ALTERNATIVE TOBACCO PRODUCTS & DEPRESSIVE SYMPTOMS
AMONG YOUNG ADULTS:
A LONGITUDINAL ANALYSIS WITH FREQUENCY OF USE
by

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ALTERNATIVE TOBACCO PRODUCTS & DEPRESSIVE SYMPTOMS AMONG YOUNG ADULTS: A LONGITUDINAL ANALYSIS WITH FREQUENCY OF USE

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The association between cigarette use and depression has been documented in many studies. Fewer studies have examined other tobacco products such as electronic cigarettes (e-cigarettes) and hookah that are used by young adults. This study examined whether increased frequency of use of these products was associated with depressive symptoms in a cohort of n=5,236 Texas college students followed from 2014 to 2017. A hierarchical model showed that increased frequency of single product use of cigarettes, refillable e-cigarettes and hookah was associated with depressive symptoms. Refillable and disposable e-cigarettes were examined separately and results did not provide evidence of a different association for each type of e-cigarette when cigarettes were not also used. Dual use of cigarettes with another product was also examined. Dual use was associated with higher depressive symptoms for most product combinations. However, infrequent dual use of disposable e-cigarettes and cigarettes may not be associated with depressive symptoms. Suggestions for further research are included.

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Cigarettes and Alternative Tobacco Products

During the 20th century tobacco use was one of the most active areas of public health and among United States (U.S.) adults the prevalence of smoking decreased from 42.4% in 1965 to 24.7% in 1997 (CDC, 1999). More recently, the 2016 National Health Interview Survey estimated the prevalence of current cigarette smoking among U.S. adults to be 15.5% (Jamal, 2018). Although cigarette use has declined, new types of tobacco products have emerged that are increasing in popularity, such as electronic cigarettes (e-cigarettes) and hookah (McMillen, Gottlieb, Shaefer, Winickoff, & Klein, 2015). The 2016 National Health Interview Survey estimated the prevalence of e-cigarettes as 15.3% for ever-use and 3.2% for current use (CDC, 2017). A study of 2014-2015 data estimated the prevalence of hookah smoking among U.S. adults as 15.8% for ever-use and 1.5% for past 30-day use (Majeed, Sterling, Weaver, Pechacek, & Eriksen, 2017). These products are more popular among young adults than older age groups (CDC, 2017; Majeed et al., 2017). Use of multiple tobacco products is common; approximately 40% of users used more than one product in 2013-2014 (Kasza et al., 2017).

Depression

Depression is a leading cause of disease burden and, according to the 2010 Global Burden of Disease study, depressive disorders were the second highest contributor of years lived with disability (Ferrari et al., 2014). More than just a disabling condition, a 2015 meta-analysis concluded that depression is associated with higher relative risk of all-cause

mortality (RR = 1.71) (Walker, McGee, & Druss, 2015). Past year prevalence of a self-reported major depressive episode among U.S. adults was 6.7% overall in 2016 (Center for Behavioral Health Statistics and Quality, 2017). Among 18-25 year-olds, the prevalence was 10.9%, compared with 7.4% among ages 26-49 and 4.8% among those 50 or older. This indicates that young adulthood is a key period in the life course for major depression.

Cigarettes and Depression

The association between cigarette use and depression has been well documented in many studies. A 2014 meta-analysis of 78 cross-sectional studies reports a statistically significant association between cigarette use and depression (OR = 1.5) (Luger, Suls, & Vander Weg, 2014). A number of hypotheses have been proposed to explain the association between cigarette use and depression including: (1) the self-medication hypothesis, that individuals who experience mental distress smoke to relieve negative affect (Audrain-McGovern, Rodriguez, & Kassel, 2009), (2) that smoking causes depression, possibly because of prolonged nicotine exposure (Boden, Fergusson, & Horwood, 2010; Markou, Kosten, & Koob, 1998), (3) that the relationship is bi-directional (Leung, Gartner, Hall, Lucke, & Dobson, 2012) or (4) that the association is not causal and may be due to common risk factors or unobserved residual confounding (Kendler et al., 1993). A recent systematic review was inconclusive regarding which of these hypotheses had the strongest support from the literature and called for more research using sophisticated methods for causal inference (Fluharty, Taylor, Grabski, & Munafò, 2017).

Alternative Tobacco Products and Depressive Symptoms

To the best of our knowledge only ten studies to date have investigated the association between e-cigarette or hookah use and depressive symptoms. Six of the ten studies examined e-cigarettes (Bandiera, Loukas, Wilkinson, & Perry, 2016; Bandiera, Loukas, Xiaoyin, Wilkinson, & Perry, 2017; Cummins, Zhu, Tedeschi, Gamst, & Myers, 2014; King, Reboussin, Spangler, Cornacchione Ross, & Sutfin, 2018; Lechner, Janssen, Kahler, Audrain-McGovern, & Leventhal, 2017; Leventhal et al., 2016) and six of the ten studies examined hookah (Bandiera et al., 2016; Fielder, Carey, & Carey, 2012; Goodwin et al., 2014; Heinz et al., 2013; King et al., 2018; Primack, Land, Fan, Kim, & Rosen, 2013). The association between e-cigarettes and depressive symptoms is a consistent research finding in all six studies but the directionality of the association remains unclear. Bandiera et al. (2017) used a cross lagged model with data from the Marketing and Promotions across Colleges in Texas project and found that depressive symptoms significantly predicted subsequent e-cigarette use six months later, but e-cigarette use did not significantly predict subsequent depressive symptoms. Lechner et al. (2017), a study of adolescents, reported a bi-directional association based on past 6-month use. Lechner used separate models to show that 1) depressive symptoms among never-users were prospectively associated with subsequent initiation of e-cigarettes and 2) use of e-cigarettes at both waves 2 and 3 was associated with a higher growth rate in depressive symptoms. In the second model, e-cigarette use, the independent variable, was measured at waves 2 and 3, and did not temporally precede the measurements for depressive symptoms. In fact, a possible explanation of Lechner's results for this second model is that adolescents with increasing depressive symptoms were more

likely to sustain e-cigarette use from wave 2 to wave 3. Although Lechner's results are interesting, that paper does not discuss that possibility, nor does it give any defense for using separate models instead of a cross-lagged model to assess bi-directionality. Lechner was also the only study to examine frequency or intensity of use and depressive symptoms but only measured frequency of e-cigarette use at one time point. None of these studies used repeated measures of frequency of individuals' e-cigarette use at multiple time points. These studies relied on between-person comparisons and could not compare the same individual's depressive symptoms when that individual was using tobacco more frequently versus less frequently (or not at all). These designs also have less statistical power than a repeated measures study with the same number of participants (Lu et al., 2013). Additionally, although a suggestion for further research in the Lechner discussion, none of these studies distinguished between types of e-cigarettes (e.g. refillable and disposable).

Past studies of the association between hookah use and depressive symptoms have been somewhat inconclusive. Most studies did not report an association between hookah use and depressive symptoms, however the largest study with n=100,891 participants did find an association (Primack et al., 2013) and the most recent study reported a marginally significant association ($p = .052$) (King et al., 2018). All of the studies on hookah use and depressive symptoms have been cross-sectional except for Fielder et al. (2012). Fielder only used depressive symptoms as measured at baseline in a sample of women. Again, none of these studies used repeated measures of individuals' frequency of hookah use or depressive symptoms at multiple time points, eliminating the possibility of within-person comparisons.

Cigars and smokeless tobacco were not found to be significantly associated with depressive symptoms by King et al. (2018) or Bandiera et al. (2016). Cigars and smokeless tobacco are less commonly used than other products (e.g. cigarettes, e-cigarettes and hookah) and King suggested the lack of significant findings for these products may be due to small sample size.

The association between use of multiple products and depressive symptoms was examined in only two of these studies (Lechner et al., 2017; Leventhal et al., 2016). Both studies examined dual use of e-cigarettes and cigarettes in adolescents. Lechner et al. measured past 6-month use and found that dual use was associated with significantly higher depressive symptoms compared with non-use, but dual use was not significantly different from single product use with respect to depressive symptoms. Leventhal et al. measured ever-use and found that n=189 adolescent dual users had lower depressive symptoms than n=152 cigarette users, but higher depressive symptoms than n=412 e-cigarette users. None of these studies have examined dual use and depressive symptoms in young adults, nor have they examined other product combinations such as dual use of hookah and cigarettes. Again, none of these studies differentiated between types of e-cigarette.

