related Conditions- Wave III (NESARC-III) were included in the study. The Alcohol Use Disorder and Associated Disabilities Interview Schedule (AUDADIS) measured past year e-cigarette and alcohol use outcomes. Based on past-year e-cigarette use, respondents were categorized as nonusers, nondaily users, or daily users. Alcohol use outcomes were drinking quantity/frequency, binge drinking frequency, AUD diagnostic status, and NIAAA defined hazardous drinking status.

Results: Controlling for demographic characteristics, daily and nondaily e-cigarette users showed increased risk of harmful alcohol use compared to e-cigarette nonusers, including hazardous drinking (AORs = 1.69; 2.43), AUD (AORs = 1.87; 2.50) and binge drinking frequency (AORs = 1.45–2.97). Nondaily e-cigarette use was associated with higher levels of risk than was daily use. Secondary analyses examined alcohol use outcomes according to participants' patterns of dual tobacco cigarette/e-cigarette use. These analyses confirmed that e-cigarette use alongside tobacco cigarette use is associated with additive risk of harmful alcohol consumption, particularly among nondaily users.

Conclusions: E-cigarette users, particularly those who engage in nondaily and dual use, show elevated rates of harmful alcohol use. Heavy drinking may constitute a source of health risk among e-cigarette users.

Keywords

e-cigarettes; alcohol use disorder; hazardous drinking; nicotine; smoking

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Introduction

Electronic cigarette (e-cigarette) use is an increasingly common method of nicotine delivery in the United States (Schoenborn and Gindi, 2015). These battery-operated smoking devices produce an aerosol containing nicotine that is inhaled by the user. Recent population-based data suggest a continuing upward trend in the prevalence of e-cigarette use among US adults (King et al., 2015), particularly among young adults and tobacco users (McMillen et al., 2015). Smokers commonly report choosing e-cigarettes over tobacco because they are perceived as safer than tobacco cigarettes (Pearson et al., 2012). Consistent with this perception, recent comprehensive reviews of the literature conclude that e-cigarettes pose fewer health risks compared to tobacco cigarettes (McNeill et al., 2015; National Academies of Sciences, Engineering, and Medicine, 2018); however, these reviews focus on direct health effects of e-cigarette use (e.g., cardiovascular disease, cancer, abuse liability). That e-cigarettes purportedly carry fewer health risks compared to their tobacco counterparts is leading smokers to reduce or discontinue their use of tobacco cigarettes in favor of e-cigarettes (Adkison et al., 2013). Considering this shift, it is critically important that we thoroughly characterize the broadly defined health risks associated with e-cigarette use. Such information will inform public policy and clinical practice.

Heightened risk of harmful alcohol consumption is one of many health risks associated with tobacco use. Tobacco cigarette users are more likely to meet criteria for alcohol use disorders (AUD) and engage in hazardous drinking (McKee et al., 2007). Risk of harmful drinking is even higher among those who engage in nondaily tobacco use compared to daily tobacco use (McKee et al., 2007, Harrison et al., 2008). Preclinical and human laboratory studies indicate that tobacco use may increase risk of harmful drinking (Verplaetse and McKee, 2017, Dermody and Hendershot, 2017, Kohut, 2017). Tobacco potentiates the reinforcing effects of alcohol (Piasecki et al., 2011), which may explain the high rate of episodic co-administration among people who use both substances (McKee and Weinberger, 2013). Acute administration of nicotine, the primary psychoactive compound in tobacco, antagonizes the intoxicating and sedating properties of alcohol (Perkins et al., 1995). Indeed, an event-level analysis of tobacco and alcohol use found that smokers consumed more alcohol during occasions where they also smoked (Witkiewitz et al., 2012). The strong causal link between tobacco and alcohol use acts to maintain both harmful behaviors, resulting in poorer health and treatment outcomes (McKee and Weinberger, 2013).

Less is known about patterns of alcohol consumption in people who use e-cigarettes. Several studies have shown that e-cigarette using college students endorse heavy drinking more often than nonusers (Saddleson et al., 2015, Littlefield et al., 2015). In a group of community dwelling adult former smokers, Hershberger et al. (2016b) found that e-cigarette users, particularly social users, reported higher rates of alcohol use and hazardous drinking. Cohn et al. (2015) found that young adult current e-cigarette users were more likely to use alcohol than their peers who did not use e-cigarettes. Taken together, these findings provide important preliminary evidence for a link between e-cigarette and alcohol use. However, these studies were conducted primarily in convenience samples of young adults and used variable definitions of problematic alcohol use. Other studies have found higher rates of alcohol use in e-cigarette users in epidemiological samples, although these studies utilize

relatively narrow assessments of alcohol use (Parikh and Bhattacharyya, 2018, Conway et al., 2018). Additional research is needed to replicate and extend these findings using current alcohol use risk classification systems and diagnostic nomenclature in nationally representative samples (Grant et al., 2015).

The objective of the current study was to examine rates of harmful alcohol use in e-cigarette using adults in the United States. The National Epidemiologic Survey on Alcohol and Related Conditions—Wave III (NESARC-III) provides an opportunity to examine correlates of e-cigarette use in a nationally representative sample of adults. This survey assessed AUD using current clinical nosology (DSM-5) and detailed alcohol use outcomes (e.g., hazardous drinking status, frequency of binge drinking episodes) according to well-validated risk criteria. Previously in a broad survey of e-cigarette use comorbidity in the NESARC-III, Chou et al. (2017) found preliminary evidence that e-cigarette users endorsed higher rates of AUD compared to nonusers. Based on this and previous findings that nondaily smokers show heavier patterns of drinking compared to daily smokers (McKee et al., 2007), we examined risk of alcohol use outcomes in both daily and nondaily e-cigarette users. We hypothesized that e-cigarette users would show higher rates of harmful alcohol use compared to nonusers, and that nondaily e-cigarette users would show higher rates of alcohol use compared to daily e-cigarette users. Recognizing the high rate of dual tobacco/e-cigarette use (Lee et al., 2014), we conducted secondary analyses to examine alcohol use risk among people endorsing different combinations of dual use. These examined alcohol use outcomes in groups endorsing all possible combinations of non-use, nondaily use, and daily use of electronic and tobacco cigarettes according to participants' reported patterns of use. We hypothesized that dual users, particularly those endorsing nondaily patterns of use (Harrison et al., 2008), would show the highest rates of harmful alcohol use (Wills et al., 2015).

