



# Longitudinal Examination of ENDS Use Among Young Adult College Students: Associations with Depressive Symptoms and Sensation Seeking

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## Abstract

The present study examined (1) intraindividual changes in the frequency of electronic nicotine delivery systems (ENDS) use across young adulthood, 18 to 30 years old, and (2) if depressive symptoms and sensation-seeking tendencies, independently and in interaction with one another, were associated with these changes. Data were from a longitudinal study of students recruited from 24 Texas colleges and followed across six waves from fall 2015 to spring 2019. Participants ( $n = 1298$ ; 36.3% non-Hispanic white, 56.3% women) were 18 to 26 years old in fall 2015 and all reported past 30-day ENDS use on at least one wave. We used growth curve modeling for an accelerated longitudinal design to examine if ENDS use frequency changed with increasing age and if depressive symptoms and sensation seeking, independently and in interaction with one another, were associated with these changes. Results showed that ENDS use frequency increased with increasing age. Depressive symptoms and sensation seeking were not independently associated with more frequent ENDS use or an accelerated increase in ENDS use frequency across increasing age. However, a significant two-way interaction indicated that young adults with elevated depressive symptoms used ENDS more frequently, but only when they had higher levels of sensation seeking. Findings indicate that young adults with depressive symptoms are a heterogeneous population and that those with high levels of sensation-seeking tendencies are at elevated risk for more frequent ENDS use. Interventions for young adults high in both sensation-seeking and depressive symptoms may help prevent and decrease ENDS use.

**Keywords** E-cigarettes · Depressive symptoms · Longitudinal · Moderators · Sensation seeking

Use of electronic nicotine delivery systems (ENDS; also referred to as electronic cigarettes) by young adults continues to be a major public health concern. According to monitoring the future data, the prevalence of current ENDS use among young adults was 16.1%, in 2021, surpassing that of cigarette smoking (9.0%) (Patrick et al., 2022). Although ENDS use is prevalent among young adults, this developmental period is characterized by volatility in tobacco use behaviors and

establishment of regular use (Hair et al., 2017, 2018; Niaura et al., 2019). Research on cigarette use indicates that although some smokers maintain smoking levels established in young adulthood prior to the age of 23 (Hair et al., 2017), others “mature out” of smoking in their mid-20 s (Chassin et al., 2000). Because there are limited longitudinal studies on ENDS use, it is unclear if longitudinal changes in ENDS use follow similar patterns to cigarette use. Recent studies with adolescents indicate that the frequency of ENDS use escalates with increasing age (Audrain-McGovern et al., 2021; Bold et al., 2018; Harrell et al., 2021). However, there are few studies examining changes in the frequency of ENDS use across young adulthood and the factors associated with these changes. The present study examined the associations of depressive symptoms and sensation seeking, independently and in interaction with one another, on intraindividual changes in ENDS use frequency from ages 18 to 30 years old.

Young adults are not equally vulnerable to ENDS use. Individuals with internalizing symptoms (such as

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depression) and externalizing behaviors (such as sensation seeking) are at higher risk for ENDS use than their counterparts (Becker et al., 2021; Marsden et al., 2019). Depression is a leading cause of morbidity worldwide that increases the risk for tobacco and ENDS use (Fluharty et al., 2017; Weinberger et al., 2017). Depressive symptoms peak during early young adulthood (Kwong et al., 2019) and contribute to concurrent and subsequent ENDS use among young adults (Bandiera et al., 2017; Marsden et al., 2019). According to self-medication models (Fluharty et al., 2017; Khantzian, 1997), individuals with depression, including those with symptoms of depression, may use ENDS as a perceived coping strategy to self-regulate mood and relieve negative affect. The use of nicotine leads to temporary reductions of negative affect that may not only deter young adults from quitting use but also encourage subsequent continued use (Brandon, 1994) and potentially more frequent use. Limited longitudinal research indicates that depressive symptoms are associated with a faster increase in the frequency of ENDS use across adolescence (Audrain-McGovern et al., 2021). But research on young adults indicates that the association between depressive symptoms and ENDS use is not consistent, with some studies failing to find a significant association (Becker et al., 2021). Thus, there may be heterogeneity in the patterns of associations between depressive symptoms and ENDS use across young adults. That is, there may be factors that moderate the association between depressive symptoms and ENDS use; one such factor is sensation seeking.