To measure depressive symptoms, most studies of alternative tobacco product use rely on questionnaires such as the Center for Epidemiologic Studies Depression 10 Scale (CES-D-10) or Patient Health Questionnaire (PHQ-9) rather than a clinical diagnosis. One exception is Cummins et al. (2014) who asked participants if they had been diagnosed with a mental health condition. Validation studies suggest that measures from questionnaires are

correlated with traditional diagnostic interviews and have acceptable sensitivity and specificity (Shean & Baldwin, 2008).

Public Health Significance

Given the increasing prevalence of alternative tobacco product use and the high disease burden of depression, their association merits further study. The relationship between alternative tobacco product use and depressive symptoms is not well understood. To the best of my knowledge this would be the first study to use repeated measures of the frequency of alternative tobacco product use to examine the association between frequency of use and depressive symptoms. It also would be the first study of depressive symptoms to analyze disposable and refillable e-cigarettes separately. Young adulthood, the focus of this study, is a key period in the life course for tobacco product use and depressive symptoms.

Furthermore, I claim that frequency of alternative tobacco product use is of intrinsic public health significance. It is plausible that the potentially harmful effects of alternative tobacco product use are positively associated with more frequent use. Dose-response is also part of the Bradford-Hill criteria, a framework that is commonly applied in epidemiology when examining associations that could be causal (Rothman & Greenland, 2005). Although the Bradford-Hill criteria were never intended as a checklist for establishing causality (Höfler, 2005), assessing the dose-response relationship between severity of depressive symptoms and frequency of alternative tobacco product use could contribute toward a deeper understanding of their association.

Specific Aims

1) To measure the association between frequency of tobacco product use and depressive symptoms among young adults. Multiple tobacco products will be studied, including e-cigarettes and hookah, in addition to cigarettes. For each tobacco product, we hypothesize that more frequent use will be associated with increased depressive symptoms.
2) To examine the association between types of e-cigarettes (i.e. refillable and disposable e-cigarettes) and depressive symptoms among young adults.
3) To assess whether dual use of cigarettes with another tobacco product has a different association with depressive symptoms than use of either product alone.

METHODS

Data Set

Data came from the Marketing and Promotions across Colleges in Texas project (M-PACT). M-PACT is a prospective cohort study of students from 24 colleges in Texas. M-PACT began in October 2014 with follow up at six-month intervals through June 2017 for a total of six repeated measures. Retention rates ranged from 78-81%. 246 participants (4.5%) had missing data in every survey wave including baseline, leaving a sample of 5,236 participants (95.5%) out of the original 5,482 participants. These 5,236 participants were 18-29 years old at baseline (mean = 21.0; standard deviation (SD) = 2.3) and 36.7% male. Many participants were non-Hispanic white (37.3%) or Hispanic (30.9%); fewer participants were Asian (16.8%), Black (7.5%) or another race/ethnicity (7.5%). Only 7.1% of students attended a two-year college rather than a four-year institution. Almost half of students had

fathers with either a Bachelor's degree (26.8%) or a graduate degree (20.8%). For more information about M-PACT see Loukas et al. (2016).

Measures

The following variables were considered in the analysis:

Socio-demographic Covariates

Sex, race/ethnicity and baseline age (standardized with mean=0 and SD=1) were considered. Since M-PACT lacks a direct measure of socio-economic status, father's education level was considered as a proxy for socio-economic status. Father's education level ranged from "No high school" to a "Graduate degree" (coded from 0-7 then standardized). Whether the participant attended a two-year or four-year college was also considered.

Depressive Symptoms

Depressive symptoms were measured with the Center for Epidemiologic Studies Depression 10 scale (CES-D-10), a 10-item measure (Andresen, Malmgren, Carter, & Patrick, 1994). Eight items asked about the frequency of a depressive symptom within the past 7 days and is scored from 0 "rarely (less than 1 day)" to 3 "most of the time (5-7 days)." Two items asked about the frequency of feeling hopeful or happy and were reverse coded. The scores were added to form a summary score with higher scores indicating a greater frequency of depressive symptoms. Cronbach's alpha for the sample at baseline was 0.81, indicating good internal consistency. Depressive symptoms were modeled as the dependent variable over waves 1-6.

Product Use: Past 30 Day Use and Frequency of Use

Past 30-day use of tobacco products was measured by the question, "During the past 30 days, have you used [product]?" To ensure proper comprehension, the survey also included pictures of the type of tobacco product described in the question. Past 30 day use was a dichotomous measure (Yes/No coded as 1/0 respectively). To measure frequency of use, participants were asked, "On how many of the last 30 days have you used such a product?" For the final model, frequency of use was modeled per every 5 days; i.e. the number of days used (range: 0-30) was divided by 5 to create a scaled variable (range: 0-6) and each unit of the scaled variable represented 5 days of use in the past 30 days. Scaling can help model convergence (Cheng, Edwards, Maldonado-Molina, Komro, & Muller, 2010) and interpretation. Product use was modeled using independent variables over waves 1-6.

Statistical Analysis

Descriptive statistics were calculated to describe the sample (Table 1). The past 30-day prevalence was calculated separately for each product. Participants could use more than one tobacco product in the past 30 days and product use was not described with mutually exclusive categories. The prevalence of past 30 day use of 2 or more products was also calculated. Frequency of use of each product was described among users of that product with the median and interquartile range (IQR).

To examine the association between product use and depressive symptoms over waves 1-6, a hierarchical (also called "mixed" or "multi-level") model was used. Hierarchical models may be the most widely used statistical method for analyzing repeated measures data (Gibbons, Hedeker, & DuToit, 2010). Depressive symptoms (CES-D-10) were modeled as

the dependent variable and product use as independent variables. This allows the association for each tobacco product to be estimated while adjusting for use of other products. CES-D-10 score, a skewed variable, was modeled as a count variable measuring frequency of depressive symptoms with a Poisson likelihood and a canonical log link (for an example of a Poisson model for CES-D-10 score see Ranney et al., 2017). All models were adjusted for socio-demographic covariates (race/ethnicity, sex, baseline age, two- vs. four-year college and father's education) and survey wave (standardized with mean=0 and SD=1). Heterogeneity between individuals was modeled with a varying ("random") intercept and slope for survey wave. Rate ratios (RR) were calculated using e^{β} and represent the multiplicative change in depressive symptoms (CES-D-10) associated with a one unit increase in the independent variable.

To select a model that fit the data well, multiple models were tried and then compared by Akaike's Information Criterion (AIC). Some models used categorical variables for frequency of use (e.g. 0 days, 1-5 days or 6+ days) and other models used continuous variables (Specific Aim 1). Each model with continuous variables for frequency use also had dichotomous variables for past 30 day use. This ensures that conclusions drawn from the frequency of use variables are due to differences in depressive symptoms between more frequent use and less frequent (but non-zero) use and not simply because there is a difference between 0 days (non-use) and 1+ days. Refillable and disposable e-cigarettes were modeled as separate product types in all models (Specific Aim 2). Interaction terms were then added for dual use of cigarettes with refillable e-cigarettes, disposable e-cigarettes, hookah and cigars (i.e. the 8 interaction terms tried included past 30 day and frequency of use variables

for cigarettes x refillable e-cigarettes, cigarettes x disposable e-cigarettes, cigarettes x hookah, and cigarettes x cigars), but no interactions were tried for smokeless tobacco, the most rarely used product. Interaction terms allow for the possibility that dual use could have a different association than what would be expected from combining the associations for each of the two products (Specific Aim 3). AIC suggested a model with continuous frequency of use variables and four interaction terms (Table 2) provided the best fit to the data. One interaction term was marginally significant (p=.07) but was retained because it improved AIC. All results reported in the text are from that model but the overall conclusions are not highly sensitive to model choice.