Method

Data Source

Data were drawn from the NESARC-III, a national survey conducted by the National Institute on Alcohol Abuse and Alcoholism (NIAAA) from April 2012 to June 2013 (Grant et al., 2014). The NESARC-III utilized a multi-stage cluster sampling procedure involving primary sampling units based on geographical regions, secondary sampling of groups from census-defined blocks, and tertiary sampling of households. Trained interviewers initiated contact with people living at the selected addresses, screened and randomly selected an eligible respondent (i.e., household member at least 18 years old), and obtained informed consent. People who agreed to participate completed an in-person computer assisted interview (Alcohol Use Disorder and Associated Disabilities Interview Schedule-5; AUDADIS-5). The AUDASIS-5 is a valid measure of alcohol and other substance use behaviors, including e-cigarette and tobacco use (Hasin et al., 2015). Participants were paid $45 before and after completing the AUDADIS-5. Data were weighted to adjust for oversampling of racial/ethnic minorities, young adults (age 18–24), and non-responders. This study incorporates data from all NESARC-III respondents (n = 36,309).

Definition and Measurement

E-cigarette and tobacco cigarette use.—Participants were categorized as e-cigarette *nonusers, nondaily users*, or *daily users* based on their responses to the questions "during the past 12 months, did you use at least 1 e-cigarette cartridge or 4 drops of e-liquid?" (possible responses: yes/no/unsure) and "about how often did you usually use e-cigarettes/e-liquid in the past year?" (every day, 5 to 6 days a week, 3 to 4 days a week, 1 to 2 days a week, 2 to 3 days a month, once a month or less/unsure). Definitions were as follows. *Nonuser*: Participant who responded "no" to any e-cigarette use in the past 12 months. *Nondaily users*: Participants who endorsed use in the past 12 months and indicated frequency of use "once a month or less" up to "5 to 6 days per week." *Daily users*: Participants who endorsed use in the past 12 months and indicated "every day" frequency of use. Secondary analyses further categorized participants according to their tobacco cigarette use. They were categorized as tobacco cigarette nonusers, nondaily users, or daily users based on their tobacco use during the past year. Participants who reported that they smoked at least 1 cigarette in the past year were asked "about how often did you usually smoke cigarettes in the past year?" Participants were categorized using the same classification strategy as described above for e-cigarette use.

Alcohol quantity/frequency measures.—Current drinkers were identified according to responses to the question, "during the last 12 months, did you have at least 1 drink of any kind of alcohol?" Alcohol use quantity was assessed by the question "how many drinks did you USUALLY have on days when you drank during the last 12 months?" Alcohol use frequency was measured according to responses to the question "during the last 12 months, about how often did you drink any kind of alcoholic beverage?" (every day, nearly every day, 3 to 4 times a week, 2 times a week, once a week, 2 to 3 times a month, once a month, 7 to 11 times in the last year, 3 to 6 times in the last year, 1 to 2 times in the last year). Responses were coded using increasing frequency cut points (Harrison et al., 2008), from drinking at least once in the past 12 months (yes/no), to drinking at least once in a month (yes/no), to drinking at least once a week (yes/no), to drinking daily or nearly every day (yes/no). Participants were coded as being in the highest frequency group for which they met criteria.

Frequency of NIAAA defined binge drinking was assessed with the question "during the last 12 months, about how often did you drink five (men)/ four (women) drinks on a single day?" (responses and coding same as above). "Extreme" high quantity binge drinking was assessed with the question "during the last 12 months, about how often did you drink 12 or more drinks on a single day?" (Patrick et al., 2013). Response options were identical to those reported above for alcohol use frequency (i.e., ranging from binging at least once in the past 12 months to binging daily or nearly every day).

Hazardous drinking and Alcohol Use Disorder diagnosis.—Past year hazardous drinking was defined according to NIAAA guidelines (https://www.rethinkingdrinking.niaaa.nih.gov). Participants who endorsed exceeding these weekly (men, > 14 drinks per week; women, > 7 drinks per week) or daily (men, 5 per day; women 4 drinks per day) guidelines in the past year were categorized as hazardous

drinkers. Other respondents were categorized as not being hazardous drinkers. Past year AUD diagnosis was evaluated using DSM-5 criteria as determined by the AUDADIS.

Covariates.—All analyses controlled for demographic variables that may be associated with e-cigarette use (i.e., race/ethnicity, sex, age, personal income, marital status). Sex, race, and marital status were coded as dichotomous variables (male/female, white/non-white, married/unmarried). Personal income was coded in one of 17 categories ($0 – 100,000+ USD).

Missing data.—The NESARC-III includes logically assigned data for respondents missing primary demographic data (e.g., race/ethnicity, age). Respondents missing primary outcome data (e.g., e-cigarette use, alcohol use outcomes, tobacco cigarette use) were removed pairwise for analyses that included the missing values. We elected not to use listwise deletion to preserve statistical power given that sample sizes were small in some cells (e.g., daily e-cigarette users).

Data Analysis

Data were analyzed with SAS version 9.4. We tested whether the proposed covariates were associated with e-cigarette use using multi-step chi square tests of independence for discrete variables and one-way analysis of variance (ANOVA) for continuous variables. The first step tested the association of each variable with e-cigarette use (user versus nonuser). The second step of each analysis further tested whether each variable was associated with type of use (daily versus nondaily use).