Sensation seeking, defined as the pursuit of a novel or risky stimuli for adventure and excitement (Zuckerman et al., 1980), is an important correlate of externalizing and risky behaviors (Roberti, 2004; Zuckerman, 2014). Similar to depressive symptoms, sensation seeking peaks during the transition to young adulthood (Zuckerman, 2014) and is linked to a heightened risk for ENDS use among young adults in cross-sectional and prospective studies (Case et al., 2017a, b; Doran & Tully, 2018). Individuals who score high on sensation seeking are hypothesized to have higher optimal levels of arousal and may seek activities and risks that stimulate and/or regulate arousal (Zuckerman et al., 1980). Compared with their peers, individuals high in sensation seeking are more sensitive to the reinforcement effects of nicotine when using ENDS (Doran et al., 2006; Lee et al., 2011) and perceive fewer risks associated with nicotine use than their peers (Doran et al., 2011), and for these reasons may continue to use nicotine with more frequency as they increase in age. Limited research indicates that sensation seeking is associated with subsequent increases in ENDS use frequency among young adults (Doran & Tully, 2018), but little is known about the association between sensation seeking and the rate of change in the frequency of ENDS use across increasing age during this developmental period.

In addition to the independent associations of depressive symptoms and sensation seeking with ENDS use, both may interact to predict ENDS use frequency. In particular, sensation seeking may moderate or exacerbate the association between depressive symptoms and young adults' ENDS use frequency over time. Young adults with elevated depressive symptoms may be more likely to use ENDS and with increased frequency across increasing age, but only when they are high in sensation seeking because they expect more negative affect reduction from nicotine (Doran et al., 2006; Lee et al., 2011) and because they attribute less risk associated with tobacco use than those low in sensation seeking (Doran et al., 2011). However, there are no studies that examine if sensation seeking moderates the association between depressive symptoms and ENDS use either concurrently or longitudinally across increasing age.

The purposes of the present study were to examine intraindividual changes (i.e., the trajectory) in the frequency of ENDS use across young adulthood, ages 18 to 30 years old, among a sample of students recruited from colleges, and determine the independent and interactive associations of depressive symptoms and sensation seeking on these changes. We used growth curve models to fit the ENDS use frequency trajectory and test study hypotheses, and we adjusted for participant socio-demographics and current (past 30-day) cigarette smoking covariates. Current cigarette smoking was included as a covariate given evidence that smokers are more likely than their peers to use ENDS (Sutfin et al., 2013). Based on research on escalating ENDS use trajectories among adolescents (Bold et al., 2018; Harrell et al., 2021), and on research and theory regarding the roles of depressive symptoms and sensation seeking on ENDS and other nicotine use (Audrain-McGovern et al., 2021; Doran & Tully, 2018; Doran et al., 2006; Lee et al., 2011), we hypothesize that (1) ENDS use frequency will take an upward trend with increasing age during young adulthood; (2) sensation seeking and depressive symptoms will be independently and positively associated with ENDS use frequency; (3) elevated depressive symptoms and sensation seeking will be associated with a faster escalation in the frequency of ENDS use as young adults grow older (i.e., the interactions between depressive symptoms and age, and between sensation seeking and age will be significant); (4) sensation seeking and depressive symptoms will interact and be associated with the frequency of ENDS use, such that sensation seeking will exacerbate the association between depressive symptoms and ENDS use frequency; and (5) the interaction between depressive symptoms and sensation seeking will be associated with faster escalations in ENDS use frequency across young adulthood (i.e., there will be a three-way interaction of depressive symptoms, sensation seeking, and age on frequency of ENDS use).

## Method

### Participants and Procedures

Participants were 1298 young adults involved in six waves of the Marketing and Promotions Across Colleges in Texas project (Project M-PACT). Project M-PACT is a longitudinal surveillance study that tracked changes in tobacco marketing and tobacco use behaviors of a cohort of 5482 college students from 2014 to 2019. Participants were 18 to 29 years old at entry into the project and attended one of 24 Texas colleges (12 four-year and 12 year-year) in the five counties surrounding Austin, Dallas/ Fort Worth, Houston, and San Antonio.

Students attending the 24 colleges were invited by email to complete an eligibility survey. To be eligible to participate, students were required to be 18 to 29 years old and full- or part-time degree- or certificate-seeking undergraduate students attending a four-year college or a vocational or technical program at a two-year college. Overall, 13,714 students were eligible and 40% participated at wave 1 ( $N = 5482$ ), which was from October 2014 to February 2015. There were five follow-up waves every 6 months until spring 2017 (waves 2–6), one abbreviated wave in fall 2017 (wave 7), and two annual follow-up waves, in spring 2018 (wave 8) and spring 2019 (wave 9). In total, we gathered tobacco use data from online surveys across nine waves spanning 4.5 years from fall 2014 to spring 2019. Retention across follow-up waves ranged from 69% (wave 9) to 81% (wave 4) of the 5482 participants. Informed consent was obtained from all participants.