To ensure the robustness of conclusions, Bayesian models were also fit to the data with regularizing priors and Markov Chain Monte Carlo (MCMC) (Appendix A). The results from frequentist and Bayesian analyses were similar and most estimates were identical when rounded to the second decimal place. Model fit for frequentist and Bayesian models was checked graphically.

To aid with model interpretation, examples of the estimated total association for product use after accounting for frequency of use, past 30 day use and relevant interactions are reported (Table 3). Missing data only affected 7.8% of observations (including incomplete observations from participants excluded from the study due to missing data). Hierarchical modeling is one of the most robust methods available for missing data in longitudinal studies (Gibbons et al., 2010). All analysis was conducted in R 2.5.1 (R Core Team, 2018) with the lme4 and brms packages (Bates, Mächler, Bolker, & Walker, 2015; Bürkner, 2017).

RESULTS

Product Use Descriptive Statistics

Cigarettes were the most common product used within the past 30 days and n=1,117 (21.3%; Table 1) of participants used at baseline. When both types of e-cigarette were considered together, past 30 day prevalence of e-cigarettes (n=907; 17.3%; data not shown) was similar to hookah (n=885; 16.9%). After separating e-cigarette use by type, refillable e-cigarettes were much more common (n=768; 14.7%) than disposable e-cigarettes (n=303; 5.8%) at baseline. Past 30 day use of two or more products was relatively common (n=1,021; 19.6%). Products were often used infrequently and the median days of use within the past 30 days ranged from 2 to 5, indicating at least half of all users used each product 5 days or less (Table 1).

Frequency of Use

A hierarchical model of waves 1-6 showed that increased frequency of use was associated with increased depressive symptoms (CES-D-10) for cigarettes, refillable e-cigarettes and hookah, the three most commonly used products. Every five days of use in the past 30 days was associated with 3% higher depressive symptoms for cigarettes (Rate Ratio (RR): 1.03; 95% CI: 1.02-1.04; p<.001; Table 2), 1% for refillable e-cigarettes (RR: 1.01; 95% CI: 1.00-1.03; p=.02), and 3% for hookah (RR: 1.03; 95% CI: 1.01-1.05; p<.01). These estimates were for use of a single product (for dual use estimates see below and table 3). The frequency of use results for disposable e-cigarettes, cigars and smokeless tobacco were not statistically significant. However, results suggested that past 30 day use of smokeless tobacco

was associated with a 1.10 times higher (Rate Ratio) CES-D-10 score (95% CI: 1.04-1.16; p<.001) regardless of frequency of use.

When a single product was used for 5 days in the past 30 days, estimates for the total effect of product use ranged from cigars (RR: 1.03 95% CI: 1.00-1.07; Table 3) to smokeless tobacco (RR: 1.10; 95% CI: 1.04-1.16). When a single product was used for 15 days in the past 30 days, estimates ranged from disposable e-cigarettes (RR: 1.05; 95% CI: 0.98-1.13) to cigarettes (RR: 1.13; 95% CI: 1.10-1.16). Hookah was associated with depressive symptoms with 5 days of use in the past 30 days (RR: 1.04; 95% CI: 1.01-1.06) and 15 days of use (RR: 1.09; 95% CI: 1.04-1.15).

E-cigarette Type

Results did not provide evidence of a difference in the associations for refillable and disposable e-cigarettes when cigarettes were not also used. The 95% intervals for disposable e-cigarettes were wide enough to encompass both zero and the estimates for refillable e-cigarettes. For example, the estimates for 5 days use of disposable e-cigarettes (RR: 1.05; 95% CI: 0.99-1.11; Table 3) were similar to the estimates for 5 days use of refillable e-cigarettes (RR: 1.04; 95% CI: 1.02-1.07).

Dual Use

When disposable e-cigarettes were used in conjunction with cigarettes, a significant interaction was observed. Results suggested that infrequent use of disposable e-cigarettes and cigarettes was not associated with depressive symptoms and 5 days of use of each product was not statistically significant (RR: 1.00; 95% CI: 0.96-1.05; Table 3).

Except for the disposable e-cigarette and cigarette interaction noted above, other interactions were small in magnitude (see table 2) and most estimates for dual product use were higher than single product use (see table 3). For example, the estimated total association for 5 days of cigarette use and 5 days of refillable e-cigarette use (RR: 1.11; 95% CI: 1.07-1.14) was higher than the estimated association for 5 days of cigarette use (RR: 1.07; 95% CI: 1.04-1.09) and higher than the estimated association for 5 days of refillable e-cigarette use (RR: 1.04; 95% CI: 1.02-1.07).

DISCUSSION

This study examines frequency of tobacco product use and depressive symptoms in a large cohort of young adults over a three-year period. Most previous studies of alternative tobacco products and depressive symptoms have examined product use without regard to frequency of use. Additionally, this study extends existing research by distinguishing between refillable and disposable e-cigarettes. Finally, the present study considers dual use of cigarettes with another tobacco product.

To the best of our knowledge, this is the first study to conclude that hookah frequency of use is associated with depressive symptoms. Previous studies have examined hookah without regard to frequency of use and only one large study found a significant association (Primack et al., 2013). This finding may not be very surprising since use of other products (e.g. cigarettes) are associated with depressive symptoms. Nevertheless, this is only the second study to report any kind of significant association between hookah and depressive symptoms.

Previous studies of e-cigarette use and depressive symptoms have found significant associations but this is one of the first studies to examine e-cigarette frequency of use specifically. Lechner et al. (2017), the only study to include frequency of use, found a positive association among adolescents, but did not distinguish between refillable and disposable e-cigarettes. The present study confirms this association for refillable e-cigarettes in a cohort of young adults with repeated measures data. However, due to wide confidence intervals for disposable e-cigarettes, this study is unable to come to firm conclusions regarding whether disposable e-cigarettes are positively associated or whether there are differences in the associations for disposable and refillable e-cigarettes when e-cigarettes were the only product used. It is true that refillable e-cigarettes have a significant association and disposable e-cigarettes do not have a significant association, however this does not imply a difference between these associations (Gelman & Stern, 2006) and the lack of significance for disposable e-cigarettes may be because fewer participants used them.

Dual use was associated with higher depressive symptoms than single product use for most product combinations examined. However, this study suggests that infrequent dual use of cigarettes and disposable e-cigarettes is not associated with depressive symptoms. A possible explanation for this finding is that this specific type of use may be representative of experimental tobacco product use behavior, distinct from that of a more committed smoker. Two previous studies examining dual use and depressive symptoms had mixed results and were in adolescent populations (Lechner et al., 2017; Leventhal et al., 2016), whereas this study was in young adults. These studies did not use past 30 day use to measure product use. Also, these studies did not differentiate between disposable and refillable e-cigarettes.

A strength of this study is the use of repeated measures data in a large cohort. This provided enough data to estimate the associations for each product while adjusting for use of other products, which is important since many people use more than one product (Kasza et al., 2017). Most previous studies (e.g. King et al., 2018) estimated the association for each product separately. Bandiera et al. (2016) adjusted for other product use, but to our knowledge this is the first study to consider interaction effects between products. Smaller sample sizes or cross-sectional data may also explain the rarity of previous findings regarding hookah.

One limitation is that data were collected at six-month intervals. If data were collected more frequently (e.g. monthly) it may be viable to determine the temporal relationship between product use and depressive symptoms. However, since most prior studies have been cross-sectional or used annual data, collecting data at six month intervals is an improvement on most contemporary tobacco use studies. Another limitation of this study is that nicotine content was not measured. Although it is possible to investigate whether frequency of use is associated with depressive symptoms, this study does not indicate whether the increase in depressive symptoms is caused by increased nicotine intake or if the increased frequency of use behavior is a byproduct of increased depressive symptoms. Future research investigating a dose-response relationship between nicotine and depressive symptoms may help support or disconfirm the hypothesis that nicotine causes depressive symptoms rather than the self-medication hypothesis. Also, the tobacco landscape is changing rapidly and this study used data from 2014 to 2017. Research on newer products (e.g. Juul) and depressive symptoms could be informative. Additionally, this study is limited

by a reliance on self-report data, which may be less accurate than objective measures (e.g. for frequency of use). Despite these limitations, this study adds to our knowledge about tobacco product use and provides strong evidence for its conclusions.