The primary analyses examined the association between e-cigarette use and alcohol use outcomes. These analyses incorporated the stratification, clustering (i.e., primary sampling unit), and unequal weighting of the sampling design. Binary nominal outcome variables (i.e., AUD, hazardous drinking) were analyzed using binary logistic regression. Quantity of typical drinking episode was analyzed using analysis of variance (ANOVA) and probed using *a priori t* tests. Ordinal variables (i.e., frequency of drinking days, frequency of binge days) were analyzed using multinomial logistic regression. Chi square tests found that the proportional odds assumption was violated for all ordinal regression models ($ps < 0.001$), so ordinal regression was not used. All analyses included the above described covariate set (i.e., sex, race, income, age, marital status). Unadjusted odds ratios and analyses of continuous outcomes not adjusted for covariates are reported in a supplemental table. A secondary set of covariate adjusted analyses were conducted that further categorized participants according to their co-occurring tobacco cigarette use (i.e., nonsmoker, non-daily smoker, daily smoker), resulting in a 3×3 matrix of 9 groups (e.g., daily cigarette user/nondaily e-cigarette user; nondaily cigarette user; e-cigarette non-user). A complete list of combinations is reported in Table 3. Given the small cell sizes for some of these groups (e.g., no tobacco cigarette use/ daily e-cigarette use; $n = 19$), these analyses should be considered exploratory. For these analyses, we only analyzed binary outcomes, because multinomial analyses resulted in additional reduction in cell size and imprecise effect size estimates. Due to the large number of potential pairwise contrasts, we conducted *a priori* analyses to compare risk between

specific subgroups of users. These analyses compared e-cigarette nonusers to daily and nondaily e-cigarette users within each tobacco cigarette use group.

For all logistic regression analyses (binary and multinomial), adjusted odds ratios (AOR) and 95% confidence intervals were calculated. All alpha levels for significance were set to $p < 0.05$.

Results

Demographics and covariates

Demographic information and frequency counts of alcohol use and e-cigarette use outcomes are presented in Table 1. Of those endorsing past year e-cigarette use, the majority reported nondaily use ($n = 1,347$) compared to daily use ($n = 401$). Men were more likely than women to report e-cigarette use, $X^2 (1, n = 36,287) = 40.44$, $p < 0.001$, although gender was not associated with frequency of use (daily vs. nondaily), $X^2 (1, n = 1,748) = 1.32$, $p = 0.251$. White respondents were more likely than racial/ethnic minorities to endorse any e-cigarette use, $X^2 (1, n = 36,287) = 236.62$, $p < 0.001$, and white users were more likely to report daily use compared to racial/ethnic minority users, $X^2 (1, n = 1,748) = 4.12$, $p = 0.042$. Nonmarried respondents were more likely than married respondents to use e-cigarettes, $X^2 (1, n = 34,539) = 34.48$, $p < 0.001$, and nonmarried users were more likely to report daily use compared to married users, $X^2 (1, n = 1,748) = 5.39$, $p = 0.020$. Users were on average younger than nonusers, $F(1, 36,285) = 391.58$, $p < 0.001$, and nondaily users were younger than daily users, $F(1, 1,747) = 34.09$, $p < 0.001$. E-cigarette users reported less personal income than did nonusers, $F(1, 36,285) = 34.34$, $p < 0.001$, but there was no significant difference in personal income between daily and nondaily users, $F(1, 1746) = 0.06$, $p = 0.811$.

Categorical Drinking Outcomes

Table 2 presents results examining past year alcohol use by e-cigarette use. Compared to past year nonusers (reference group [ref]), daily and nondaily e-cigarette users were 45% and 137% more likely to report past year alcohol use, respectively. Nondaily users were 63% more likely than daily users (ref) to report past year alcohol use. E-cigarette users showed higher odds of meeting past year AUD criteria. Compared to nonusers (ref), nondaily users and daily users were 144% and 89% more likely to meet criteria for past year AUD, respectively. There was no significant difference in risk of meeting AUD criteria between daily (ref) and nondaily users. Compared to nonusers (ref), nondaily users and daily users were 148% and 69% more likely to meet past year hazardous drinking criteria, respectively. Nondaily users were 47% more likely than daily users (ref) to meet past year hazardous drinking criteria.

Typical Drinking Quantity and Frequency

Quantity of alcohol consumption during drinking episodes and frequency of alcohol use are reported in Table 2. Regarding drinking quantity, there was a significant main effect of e-cigarette use group, $F(2, 113) = 64.83$, $p < 0.001$. Post hoc tests found that compared to nonusers, both daily users (adjusted mean difference = 0.80 drinks, $t(113) = 4.23$, $p < .001$)

and nondaily users (adjusted mean difference = 1.16 drinks, $t(113) = 9.60$, $p < 0.001$) reported larger typical drinking quantity. There was no significant difference between nondaily and daily (ref) users (adjusted mean difference = 0.35 drinks, $t(113) = 1.45$, $p = 0.149$). Multinomial logistic regression analyses found that e-cigarette use was associated with higher odds of inclusion in higher frequency drinking groups. Compared to daily users (ref), nondaily users were more likely to report weekly and daily drinking.

Binge Drinking (5/4+) Frequency

Frequency of binge drinking per NIAAA criteria among each group is described in Table 1 and results of multinomial logistic regression are reported in Table 2. Both daily and nondaily users showed increased odds of inclusion in most binge drinking frequency categories relative to nonusers. We found no significant difference in binge drinking frequency between nondaily and daily users.

Extreme (12+) Episodic Binge Drinking

Frequency of extreme episodic binge drinking (i.e., 12+ drinks in a single day) in each group is reported in Table 1 and results of the multinomial logistic regression are reported in Table 2. As seen in Table 2, nondaily users showed higher rates of inclusion in all frequency categories other than daily extreme binge drinking compared to nonusers. Daily users showed significantly higher risk than nonusers of yearly binge drinking, although they did not show increased risk of inclusion in other frequency categories. Nondaily users showed higher risk of inclusion in the monthly extreme binge drinking category compared to nonusers.

Secondary Analyses of Alcohol Use Outcomes and Patterns of E-cigarette/Tobacco Cigarette Dual Use

Results of these secondary analyses are reported in Table 3. Participants who endorsed any level of tobacco cigarette use reported higher rates of harmful alcohol use outcomes. Across several outcome categories, participants who reported nondaily e-cigarette use alongside their tobacco cigarette use (i.e., dual users) showed higher rates of alcohol use outcomes compared to those who used tobacco cigarettes alone. Participants who endorsed non-daily use of both e-cigarettes and tobacco cigarettes showed particularly high rates of harmful alcohol use: this group showed a 644% increased likelihood of alcohol use, 599% increased likelihood of hazardous drinking, and 420% increased likelihood of AUD, compared to participants who denied using either tobacco cigarettes or e-cigarettes. This pattern was less evident among daily e-cigarette users (see Table 3).

Discussion

The present study examined rates of harmful alcohol use among e-cigarette users in the United States. E-cigarette users were more likely to engage in harmful alcohol use relative to their non-using peers. This finding is important because it suggests that, like with tobacco cigarettes (McKee et al., 2007), e-cigarette use is associated with high rates of alcohol consumption and harmful patterns of alcohol use. The increased level of risk held across a

range of alcohol use outcomes, ranging from increased drinking quantity/frequency to higher rates of "extreme" binge drinking (12+ drinks/day) and meeting AUD diagnostic criteria.

In considering the implications of the association between e-cigarettes and harmful alcohol use, it is informative to compare our findings here to prior research documenting an association between alcohol use and tobacco cigarette use. Such comparisons provide information on the relative risk of e-cigarettes against tobacco cigarettes. We found that e-cigarette use was associated with approximately 2–3× greater odds of harmful alcohol use. In contrast, studies utilizing similar methodologies have found that current tobacco cigarette users, including both daily and occasional smokers, show relatively higher odds (i.e., 3–5×) of negative alcohol use outcomes (McKee et al., 2007, Harrison et al., 2008). While e-cigarette use was associated with higher rates of problem alcohol use, the magnitude of this association was smaller relative to tobacco cigarettes. Our secondary analyses examining patterns of dual use also provide insight into this issue. Although the analyses were not sufficiently powered to provide precise estimates, they offer insight into rates of alcohol use among groups of single device users (e.g., people using e-cigarettes daily with no tobacco cigarette use or *vice versa*). When interpreted alongside previous findings, our results offer some additional support for the notion that e-cigarette use is associated with lower likelihood of harmful alcohol use outcomes compared to tobacco cigarette use.

One possibility for the lower risk in e-cigarette users compared to tobacco cigarette users is that e-cigarettes contain highly variable levels of nicotine. Some devices are even sold nicotine free. Laboratory research supports a dose-dependent effect of nicotine on alcohol use outcomes (Acheson et al., 2006), so high nicotine concentration products may be associated with higher alcohol use risk. If nicotine intake is the primary mechanism of increased risk of harmful alcohol use in e-cigarette users, then e-cigarette users whose devices contain minimal or no nicotine would not show heightened risk. There is considerable variability in nicotine levels across e-cigarette brands (Goniewicz et al., 2013); future studies should gather detailed information regarding typical nicotine content of respondents' preferred brands so this possibility can be tested directly.

There were notable differences in alcohol use outcomes between daily and nondaily e-cigarette users. Specifically, nondaily e-cigarette users were more likely than daily users to endorse hazardous drinking. This finding is consistent with prior findings on tobacco cigarette smokers: nondaily smokers were more likely than daily smokers to engage in harmful alcohol use (Harrison et al., 2008). Among nondaily tobacco cigarette smokers, most smoking episodes occur while those individuals are drinking (Harrison and McKee, 2008). It is hypothesized that the nicotine potentiates the alcohol-related reinforcement and counteracts sedation with the net effect of increased consumption over a longer duration. The same pattern of co-use may exist among e-cigarette users. This is particularly concerning given that nondaily e-cigarette use is more common than daily use (Sharapova et al., 2018).

Secondary exploratory analyses of alcohol use outcomes stratified users into groups according to their dual use of tobacco cigarette/e-cigarette. Consistent with prior research, these analyses found that dual use was highly prevalent. Further, results support our

hypotheses and prior prediction that dual-use of tobacco and e-cigarettes confers additional risk of harmful alcohol use (Hershberger et al., 2016a) and identifies nondaily dual-users as being at particularly high risk. Other research finds relatively high levels of nicotine dependence seen among dual users compared to tobacco or e-cigarettes alone (Rostron et al., 2016). Further, dual users may be supplementing their nicotine intake using e-cigarettes in locations where tobacco cigarette use is prohibited (e.g., bars), which may promote additional alcohol use. Research examining co-use of tobacco/e-cigarettes and alcohol consumption at the episodic level will be required to understand the mechanisms by which dual use is associated with heightened risk of harmful alcohol consumption.

NESARC-III data are cross-sectional so we cannot directly examine the mechanisms of the observed effect. We attempted to reduce the risk of confounding factors by statistically controlling for demographic variables; however, we were not able to control for all potential confounders. With that said, prior laboratory-based research suggests that nicotine, the primary psychoactive compound in e-cigarettes, increases alcohol consumption (Rose et al., Barrett et al., 2006, Mello et al., 1987), and longitudinal studies find evidence that tobacco use causes subsequent increases in hazardous drinking (Harrison and McKee, 2011). Taken together, these findings support our view that e-cigarette use may increase risk of harmful alcohol use among users. Nonetheless, other factors not measured in the NESARC-III that predict both e-cigarette use and hazardous drinking, such as impulsivity (Chivers et al., 2016, Lejuez et al., 2010), may account for the observed association between alcohol and e-cigarette use. Hershberger and Cyders (2017) provide a comprehensive review of potential mechanism of increased alcohol use rates in e-cigarette users, ranging from shared expectancies to cross-substance cue induced craving. Here, we echo their conclusion that experimental and longitudinal research will be necessary to disentangle the complex and potentially bidirectional association between e-cigarette and alcohol use.