CONCLUSION

Increased frequency of single product use of cigarettes, refillable e-cigarettes and hookah are associated with depressive symptoms. For single product use, there is no evidence to suggest a difference by e-cigarette type (refillable and disposable e-cigarettes) and depressive symptoms. Dual use is typically associated with higher depressive symptoms than single use, except when disposable e-cigarettes and cigarettes are both used infrequently. Future research on tobacco product use would be more informative if it included nuances such as frequency of use, type of e-cigarette and quantity of nicotine.

Table 1. Descriptive Statistics of Baseline Data (November 2014; n=5,236)

Socio-demographics	**Mean**	**SD**
Age	21.0	2.3
	n	**%**
Male	1,919	36.7
Race/Ethnicity		
White	1,953	37.3
Hispanic	1,620	30.9
Black	391	7.5
Asian	881	16.8
Other	391	7.5
Two-year college (vs. four-year)	373	7.1
Father's education		
No high school	339	6.5
Some high school	390	7.4
Graduated high school	790	15.1
Vocational/Technical school	208	4.0
Some college	742	14.2
Associate's degree	276	5.3
Bachelor's degree	1,404	26.8
Graduate degree	1,087	20.8
Past 30 day use (non-exclusive)	**n**	**%**
Cigarettes	1,117	21.3
Refillable E-cigarettes	768	14.7
Disposable E-cigarettes	303	5.8
Hookah	885	16.9
Cigars	512	9.8
Smokeless	156	3.0
Use of 2+ products	1,021	19.6
Frequency of use among users (Days used in the past 30 days)	**Median**	**IQR**[a]
Cigarettes	5	2-20
Refillable E-cigarettes	3	1-10
Disposable E-cigarettes	2	1-5.5
Hookah	2	1-4
Cigar	2	1-4
Smokeless	5	1-21
Depressive Symptoms	**Median**	**IQR**[a]
CES-D-10	7	4-11

a. Interquartile range is the 25th and 75th percentile of the distribution.

Table 2. Hierarchical Poisson Model for CES-D-10 Score (Waves 1-6)

	Rate Ratio[b]	95% CI	p-value
Frequency of use[c] [range: 0-6]			
Cigarettes	1.03	1.02-1.04	<.001
Refillable e-cigarettes	1.01	1.00-1.03	0.02
Disposable e-cigarettes	1.00	0.98-1.03	0.92
Hookah	1.03	1.01-1.05	<.01
Cigars	1.01	0.99-1.04	0.35
Smokeless	1.00	1.00-1.00	0.92
Past 30 day use[d]			
Cigarettes	1.04	1.01-1.06	<.01
Refillable e-cigarettes	1.03	1.00-1.05	0.04
Disposable e-cigarettes	1.05	0.99-1.11	0.13
Hookah	1.01	0.99-1.03	0.50
Cigars	1.02	0.99-1.05	0.14
Smokeless	1.10	1.04-1.16	<.01
Frequency of use interactions			
Cigarettes & Refillable e-cigarettes	1.00	0.99-1.00	0.07
Cigarettes & Disposable e-cigarettes	1.01	1.01-1.02	<.001
Cigarettes & Cigars	0.99	0.99-1.00	<.05
Past 30 day use interaction			
Cigarettes & Disposable e-cigarettes	0.88	0.82-0.95	<.01

The model adjusted for socio-demographic covariates (race/ethnicity, sex, baseline age, two- vs. four-year college, and father's education) and survey wave.

b. Rate ratios were calculated using e^{β} and represent the multiplicative change in depressive symptoms (CES-D-10) associated with a one unit increase in the independent variable.

c. The number of days of tobacco product use in the past 30 days was scaled so that each one unit increase represents an additional 5 days of use.

d. Past 30 day use was adjusted for frequency of use. Conclusions about the total effect of tobacco product use should account for both frequency of use and past 30 day use (see table 3).

Table 3. Total Estimated Associations for Tobacco Product Use

Tobacco Product(s)	5 days of use in the past 30 days Rate Ratio	95% CI	15 days of use in the past 30 days Rate Ratio	95% CI
Single Product Use				
Cigarettes	1.07	1.04-1.09	1.13	1.10-1.16
Refillable e-cigarettes	1.04	1.02-1.07	1.07	1.04-1.11
Disposable e-cigarettes	1.05	0.99-1.11	1.05	0.98-1.13
Hookah	1.04	1.01-1.06	1.09	1.04-1.15
Cigars	1.03	1.00-1.07	1.06	0.99-1.14
Smokeless	1.10	1.04-1.16	1.10	1.04-1.15
Dual Use (ATP[e] = 5 days)				
Cigarettes with refillable e-cigarettes = 5 days	1.11	1.07-1.14	1.16	1.12-1.20
Cigarettes with disposable e-cigarettes = 5 days	1.00	0.96-1.05	1.09	1.04-1.14
Cigarettes with hookah = 5 days	1.11	1.07-1.14	1.17	1.13-1.21
Cigarettes with cigars = 5 days	1.10	1.06-1.13	1.14	1.10-1.18
Dual Use (Cigarettes = 5 days)				
Refillable e-cigarettes with cigarettes = 5 days	-[f]		1.13	1.09-1.17
Disposable e-cigarettes with cigarettes = 5 days	-[f]		1.03	0.97-1.10
Hookah with cigarettes = 5 days	-[f]		1.17	1.11-1.23
Cigars with cigarettes = 5 days	-[f]		1.11	1.04-1.18

Estimates are based on the model in table 2 and account for frequency of use, past 30 day use and relevant interactions. All associations are adjusted for socio-demographic covariates (race/ethnicity, sex, baseline age, two- vs. four-year college, and father's education) and survey wave.

e. Alternative Tobacco Product (ATP).

f. Estimates for dual use of cigarettes and another product (5 days each) are already provided above and are not repeated here.

REFERENCES

Amato, M. S., Boyle, R. G., & Levy, D. (2016). How to define e-cigarette prevalence? Finding clues in the use frequency distribution. *Tobacco Control*, *25*(e1), e24–e29. https://doi.org/10.1136/tobaccocontrol-2015-052236

Andresen, E. M., Malmgren, J. A., Carter, W. B., & Patrick, D. L. (1994). Screening for Depression in Well Older Adults: Evaluation of a Short Form of the CES-D. *American Journal of Preventive Medicine*, *10*(2), 77–84. https://doi.org/10.1016/S0749-3797(18)30622-6

Audrain-McGovern, J., Rodriguez, D., & Kassel, J. D. (2009). Adolescent smoking and depression: evidence for self-medication and peer smoking mediation. *Addiction*, *104*(10), 1743–1756. https://doi.org/10.1111/j.1360-0443.2009.02617.x

Bandiera, F. C., Loukas, A., Wilkinson, A. V., & Perry, C. L. (2016). Associations between tobacco and nicotine product use and depressive symptoms among college students in Texas. *Addictive Behaviors*, *63*, 19–22. https://doi.org/10.1016/j.addbeh.2016.06.024

Bandiera, F. C., Loukas, A., Xiaoyin, L., Wilkinson, A., & Perry, C. (2017). Depressive Symptoms Predict Current E-Cigarette Use Among College Students in Texas. *Nicotine & Tobacco Research*. https://doi.org/10.1093/ntr/ntx014

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using **lme4**. *Journal of Statistical Software*, *67*(1). https://doi.org/10.18637/jss.v067.i01

Boden, J. M., Fergusson, D. M., & Horwood, L. J. (2010). Cigarette smoking and depression: tests of causal linkages using a longitudinal birth cohort. *British Journal of Psychiatry*, *196*(06), 440–446. https://doi.org/10.1192/bjp.bp.109.065912

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*(1). https://doi.org/10.18637/jss.v080.i01

Carpenter, B., Gelman, A., Hoffman, M. D., Lee, D., Goodrich, B., Betancourt, M., … Riddell, A. (2017). Stan: A Probabilistic Programming Language. *Journal of Statistical Software*, *76*(1). https://doi.org/10.18637/jss.v076.i01

CDC. (1999). Achievements in Public Health, 1900-1999: Tobacco Use -- United States, 1900-1999. Retrieved May 30, 2018, from https://www.cdc.gov/mmwr/preview/mmwrhtml/mm4843a2.htm

CDC. (2017). QuickStats: Percentage of Adults Who Ever Used an E-cigarette and Percentage Who Currently Use E-cigarettes, by Age Group — National Health Interview Survey, United States, 2016. *MMWR. Morbidity and Mortality Weekly Report*, *66*. https://doi.org/10.15585/mmwr.mm6633a6

Center for Behavioral Health Statistics and Quality. (2017). 2016 National Survey on Drug Use and Health Methodological Summary and Definitions.htm.