From a policy standpoint, these findings raise concerns about the use of e-cigarettes in alcohol-serving establishments. Legislative bans of smoking in drinking venues are associated with a reduction in alcohol consumption (McKee et al., 2009) and risk of AUD (Young-Wolff et al., 2013). By disallowing the use of tobacco in establishments where patrons typically drink, these policies seem to have reduced rates of harmful drinking, likely by reducing the frequency with which tobacco and alcohol are co-administered. Far fewer states or localities have instated indoor e-cigarette bans, and several states do not allow municipal policies restricting indoor e-cigarette use. Given the findings of the current study, permissive policy towards e-cigarette use in drinking establishments may indirectly increase rates of alcohol use in these areas.

Limitations

These findings should be considered in the context of several limitations. First, the NESARC-III was conducted between 2012 and 2013. E-cigarette use is becoming more frequent in the United States (McMillen et al., 2015). Rates of co-use may have changed as e-cigarette use has become more common. We chose to use data from the NESARC-III because it included detailed reporting of alcohol use according to current diagnostic and classification systems (Grant et al., 2015). The e-cigarette/alcohol use link should be

reevaluated as newer national survey data become available. Second, the base-rates of some behaviors (e.g., extreme binge drinking) were low, resulting in imprecise estimates of odds ratios. Despite some instances of non-significance, however, broader trends in the data support our above conclusions. Finally, our secondary analyses of e-cigarette/tobacco co-use did not account for forms of tobacco use other than tobacco cigarettes (e.g., hookah, cigar, smokeless tobacco). We chose to omit other forms of tobacco use from our analyses so that results are directly comparable to prior studies (Harrison et al., 2008); however, in the future it may be worthwhile to examine rates of non-cigarette tobacco use among e-cigarette users, as these forms of tobacco are common among key demographics (Lee et al., 2014).

Conclusions

The results of current study extend our understanding of alcohol use in e-cigarette users in a representative sample of adults in the United States. People who use e-cigarettes, particularly nondaily users, are at increased risk for engaging in harmful alcohol use. Secondary analyses found that among e-cigarette users, those who also endorse nondaily use of tobacco cigarettes show the highest rates of harmful alcohol use outcomes. These findings identify a group of high risk users (i.e., nondaily dual users) that warrant additional research. Although recent data suggest that e-cigarettes may have fewer direct health consequences compared to tobacco cigarettes (Hajek et al., 2014), these findings highlight the importance of thoroughly examining health correlates of e-cigarette use before drawing conclusions about relative safety.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

References

Acheson A, Mahler SV, Chi H, de Wit H (2006) Differential effects of nicotine on alcohol consumption in men and women. Psychopharmacology (Berl) 186:54–63. [PubMed: 16565827]

Adkison SE, O'Connor RJ, Bansal-Travers M, Hyland A, Borland R, Yong HH, Cummings KM, McNeill A, Thrasher JF, Hammond D, Fong GT (2013) Electronic nicotine delivery systems: international tobacco control four-country survey. Am J Prev Med 44:207–215. [PubMed: 23415116]

Barrett SP, Tichauer M, Leyton M, Pihl RO (2006) Nicotine increases alcohol self-administration in non-dependent male smokers. Drug Alcohol Depend 81:197–204. [PubMed: 16054779]

Chivers LL, Hand DJ, Priest JS, Higgins ST (2016) E-cigarette use among women of reproductive age: impulsivity, cigarette smoking status, and other risk factors. Prev Med 92:126–134. [PubMed: 27492277]

Chou SP, Saha TD, Zhang H, Ruan WJ, Huang B, Grant BF, Blanco C, Compton W (2017) Prevalence, correlates, comorbidity and treatment of electronic nicotine delivery system use in the United States. Drug Alcohol Depend 178:296–301. [PubMed: 28686988]

Cohn A, Villanti A, Richardson A, Rath JM, Williams V, Stanton C, Mermelstein R (2015) The association between alcohol, marijuana use, and new and emerging tobacco products in a young adult population. Addict Behav 48:79–88. [PubMed: 26042613]

Conway KP, Green VR, Kasza KA, Silveira ML, Borek N, Kimmel HL, Sargent JD, Stanton CA, Lambert E, Hilmi N, Reissig CJ, Jackson KJ, Tanski SE, Maklan D, Hyland AJ, Compton WM (2018) Co-occurrence of tobacco product use, substance use, and mental health problems among youth: Findings from wave 1 (2013–2014) of the Population Assessment of Tobacco and Health (PATH) study. Addict Behav 76:208–217. [PubMed: 28846942]

Dermody SS, Hendershot CS (2017) A critical review of the effects of nicotine and alcohol coadministration in human laboratory studies. Alcohol Clin Exp Res 41:473–486. [PubMed: 28247555]

Goniewicz ML, Kuma T, Gawron M, Knysak J, Kosmider L (2013) Nicotine levels in electronic cigarettes. Nicotine Tob Res 15:158–166. [PubMed: 22529223]

Grant B, Amsbary M, Chu A, Sigman R, Kali J, Sugawana Y, Jiao R, Goldstein R, Jung J, Zhang H (2014) Source and Accuracy Statement: National Epidemiologic Survey on Alcohol and Related Conditions-III (NESARC-III). National Institute on Alchool Abuse and Alcoholism, Rockville, MD.

Grant BF, Goldstein RB, Saha TD, Chou SP, Jung J, Zhang H, Pickering RP, Ruan WJ, Smith SM, Huang B, Hasin DS (2015) Epidemiology of DSM-5 alcohol use disorder: results from the National Epidemiologic Survey on Alcohol and Related Conditions III. JAMA Psychiatry 72:757–766. [PubMed: 26039070]

Hajek P, Etter JF, Benowitz N, Eissenberg T, McRobbie H (2014) Electronic cigarettes: review of use, content, safety, effects on smokers and potential for harm and benefit. Addiction 109:1801–1810. [PubMed: 25078252]

Harrison EL, Desai RA, McKee SA (2008) Nondaily smoking and alcohol use, hazardous drinking, and alcohol diagnoses among young adults: findings from the NESARC. Alcohol Clin Exp Res 32:2081–2087. [PubMed: 18828805]

Harrison EL, McKee SA (2008) Young adult non-daily smokers: patterns of alcohol and cigarette use. Addict Behav 33:668–674. [PubMed: 18093745]

Harrison EL, McKee SA (2011) Non-daily smoking predicts hazardous drinking and alcohol use disorders in young adults in a longitudinal U.S. sample. Drug Alcohol Depend 118:78–82. [PubMed: 21441000]

Hasin DS, Greenstein E, Aivadyan C, Stohl M, Aharonovich E, Saha T, Goldstein R, Nunes EV, Jung J, Zhang H, Grant BF (2015) The Alcohol Use Disorder and Associated Disabilities Interview Schedule-5 (AUDADIS-5): procedural validity of substance use disorders modules through clinical re-appraisal in a general population sample. Drug Alcohol Depend 148:40–46. [PubMed: 25604321]

Rethinking drinking: Alcohol and your health. NIH Publication No. 15–3770. Available from: https://www.rethinkingdrinking.niaaa.nih.gov. Accessed February 2, 2018.

Hershberger A, Cyders MA (2017) "Essentially, All Models are Wrong, but Some Are Useful": A preliminary conceptual model of co-occurring e-cig and alcohol use. Curr Addict Rep 4:200–208. [PubMed: 29057201]

Hershberger AR, Karyadi KA, VanderVeen JD, Cyders MA (2016a) Combined expectancies of alcohol and e-cigarette use relate to higher alcohol use. Addict Behav 52:13–21. [PubMed: 26334561]

Hershberger AR, VanderVeen JD, Karyadi KA, Cyders MA (2016b) Transitioning from cigarettes to electronic cigarettes increases alcohol consumption. Subst Use Misuse 51:1838–1845. [PubMed: 27653988]

King BA, Patel R, Nguyen KH, Dube SR (2015) Trends in awareness and use of electronic cigarettes among US adults, 2010–2013. Nicotine Tob Res 17:219–227. [PubMed: 25239961]

Kohut SJ (2017) Interactions between nicotine and drugs of abuse: A review of preclinical findings. Am J Drug Alcohol Abuse 43:155–170. [PubMed: 27589579]

Lee YO, Hebert CJ, Nonnemaker JM, Kim AE (2014) Multiple tobacco product use among adults in the United States: cigarettes, cigars, electronic cigarettes, hookah, smokeless tobacco, and snus. Prev Med 62:14–19. [PubMed: 24440684]

Lejuez CW, Magidson JF, Mitchell SH, Sinha R, Stevens MC, de Wit H (2010) Behavioral and biological indicators of impulsivity in the development of alcohol use, problems, and disorders. Alcohol Clin Exp Res 34:1334–1345. [PubMed: 20491733]

Littlefield AK, Gottlieb JC, Cohen LM, Trotter DR (2015) Electronic cigarette use among college students: links to gender, race/ethnicity, smoking, and heavy drinking. J Am Coll Health 63:523–529. [PubMed: 26057365]

McKee SA, Falba T, O'Malley SS, Sindelar J, O'Connor PG (2007) Smoking status as a clinical indicator for alcohol misuse in US adults. Archives of Internal Medicine 167:716–721. [PubMed: 17420431]

McKee SA, Higbee C, O'Malley S, Hassan L, Borland R, Cummings KM, Hastings G, Fong GT, Hyland A (2009) Longitudinal evaluation of smoke-free Scotland on pub and home drinking behavior: findings from the International Tobacco Control Policy Evaluation Project. Nicotine Tob Res 11:619–626. [PubMed: 19351787]

McKee SA, Weinberger AH (2013) How can we use our knowledge of alcohol-tobacco interactions to reduce alcohol use? Annu Rev Clin Psychol 9:649–674. [PubMed: 23157448]

McMillen RC, Gottlieb MA, Shaefer RM, Winickoff JP, Klein JD (2015) Trends in electronic cigarette use among U.S. adults: Use is increasing in both smokers and nonsmokers. Nicotine Tob Res 17:1195–1202. [PubMed: 25381306]

McNeill A, Brose LA, Calder R, Hitchman SC, Hajek P, McRobbie H (2015) E-Cigarettes: An Evidence Update. Public Health England, London.

Mello NK, Mendelson JH, Palmieri SL (1987) Cigarette smoking by women: interactions with alcohol use. Psychopharmacology (Berl) 93:8–15. [PubMed: 3114817]

National Academies of Sciences, Engineering, and Medicine (2018) Public Health Consequences of E-Cigarettes. The National Academies Press, Washington, DC. doi: 10.17226/24952

Parikh AS, Bhattacharyya N (2018) Patterns of concurrent cigarette, alcohol, and e-cigarette use: Off-setting or additive behaviors? Laryngoscope. Advanced online publication.