Cheng, J., Edwards, L. J., Maldonado-Molina, M. M., Komro, K. A., & Muller, K. E. (2010). Real Longitudinal Data Analysis for Real People: Building a Good Enough Mixed Model. *Statistics in Medicine*, *29*(4), 504–520. https://doi.org/10.1002/sim.3775

Cummins, S. E., Zhu, S.-H., Tedeschi, G. J., Gamst, A. C., & Myers, M. G. (2014). Use of e-cigarettes by individuals with mental health conditions. *Tobacco Control*, *23*(suppl 3), iii48-iii53. https://doi.org/10.1136/tobaccocontrol-2013-051511

Ferrari, A. J., Norman, R. E., Freedman, G., Baxter, A. J., Pirkis, J. E., Harris, M. G., … Whiteford, H. A. (2014). The Burden Attributable to Mental and Substance Use Disorders as Risk Factors for Suicide: Findings from the Global Burden of Disease Study 2010. *PLOS ONE*, *9*(4), e91936. https://doi.org/10.1371/journal.pone.0091936

Fielder, R. L., Carey, K. B., & Carey, M. P. (2012). Predictors of Initiation of Hookah Tobacco Smoking: A One-Year Prospective Study of First-Year College Women. *Psychology of Addictive Behaviors : Journal of the Society of Psychologists in Addictive Behaviors*, *26*(4), 963–968. https://doi.org/10.1037/a0028344

Fluharty, M., Taylor, A. E., Grabski, M., & Munafò, M. R. (2017). The Association of Cigarette Smoking With Depression and Anxiety: A Systematic Review. *Nicotine & Tobacco Research*, *19*(1), 3–13. https://doi.org/10.1093/ntr/ntw140

Gelman, A., & Rubin, D. B. (1992). Inference from Iterative Simulation Using Multiple Sequences. *Statistical Science*, *7*(4), 457–472. https://doi.org/10.1214/ss/1177011136

Gelman, A., & Stern, H. (2006). The difference between "significant" and "not significant" is not itself statistically significant. *The American Statistician*, *60*(4), 328–331.

Gibbons, R. D., Hedeker, D., & DuToit, S. (2010). Advances in Analysis of Longitudinal Data. *Annual Review of Clinical Psychology*, *6*, 79–107. https://doi.org/10.1146/annurev.clinpsy.032408.153550

Goodwin, R. D., Grinberg, A., Shapiro, J., Keith, D., McNeil, M. P., Taha, F., … Hart, C. L. (2014). Hookah use among college students: Prevalence, drug use, and mental health. *Drug & Alcohol Dependence*, *141*, 16–20. https://doi.org/10.1016/j.drugalcdep.2014.04.024

Heinz, A. J., Giedgowd, G. E., Crane, N. A., Veilleux, J. C., Conrad, M., Braun, A. R., … Kassel, J. D. (2013). A comprehensive examination of hookah smoking in college students: Use patterns and contexts, social norms and attitudes, harm perception, psychological correlates and co-occurring substance use. *Addictive Behaviors*, *38*(11), 2751–2760. https://doi.org/10.1016/j.addbeh.2013.07.009

Höfler, M. (2005). The Bradford Hill considerations on causality: a counterfactual perspective. *Emerging Themes in Epidemiology*, *2*, 11. https://doi.org/10.1186/1742-7622-2-11

Jamal, A. (2018). Current Cigarette Smoking Among Adults — United States, 2016. *MMWR. Morbidity and Mortality Weekly Report*, *67*. https://doi.org/10.15585/mmwr.mm6702a1

Kasza, K. A., Ambrose, B. K., Conway, K. P., Borek, N., Taylor, K., Goniewicz, M. L., … Hyland, A. J. (2017). Tobacco-Product Use by Adults and Youths in the United States in 2013 and 2014. *New England Journal of Medicine*, *376*(4), 342–353. https://doi.org/10.1056/NEJMsa1607538

Kendler, K., Neale, M., MacLean, C., Heath, A., Eaves, L., & Kessler, R. (1993). Smoking and major depression A causal analysis. *Archives of General Psychiatry*.

King, J. L., Reboussin, B. A., Spangler, J., Cornacchione Ross, J., & Sutfin, E. L. (2018). Tobacco product use and mental health status among young adults. *Addictive Behaviors*, *77*, 67–72. https://doi.org/10.1016/j.addbeh.2017.09.012

Lechner, W. V., Janssen, T., Kahler, C. W., Audrain-McGovern, J., & Leventhal, A. M. (2017). Bi-directional associations of electronic and combustible cigarette use onset patterns with depressive symptoms in adolescents. *Preventive Medicine*, *96*, 73–78. https://doi.org/10.1016/j.ypmed.2016.12.034

Leung, J., Gartner, C., Hall, W., Lucke, J., & Dobson, A. (2012). A longitudinal study of the bi-directional relationship between tobacco smoking and psychological distress in a community sample of young Australian women. *Psychological Medicine*, *42*(06), 1273–1282. https://doi.org/10.1017/S0033291711002261

Leventhal, A. M., Strong, D. R., Sussman, S., Kirkpatrick, M. G., Unger, J. B., Barrington-Trimis, J. L., & Audrain-McGovern, J. (2016). Psychiatric comorbidity in adolescent electronic and conventional cigarette use. *Journal of Psychiatric Research*, *73*, 71–78. https://doi.org/10.1016/j.jpsychires.2015.11.008

Lewandowski, D., Kurowicka, D., & Joe, H. (2009). Generating random correlation matrices based on vines and extended onion method. *Journal of Multivariate Analysis*, *100*(9), 1989–2001. https://doi.org/10.1016/j.jmva.2009.04.008

Loukas, A., Chow, S., Pasch, K. E., Li, X., Hinds, J. T., Marti, C. N., … Perry, C. L. (2016). College students' polytobacco use, cigarette cessation, and dependence. *American Journal of Health Behavior*, *40*(4), 514–522. https://doi.org/10.5993/AJHB.40.4.13

Lu, N., Han, Y., Chen, T., Gunzler, D. D., Xia, Y., Lin, J. Y., & Tu, X. M. (2013). Power analysis for cross-sectional and longitudinal study designs. *Shanghai Archives of Psychiatry*, *25*(4), 259–262. https://doi.org/10.3969/j.issn.1002-0829.2013.04.009

Luger, T. M., Suls, J., & Vander Weg, M. W. (2014). How robust is the association between smoking and depression in adults? A meta-analysis using linear mixed-effects models. *Addictive Behaviors*, *39*(10), 1418–1429. https://doi.org/10.1016/j.addbeh.2014.05.011

Majeed, B. A., Sterling, K. L., Weaver, S. R., Pechacek, T. F., & Eriksen, M. P. (2017). Prevalence and harm perceptions of hookah smoking among U.S. adults, 2014–2015. *Addictive Behaviors*, *69*, 78–86. https://doi.org/10.1016/j.addbeh.2017.01.032

Markou, A., Kosten, T. R., & Koob, G. F. (1998). Neurobiological similarities in depression and drug dependence: A self-medication hypothesis. *Neuropsychopharmacology*, *18*(3), 135–174. https://doi.org/10.1016/S0893-133X(97)00113-9

McElreath, R. (2016). *Statistical rethinking: a Bayesian course with examples in R and Stan*. Boca Raton: CRC Press/Taylor & Francis Group.