Patrick ME, Schulenberg JE, Martz ME, Maggs JL, O'Malley PM, Johnston LD (2013) Extreme binge drinking among 12th-grade students in the United States: prevalence and predictors. JAMA Pediatr 167:1019–1025. [PubMed: 24042318]

Pearson JL, Richardson A, Niaura RS, Vallone DM, Abrams DB (2012) e-cigarette awareness, use, and harm perceptions in US adults. Am J Public Health 102:1758–1766. [PubMed: 22813087]

Perkins KA, Sexton JE, DiMarco A, Grobe JE, Scierka A, Stiller RL (1995) Subjective and cardiovascular responses to nicotine combined with alcohol in male and female smokers. Psychopharmacology (Berl) 119:205–212. [PubMed: 7659768]

Piasecki TM, Jahng S, Wood PK, Robertson BM, Epler AJ, Cronk NJ, Rohrbaugh JW, Heath AC, Shiffman S, Sher KJ (2011) The subjective effects of alcohol-tobacco co-use: an ecological momentary assessment investigation. J Abnorm Psychol 120:557–571. [PubMed: 21443289]

Rose JE, Brauer LH, Behm FM, Cramblett M, Calkins K, Lawhon D (2004) Psychopharmacological interactions between nicotine and ethanol. Nicotine Tob Res 6:133–144. [PubMed: 14982697]

Rostron BL, Schroeder MJ, Ambrose BK (2016) Dependence symptoms and cessation intentions among US adult daily cigarette, cigar, and e-cigarette users, 2012–2013. BMC Public Health 16:814. [PubMed: 27538489]

Saddleson ML, Kozlowski LT, Giovino GA, Hawk LW, Murphy JM, MacLean MG, Goniewicz ML, Homish GG, Wrotniak BH, Mahoney MC (2015) Risky behaviors, e-cigarette use and susceptibility of use among college students. Drug Alcohol Depend 149:25–30. [PubMed: 25666362]

Schoenborn CA, Gindi RM (2015) Electronic cigarette use among adults: United States, 2014. NCHS Data Brief 217: 1–8.

Sharapova SR, Singh T, Agaku IT, Kennedy SM, King BA (2018) Patterns of e-cigarette use frequency: National Adult Tobacco Survey, 2012–2014. Am J Prev Med 54:284–288. [PubMed: 29129463]

Verplaetse TL, McKee SA (2017) An overview of alcohol and tobacco/nicotine interactions in the human laboratory. Am J Drug Alcohol Abuse 43:186–196. [PubMed: 27439453]

Wills TA, Knight R, Williams RJ, Pagano I, Sargent JD (2015) Risk factors for exclusive e-cigarette use and dual e-cigarette use and tobacco use in adolescents. Pediatrics 135:e43–51. [PubMed: 25511118]

Witkiewitz K, Desai SA, Steckler G, Jackson KM, Bowen S, Leigh BC, Larimer ME (2012) Concurrent drinking and smoking among college students: an event-level analysis. Psychol Addict Behav 26:649–654. [PubMed: 21895348]

Young-Wolff KC, Hyland AJ, Desai R, Sindelar J, Pilver CE, McKee SA (2013) Smoke-free policies in drinking venues predict transitions in alcohol use disorders in a longitudinal U.S. sample. Drug Alcohol Depend 128:214–221. [PubMed: 22999418]

Table 1.

Demographic, alcohol use, and tobacco cigarette use by e-cigarette user group in the National Epidemiologic Survey on Alcohol and Related Conditions (III) ($n = 36,309$)

	All (n = 36,309)		Nonusers (n = 34,539)		Nondaily users (n = 1,347)		Daily users (n = 401)	
	n (M)	% (SD)	*n* (M)	% (SD)	*n* (M)	% (SD)	*n* (M)	% (SD)
Age	(45.63)	(17.53)	(46.04)	(17.60)	(36.53)	(13.62)	(41.10)	(14.28)
Sex								
Male	15,862	43.7	14,950	43.3	685	50.9	217	54.1
Female	20,447	56.3	19,589	56.7	662	49.1	184	45.9
Race (White)								
White	19,194	52.9	17,940	51.9	937	69.6	300	74.8
Non-white	17,115	47.2	16,599	48.1	410	30.4	101	25.2
Personal Income	(7.21)	(4.56)	(7.25)	(4.58)	(6.75)	(4.17)	(6.63)	(4.04)
Marital Status								
Unmarried	19,515	53.7	18,446	53.4	836	62.1	233	55.6
Married	16,794	46.3	16,093	46.6	511	37.9	178	44.4
Any alcohol use past year								
No	10,531	29.0	10,288	29.8	163	12.1	74	18.5
Yes	25,758	70.9	24,231	70.2	1,184	87.9	327	81.5
Alcohol use disorder (AUD)								
No	31,176	85.9	29,970	86.8	887	65.9	300	74.8
Yes	5,133	14.1	4,569	13.2	460	34.1	101	25.2
Hazardous drinking (past year)								
No	22,707	62.5	22,048	63.8	468	34.7	178	44.4
Yes	13,602	37.5	12,491	36.2	879	65.3	223	55.6
Highest drinking frequency group								
No episodes past year	10,531	29.0	10,288	29.8	163	12.1	74	18.5
1+ episode per year	7,420	20.4	7,027	20.3	292	21.7	97	24.2
1+ episode per month	6,041	16.6	5,708	16.5	263	19.5	66	16.5
1+ episode per week	9,290	25.6	8,684	25.1	483	35.9	117	29.2
1+ episode per day	3,007	8.3	2,812	8.1	146	10.8	47	11.7
Highest binge episode (5/4+) frequency group								
No binge episode past year	24,581	67.7	23,829	69.0	536	39.8	203	50.6
1+ episode per year	4,818	13.3	4,470	12.9	275	20.4	70	17.5
1+ episode per month	2,629	7.2	2,394	6.9	191	14.2	42	10.5
1+ episode per week	3,274	9.0	2,927	8.5	279	20.7	66	16.5
1+ episode per day	902	2.5	818	2.4	63	4.7	5.0	5.0
Highest extreme binge drinking (12+) frequency group								
No binge episode past year	33,442	92.2	32,044	92.9	1,053	78.2	327	81.5
1+ episode per year	1,370	3.8	1,173	3.4	147	10.9	47	11.7
1+ episode per month	624	1.7	546	1.6	67	5.0	10	2.5
1+ episode per week	662	1.8	586	1.7	65	4.8	11	2.7

	All (n = 36,309)		Nonusers (n = 34,539)		Nondaily users (n = 1,347)		Daily users (n = 401)	
	n (M)	% (SD)	*n* (M)	% (SD)	*n* (M)	% (SD)	*n* (M)	% (SD)
1+ episode per day	165	0.5	146	0.4	14	1.0	5	1.2
Average drinking quantity per episode (drinkers only)	(2.76)	(2.62)	(2.70)	(2.55)	(3.89)	(3.30)	(3.56)	(3.31)
Past Year Tobacco Cigarette Use Status								
Nonsmoker	27,000	74.4	26,864	77.8	116	8.6	19	4.7
Nondaily smoker	2,120	5.8	1,844	5.3	235	17.4	38	9.5
Daily smoker	7,181	19.8	5,825	16.9	996	73.9	343	85.5

Note. Unweighted % are reported.