McMillen, R. C., Gottlieb, M. A., Shaefer, R. M. W., Winickoff, J. P., & Klein, J. D. (2015). Trends in Electronic Cigarette Use Among U.S. Adults: Use is Increasing in Both Smokers and Nonsmokers. *Nicotine & Tobacco Research*, *17*(10), 1195–1202. https://doi.org/10.1093/ntr/ntu213

Primack, B. A., Land, S. R., Fan, J., Kim, K. H., & Rosen, D. (2013). Associations of Mental Health Problems With Waterpipe Tobacco and Cigarette Smoking Among College Students. *Substance Use & Misuse*, *48*(3), 211–219. https://doi.org/10.3109/10826084.2012.750363

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org/.

Ranney, M. L., Goldstick, J., Eisman, A., Carter, P. M., Walton, M., & Cunningham, R. M. (2017). Effects of a brief ED-based alcohol and violence intervention on depressive symptoms. *General Hospital Psychiatry*, *46*, 44–48. https://doi.org/10.1016/j.genhosppsych.2017.01.008

Rothman, K. J., & Greenland, S. (2005). Causation and Causal Inference in Epidemiology. *American Journal of Public Health*, *95*(S1), S144–S150. https://doi.org/10.2105/AJPH.2004.059204

Shean, G., & Baldwin, G. (2008). Sensitivity and specificity of depression questionnaires in a college-age sample. *The Journal of Genetic Psychology*, *169*(3), 281–292.

van de Schoot, R., Kaplan, D., Denissen, J., Asendorpf, J. B., Neyer, F. J., & van Aken, M. A. (2014). A Gentle Introduction to Bayesian Analysis: Applications to Developmental Research. *Child Development*, *85*(3), 842–860. https://doi.org/10.1111/cdev.12169

Walker, E. R., McGee, R. E., & Druss, B. G. (2015). Mortality in Mental Disorders and Global Disease Burden Implications: A Systematic Review and Meta-analysis. *JAMA Psychiatry*, *72*(4), 334. https://doi.org/10.1001/jamapsychiatry.2014.2502

Watanabe, S. (2010). Asymptotic Equivalence of Bayes Cross Validation and Widely Applicable Information Criterion in Singular Learning Theory. *Journal of Machine Learning Research*, *11*(Dec), 3571–3594.

APPENDICES

Appendix A: Bayesian Models

Bayesian hierarchical Poisson models were used with normally distributed priors for each non-varying ("fixed") coefficient (for helpful overviews of Bayesian statistics see McElreath, 2016 or van de Schoot et al., 2014). For main effects, the prior was centered at 0 with SD=log(1.25). This expresses an expectation of 95% confidence that each independent variable would be associated with no more than a 50% increase (or the equivalent decrease on the log scale) in depressive symptoms (CES-D-10 score) and that smaller associations are more likely than large positive or negative associations. Small changes in CES-D-10 score can be practically significant and reflect large changes in overall mental health. Also, the maximum score is 30 and the median score is 7. Therefore, we feel it is appropriate to assign a small prior probability to very large associations. This approach does not eliminate the possibility of large associations, especially since the sample size is large, but these models would require more evidence to conclude that associations are large than to conclude that associations are small. This is arguably conservative. Importantly, past research would suggest the association between depressive symptoms and product use is more likely to be positive than negative. Therefore, centering priors for these coefficients at zero should be considered conservative for this research question. The priors for interaction effects were centered at 0 with SD=log(1.1), expressing an expectation that interaction effects are likely to be smaller in magnitude than main effects. The prior for the non-varying intercept was centered at the log mean of CES-D-10 with SD=1. Since all continuous independent variables (besides frequency of use) were centered at the mean, it seems reasonable to expect

the intercept to be close to the mean, however the standard deviation also allows for the possibility of very different values. The priors for the other parts of the models are commonly used in modern Bayesian analyses (McElreath, 2016): a half-normal prior with SD=1 for the standard deviation of the varying intercept and slope, and an LKJ(3) prior for the correlation of the varying intercept and slope (Lewandowski, Kurowicka, & Joe, 2009). As a further sensitivity analysis, models with priors that were twice as wide and twice as narrow were fit to the data (Tables A3 and A4) in addition to the frequentist analysis (Table 2). As is common in large samples, Bayesian results were highly similar to the frequentist analysis regardless of the priors used.

The Bayesian models were fit using Markov Chain Monte Carlo (MCMC) in STAN (Carpenter et al., 2017). MCMC convergence was examined with trace plots and the Gelman-Rubin convergence statistic (Gelman & Rubin, 1992). Model fit was assessed graphically with posterior predictive check (Figure A1).

Several models were fit to the data. Model 1 used dichotomous variables for past 30-day use of each tobacco product. Model 2 considered whether each tobacco product was used more than 5 days in the past 30 days, a cutoff suggested in Amato, Boyle and Levy (2016). Model 3 included dichotomous variables for past 30-day use and continuous variables for the number of days used in the past 30 days. Interaction terms were then added to each of these three models for dual use of cigarettes with refillable e-cigarettes, disposable e-cigarettes, hookah and cigars, but no interactions were tried for smokeless tobacco, the most rarely used product. Of these six models, the model with the interaction terms and continuous frequency of use variables (Model 6) best fit the data according to the Widely Applicable Information

Criterion (WAIC) (Watanabe, 2010). The final Bayesian model (Table A1) was created by removing interaction terms from Model 6 when $Pr(\beta>0)\geq0.95$ or $Pr(\beta<0)\geq0.95$ which further improved model fit according to WAIC.

Point and interval estimates are given by the posterior mean and equi-tailed credible intervals. Posterior probabilities were calculated for hypotheses of interest. A posterior probability is the probability that a hypothesis is true based on the data, the model and the priors. Probabilities closer to 1 indicate higher probabilities of the hypothesis being true, probabilities of .5 indicate an equal probability of the hypothesis being true or false, and probabilities closer to 0 indicate a lower probability of the hypothesis being true (or, equivalently, a higher probability of the hypothesis being false).

Table A1. Bayesian Hierarchical Poisson Model for CES-D-10 Score

	Rate Ratio[g]	95% CI		Posterior Probability[h] (β>0)
Frequency of use[i] [range: 0-6]				
Cigarettes	1.03	1.02	1.04	1.00
Refillable e-cigarettes	1.01	1.00	1.03	0.99
Disposable e-cigarettes	1.00	0.98	1.03	0.57
Hookah	1.03	1.01	1.05	1.00
Cigars	1.01	0.99	1.04	0.82
Smokeless	1.00	1.00	1.00	0.46
Past 30 day use[j]				
Cigarettes	1.04	1.01	1.06	1.00
Refillable e-cigarettes	1.03	1.00	1.05	0.98
Disposable e-cigarettes	1.04	0.98	1.10	0.89
Hookah	1.01	0.99	1.03	0.76
Cigars	1.02	0.99	1.05	0.93
Smokeless	1.09	1.04	1.16	1.00
Frequency of use interactions				
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.04
Cigarettes & Disposable e-cigarettes	1.01	1.01	1.02	>.99
Cigarettes & Cigars	0.99	0.99	1.00	0.02
Past 30 day use interaction				
Cigarettes & Disposable e-cigarettes	0.90	0.84	0.96	<.01

The model adjusted for socio-demographic covariates (race/ethnicity, sex, baseline age, father's education and two- vs. four-year college) and survey wave.

g. Rate ratios were calculated using e^{β} and represent the multiplicative change in depressive symptoms (CES-D-10) associated with a one unit increase in the independent variable.

h. Posterior probabilities here are the probability of a positive association based on the data, the model and the priors. The posterior probability of a negative association is 1-Pr(β>0).

i. The number of days of tobacco product use in the past 30 days was scaled so that each one unit increase represents an additional 5 days of use.

j. Past 30 day use was adjusted for frequency of use. Conclusions about the total effect of tobacco product use should account for both frequency of use and past 30 day use (see table 3).