Table 2.

Group comparisons of alcohol use patterns and classifications by e-cigarette use ($n = 36,309$)

	Nonuser	Nondaily users		Daily users	
		AOR	**95% CI**	**AOR**	**95% CI**
Alcohol user	ref	2.37 [a,b]	(1.95–2.89)	1.45 [a,b]	(1.01–2.08)
Alcohol use disorder	ref	2.44 [a]	(2.09–2.84)	1.89 [a]	(1.42–2.52)
Hazardous drinker	ref	2.48 [a,b]	(2.16–2.85)	1.69 [a,b]	(1.32–2.16)
Highest drinking frequency group (vs. nondrinker)					
1+ episode per year	ref	2.24 [a]	(1.79 – 2.81)	1.67 [a]	(1.08 – 2.59)
1+ episode per month	ref	2.03 [a]	(1.59 – 2.60)	1.34	(0.81 – 2.24)
1+ episode per week	ref	2.51 [a,b]	(2.05 – 3.09)	1.34 [b]	(0.94 – 1.91)
1+ episode per day	ref	3.24 [a,b]	(2.26 – 4.47)	1.57 [a,b]	(1.02 – 2.43)
Highest binge drinking frequency group (vs. no binge episodes)					
1+ episode per year	ref	1.63 [a]	(1.39 – 1.91)	1.30	(0.91–1.83)
1+ episode per month	ref	2.57 [a]	(2.07 – 3.19)	1.86 [a]	(1.23–2.81)
1+ episode per week	ref	3.30 [a]	(2.76 – 3.95)	2.25 [a]	(1.56–3.25)
1+ episode per day	ref	2.90 [a]	(1.90 – 4.44)	2.10 [a]	(1.26–3.50)
Highest extreme (12+) binge drinking frequency group (vs. no extreme binges)					
1+ episode per year	ref	2.70 [a]	(2.12–3.45)	2.61 [a]	(1.83–3.72)
1+ episode per month	ref	2.63 [a,b]	(1.83–3.78)	1.17 [b]	(0.56–2.44)
1+ episode per week	ref	2.45 [a]	(1.92–3.12)	1.39	(0.72–2.69)
1+ episode per day	ref	1.99	(0.98–4.04)	2.41	(0.84–6.86)
Typical drinking quantity (mean [SE]; past year drinkers only)	2.73 (0.02)	3.88 (0.12) [a]		3.53 (0.19) [a]	

All analyses were adjusted for race, marital status, sex, age, and personal income.

[a]Group is significantly different compared to nonusers (ref), $p < 0.05$.

[b]Significant difference between daily and nondaily users, $p < 0.05$.

Table 3.

Alcohol use outcomes among participants endorsing different patterns of dual-use of e-cigarettes and tobacco cigarettes

	Past year alcohol use outcome					
	Alcohol user		**Hazardous drinker**		**Alcohol use disorder**	
	AOR (% yes)	**95% CI**	**AOR (% yes)**	**95% CI**	**AOR (% yes)**	**95% CI**
No tobacco cigarette use						
No e-cig use ($n = 26,864$)	Ref (66.9%)		Ref (30.6%)		Ref (9.8%)	
Nondaily e-cig use ($n = 116$)	2.37 (87.9%)[a,b]	(1.24–4.54)	2.16 (62.1%)[a,b]	(1.46–3.21)	2.54 (35.3%)[a,b]	(1.52–4.25)
Daily e-cig use ($n = 19$)	1.21 (73.7%)	(0.38–3.83)	1.46 (42.1%)	(0.61–3.49)	3.56 (26.3%)[a,b]	(1.24–10.26)
Nondaily tobacco cigarette use						
No e-cig use ($n = 1,844$)	3.27 (88.8%)[a]	(2.65–4.04)	3.23 (64.6%)[a]	(2.88–3.84)	3.18 (30.0%)[a]	(2.76–3.66)
Nondaily e-cig use ($n = 235$)	7.44 (94.9%)[a,b]	(3.88–14.27)	6.99 (80.9%)[a,b]	(4.69–10.44)	5.20 (48.5%)[a,b]	(3.77–7.17)
Daily e-cig use ($n = 38$)	10.36 (94.7%)[a]	(2.16–49.70)	4.67 (71.1%)[a]	(1.99–11.00)	2.94 (26.3%)[a]	(1.00–8.61)
Daily tobacco cigarette use						
No e-cig use ($n = 5,825$)	1.75 (79.5%)[a]	(1.58–1.93)	2.41 (53.0%)[a]	(2.21–2.62)	2.62 (23.9%)[a]	(2.36–2.92)
Nondaily e-cig use ($n = 996$)	2.47 (86.2%)[a,b]	(1.99–3.07)	2.88 (61.9%)[a,b]	(2.46–3.38)	3.07 (30.6%)[a]	(2.55–3.70)
Daily e-cig use ($n = 343$)	1.57 (80.8%)[a]	(1.07–2.28)	2.05 (54.8%)[a]	(1.58–2.66)	2.55 (25.1%)[a]	(1.84–3.53)

All analyses were adjusted for race, marital status, sex, age, and personal income. Unweighted % are reported. E-cig refers to e-cigarette.

[a] Group is significantly different compared to no tobacco cigarette/e-cigarette reference group, $p < 0.05$.

[b] Group is significantly different than no e-cig use group within its tobacco cigarette use category.