Figure A1. Model Goodness of Fit Plot: Cumulative Density with Posterior Predictive Check

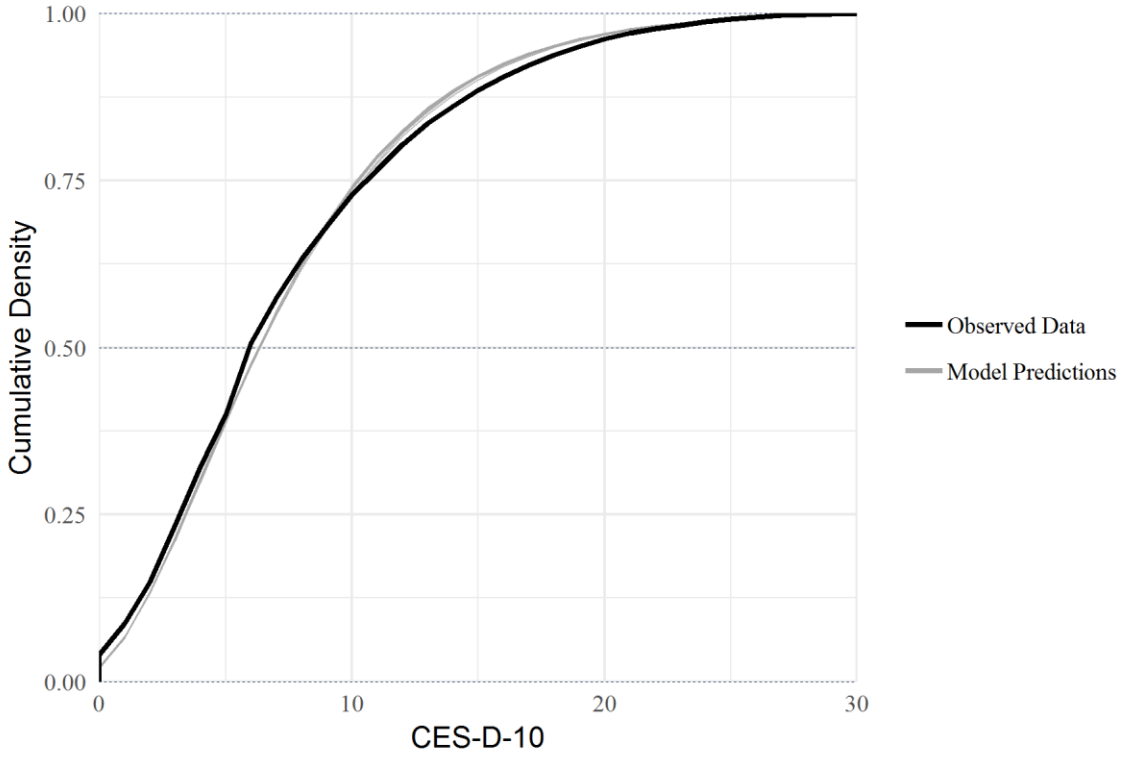

Table A2. Candidate Bayesian Hierarchical Poisson Models for CES-D-10 Score

	Rate Ratio[k]	95% CI		Posterior Probability (β>0)	WAIC[n]
Model 1					139,997
Past 30 day use					
Cigarettes	1.06	1.04	1.09	>.99	
Refillable e-cigarettes	1.04	1.02	1.06	>.99	
Disposable e-cigarettes	1.01	0.97	1.04	0.61	
Hookah	1.02	1.00	1.04	0.98	
Cigars	1.03	1.00	1.05	0.98	
Smokeless	1.10	1.05	1.16	>.99	

Model 2					139,985
Cigarettes					
	0 days	Ref			
	1-5 days	1.04	1.02	1.07	>.99
	6+ days	1.12	1.09	1.15	>.99
Refillable e-cigarettes					
	0 days	Ref			
	1-5 days	1.03	1.01	1.06	0.99
	6+ days	1.06	1.02	1.10	>.99
Disposable e-cigarettes					
	0 days	Ref			
	1-5 days	0.98	0.94	1.01	0.10
	6+ days	1.07	1.01	1.13	0.99
Hookah					
	0 days	Ref			
	1-5 days	1.02	1.00	1.04	0.95
	6+ days	1.08	1.03	1.14	>.99
Cigars					
	0 days	Ref			
	1-5 days	1.03	1.00	1.06	0.98
	6+ days	0.99	0.93	1.05	0.36
Smokeless					
	0 days	Ref			
	1-5 days	1.10	1.04	1.16	>.99
	6+ days	1.09	1.01	1.17	0.99

Model 3					139,975
Frequency of use[l]					
[range: 0-6]					
Cigarettes	1.03	1.02	1.03	>.99	
Refillable e-cigarettes	1.01	1.00	1.02	0.97	
Disposable e-cigarettes	1.03	1.01	1.05	0.99	
Hookah	1.03	1.01	1.04	>.99	
Cigars	0.99	0.98	1.01	0.28	
Smokeless	1.00	1.00	1.00	0.41	
Past 30 day use[m]					
Cigarettes	1.03	1.01	1.05	0.99	
Refillable e-cigarettes	1.03	1.00	1.05	0.98	
Disposable e-cigarettes	0.97	0.93	1.01	0.06	
Hookah	1.01	0.99	1.03	0.77	
Cigars	1.03	1.00	1.06	0.96	
Smokeless	1.10	1.04	1.16	>.99	
Model 4					140,007
Past 30 day use					
Cigarettes	1.07	1.05	1.10	>.99	
Refillable e-cigarettes	1.04	1.01	1.07	>.99	
Disposable e-cigarettes	1.05	0.99	1.10	0.95	
Hookah	1.03	1.00	1.06	0.99	
Cigars	1.02	0.98	1.05	0.80	
Smokeless	1.10	1.05	1.16	>.99	
Past 30 day use interactions					
Cigarettes & Refillable e-cigarettes	1.00	0.96	1.04	0.43	
Cigarettes & Disposable e-cigarettes	0.94	0.88	1.00	0.03	
Cigarettes & Hookah	0.98	0.94	1.02	0.12	
Cigarettes & Cigars	1.02	0.98	1.07	0.82	
Model 5					139,965
Cigarettes					
0 days	Ref				
1-5 days	1.05	1.03	1.08	>.99	
6+ days	1.12	1.08	1.17	>.99	
Refillable e-cigarettes					
0 days	Ref				
1-5 days	1.04	1.01	1.08	>.99	
6+ days	1.05	1.00	1.10	0.96	

Disposable e-cigarettes				
0 days	Ref			
1-5 days	1.02	0.96	1.08	0.75
6+ days	1.08	0.99	1.17	0.96
Hookah				
0 days	Ref			
1-5 days	1.02	0.99	1.04	0.89
6+ days	1.14	1.07	1.22	>.99
Cigars				
0 days	Ref			
1-5 days	1.02	0.98	1.05	0.82
6+ days	1.00	0.92	1.09	0.48
Smokeless				
0 days	Ref			
1-5 days	1.10	1.04	1.16	>.99
6+ days	1.09	1.01	1.18	0.99
Interactions				
Cigarettes 1-5 days & Refillable e-cigarettes 1-5 days	0.95	0.90	1.00	0.04
Cigarettes 6+ days & Refillable e-cigarettes 1-5 days	1.00	0.94	1.06	0.47
Cigarettes 1-5 days & Refillable e-cigarettes 6+ days	1.07	1.00	1.15	0.98
Cigarettes 6+ days & Refillable e-cigarettes 6+ days	0.97	0.90	1.04	0.19
Cigarettes 1-5 days & Disposable e-cigarettes 1-5 days	0.97	0.90	1.05	0.25
Cigarettes 6+ days & Disposable e-cigarettes 1-5 days	0.90	0.84	0.98	0.01
Cigarettes 1-5 days & Disposable e-cigarettes 6+ days	0.92	0.82	1.03	0.08
Cigarettes 6+ days & Disposable e-cigarettes 6+ days	1.03	0.93	1.14	0.69
Cigarettes 1-5 days & Hookah 1-5 days	1.01	0.96	1.05	0.62
Cigarettes 6+ days & Hookah 1-5 days	0.99	0.94	1.04	0.35
Cigarettes 1-5 days & Hookah 6+ days	0.85	0.78	0.93	<.01
Cigarettes 6+ days & Hookah 6+ days	0.95	0.87	1.04	0.14

Cigarettes 1-5 days & Cigars 1-5 days	1.00	0.94	1.05	0.47	
Cigarettes 6+ days & Cigars 1-5 days	1.05	0.99	1.12	0.96	
Cigarettes 1-5 days & Cigars 6+ days	1.00	0.90	1.13	0.53	
Cigarettes 6+ days & Cigars 6+ days	0.98	0.89	1.09	0.37	
Model 6					139,959
Frequency of use[l] [range: 0-6]					
Cigarettes	1.03	1.02	1.04	>.99	
Refillable e-cigarettes	1.01	1.00	1.03	0.99	
Disposable e-cigarettes	1.00	0.98	1.03	0.59	
Hookah	1.03	1.01	1.05	>.99	
Cigars	1.01	0.99	1.04	0.84	
Smokeless	1.00	1.00	1.00	0.48	
Past 30 day use[m]					
Cigarettes	1.04	1.01	1.07	>.99	
Refillable e-cigarettes	1.03	0.99	1.06	0.94	
Disposable e-cigarettes	1.04	0.98	1.10	0.88	
Hookah	1.02	0.99	1.04	0.87	
Cigars	1.01	0.97	1.05	0.63	
Smokeless	1.09	1.04	1.16	>.99	
Frequency of use interactions					
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.04	
Cigarettes & Disposable e-cigarettes	1.01	1.01	1.02	>.99	
Cigarettes & Hookah	1.00	0.99	1.01	0.39	
Cigarettes & Cigars	0.99	0.99	1.00	0.02	
Past 30 day use interactions					
Cigarettes & Refillable e-cigarettes	1.00	0.96	1.05	0.56	
Cigarettes & Disposable e-cigarettes	0.90	0.84	0.96	<.01	
Cigarettes & Hookah	0.98	0.94	1.02	0.13	
Cigarettes & Cigars	1.03	0.98	1.08	0.86	

All models adjusted for socio-demographic covariates (race/ethnicity, sex, baseline age, two- vs. four-year college and father's education) and survey wave.

k. Rate ratios were calculated using e^{β} and represent the multiplicative change in depressive symptoms (CES-D-10) associated with a one unit increase in the independent variable.

l. The number of days of tobacco product use in the past 30 days was scaled so that each one unit increase represents an additional 5 days of use.

m. In models 3 and 6, past 30 day use was adjusted for frequency of use. Conclusions about the total effect of tobacco product use should account for both frequency of use and past 30 day use.

n. Widely Applicable Information Criterion for the final model (in table A1) is 139,947.

Table A3. Bayesian Hierarchical Poisson Models with Different Priors

	Rate Ratio	95% CI		Posterior Probability (β>0)
Table A1 Model (Wider Priors)				
Frequency of use				
[range: 0-6]				
Cigarettes	1.03	1.02	1.04	>.99
Refillable e-cigarettes	1.01	1.00	1.03	0.99
Disposable e-cigarettes	1.00	0.98	1.03	0.54
Hookah	1.03	1.01	1.05	>.99
Cigars	1.01	0.99	1.04	0.81
Smokeless	1.00	1.00	1.00	0.46
Past 30 day use				
Cigarettes	1.04	1.01	1.06	>.99
Refillable e-cigarettes	1.03	1.00	1.05	0.98
Disposable e-cigarettes	1.05	0.99	1.11	0.93
Hookah	1.01	0.98	1.03	0.76
Cigars	1.02	0.99	1.05	0.94
Smokeless	1.10	1.04	1.16	>.99
Frequency of use interactions				
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.03
Cigarettes & Disposable e-cigarettes	1.01	1.01	1.02	>.99
Cigarettes & Cigars	0.99	0.99	1.00	0.04
Past 30 day use interaction				
Cigarettes & Disposable e-cigarettes	0.89	0.83	0.95	<.01

Table A1 Model (Narrower Priors)

Frequency of use				
[range: 0-6]				
Cigarettes	1.03	1.02	1.04	>.99
Refillable e-cigarettes	1.01	1.00	1.03	0.99
Disposable e-cigarettes	1.00	0.98	1.03	0.65
Hookah	1.03	1.01	1.05	>.99
Cigars	1.01	0.99	1.04	0.81
Smokeless	1.00	1.00	1.00	0.50
Past 30 day use				
Cigarettes	1.03	1.01	1.06	>.99
Refillable e-cigarettes	1.03	1.00	1.05	0.98
Disposable e-cigarettes	1.02	0.97	1.08	0.74
Hookah	1.01	0.99	1.03	0.76
Cigars	1.02	0.99	1.05	0.93
Smokeless	1.09	1.03	1.15	>.99
Frequency of use interactions				
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.03
Cigarettes & Disposable e-cigarettes	1.01	1.01	1.02	>.99
Cigarettes & Cigars	0.99	0.99	1.00	0.04
Past 30 day use interaction				
Cigarettes & Disposable e-cigarettes	0.89	0.83	0.95	<.01

Table A2 Model 6 (Wider Priors)

Frequency of use				
[range: 0-6]				
Cigarettes	1.03	1.02	1.04	>.99
Refillable e-cigarettes	1.01	1.00	1.03	0.99
Disposable e-cigarettes	1.00	0.98	1.03	0.53
Hookah	1.03	1.01	1.05	>.99
Cigars	1.01	0.99	1.04	0.86
Smokeless	1.00	1.00	1.00	0.48
Past 30 day use				
Cigarettes	1.04	1.01	1.07	0.99
Refillable e-cigarettes	1.02	0.99	1.06	0.92
Disposable e-cigarettes	1.05	0.98	1.11	0.91
Hookah	1.02	0.99	1.04	0.86
Cigars	1.00	0.97	1.04	0.57
Smokeless	1.10	1.03	1.16	>.99
Frequency of use interactions				
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.03
Cigarettes & Disposable e-cigarettes	1.01	1.01	1.02	>.99
Cigarettes & Hookah	1.00	0.99	1.01	0.41
Cigarettes & Cigars	0.99	0.99	1.00	0.02
Past 30 day use interaction				
Cigarettes & Refillable e-cigarettes	1.01	0.96	1.05	0.59
Cigarettes & Disposable e-cigarettes	0.89	0.83	0.96	<.01
Cigarettes & Hookah	0.98	0.94	1.02	0.15
Cigarettes & Cigars	1.03	0.98	1.08	0.89

Table A2 Model 6 (Narrower Priors)

Frequency of use				
[range: 0-6]				
Cigarettes	1.03	1.02	1.04	>.99
Refillable e-cigarettes	1.01	1.00	1.03	0.99
Disposable e-cigarettes	1.00	0.98	1.03	0.65
Hookah	1.03	1.01	1.05	>.99
Cigars	1.01	0.99	1.04	0.82
Smokeless	1.00	1.00	1.00	0.48
Past 30 day use				
Cigarettes	1.04	1.01	1.06	>.99
Refillable e-cigarettes	1.03	0.99	1.06	0.95
Disposable e-cigarettes	1.02	0.96	1.07	0.73
Hookah	1.02	0.99	1.04	0.88
Cigars	1.01	0.97	1.05	0.71
Smokeless	1.09	1.04	1.15	>.99
Frequency of use interactions				
Cigarettes & Refillable e-cigarettes	1.00	0.99	1.00	0.04
Cigarettes & Disposable e-cigarettes	1.01	1.00	1.02	>.99
Cigarettes & Hookah	1.00	0.99	1.01	0.40
Cigarettes & Cigars	0.99	0.99	1.00	0.03
Past 30 day use interaction				
Cigarettes & Refillable e-cigarettes	1.00	0.96	1.04	0.52
Cigarettes & Disposable e-cigarettes	0.93	0.88	0.98	<.01
Cigarettes & Hookah	0.98	0.95	1.02	0.13
Cigarettes & Cigars	1.02	0.98	1.07	0.85

Table A4. Priors Used for Models in Table A3

Model Parameter(s)	Wider Priors	Narrower Priors
Main effects	Normal(0, 0.4462)	Normal(0, 0.11155)
Interaction terms	Normal(0, 0.1906)	Normal(0, 0.04765)
Intercept	Normal(2.0689, 2)	Normal(2.0689, .5)
Varying Intercept & Slope (SD)	Half-normal(2)	Half-normal(.5)
Correlation of Varying Intercept & Slope	LKJ(1.5)	LKJ(6)