Additional procedural details and inclusion criteria for Project M-PACT have been reported elsewhere (Loukas et al., 2016).

Data from waves 1 and 2 of Project M-PACT were not included in the current study because the frequency of ENDS device used was not assessed. Data were thus limited to those from wave 3 and thereafter. We also excluded data from the wave 7 abbreviated survey because this survey inquired about tobacco use only and did not contain questions about depressive symptoms and sensation seeking. Thus, six waves of data were used in this study, including wave 3 (fall 2015) through wave 6 (spring 2017) and waves 8 and 9 (spring 2018 and 2019, respectively). For the purposes of this study, only data from participants reporting past 30-day use of an ENDS product in one or more of the six waves and those who were 18 to 26 years old at wave 3 (i.e., the study baseline) were included. Given the 3.5-year study period, the latter requirement ensured that we would capture intraindividual changes in ENDS use frequency across young adulthood, ages 18 to 30 years old (Nelson, 2021). Of the 1417 participants who reported past 30-day ENDS use in at least one of the six included waves, we excluded 119 participants due to incomplete data in the model predictors and covariates. In total, the sample size for this study was 1298 participants. The 1298 participants had a mean age of 21.6 years (range = 18.9–26.9,  $SD = 1.89$ ) at baseline, slightly over half were female, the majority attended a 4-year college, and most reported either non-Hispanic white or Hispanic/Latino race/ethnicity. Table 1 shows the socio-demographic characteristics of the sample across all six waves.

**Table 1** Descriptive statistics for socio-demographic and study variables by wave; Fall 2015–Spring 2019

	Fall 15 <i>n</i> = 1129	Spring 16 <i>n</i> = 1175	Fall 16 <i>n</i> = 1149	Spring 17 <i>n</i> = 1179	Spring 18 <i>n</i> = 1110	Spring 19 <i>n</i> = 1030
Mean age in years	21.6 (1.89)	22.0 (1.89)	22.5 (1.88)	23.0 (1.88)	24.0 (1.86)	25.1 (1.87)
% male	43.8	43.7	42.5	42.7	43.5	41.6
% non-Hispanic white	35.3	35.0	35.5	35.3	35.8	35.2
% Hispanic	33.3	33.6	33.4	33.5	33.5	33.2
% Asian American	16.1	16.6	15.9	15.9	16.5	16.3
% African American	6.5	6.0	6.2	6.2	5.4	5.8
% Other	8.9	8.8	9.0	9.2	8.8	9.4
% four-year college	94.1	93.4	94.0	93.8	93.8	93.4
% current smoker	38.9	38.0	36.3	37.2	33.8	28.3
Mean depressive symptoms	9.0 (6.25)	9.0 (6.05)	9.0 (6.22)	8.9 (6.35)	8.7 (6.14)	8.7 (6.03)
Mean sensation seeking	3.5 (0.92)	3.5 (0.92)	3.5 (0.9)	3.4 (0.91)	3.4 (0.9)	3.4 (0.92)
Mean ENDS use frequency	3.4 (7.5)	3.4 (7.73)	3.0 (7.33)	2.9 (7.36)	4.2 (8.73)	5.3 (9.83)

## Measures

### Frequency of ENDS Use

Frequency of ENDS use was assessed at each of the six study waves using the question, “How many of the past 30 days have you used any ENDS product (i.e., an e-cigarette, vape pen, e-hookah, or mod), even one or two puffs, as intended (i.e., with nicotine cartridges and/or e-liquid/e-juice)?” Although the item remained the same across all waves, the exemplar types and brands of ENDS were expanded when new products were introduced to the market, including vape pods in the last two study waves. Response options ranged from 0 to 30 days. To reduce skewness, responses were log transformed by first adding 1 to the raw values so that log-transformed values ranged from 0 to 3.43. We refer to the transformed variable as log-ENDS use.

### Depressive Symptoms

Depressive symptoms were assessed at all six waves with the 10-item short-form Center for Epidemiologic Studies Depression 10 Scale (CES-D-10) (Andresen et al., 1994). This widely used scale assesses the frequency of symptoms of depression occurring over the past week, including depressed affect, positive affect, and somatic complaints. The 10 items were scored on a scale ranging from 0 (rarely or none of the time) to 3 (most of the time) and were summed and standardized, with higher scores reflecting higher levels of depressive symptoms. For the present sample, internal consistency reliability was  $\alpha=0.85$ . Depressive symptoms were transformed to z scores (i.e., grand-mean centered).

### Sensation Seeking

Sensation seeking was assessed at all six waves with the four-item Brief Sensation Seeking Scale-4 (BSSS-4) (Stephenson et al., 2003). Participants were asked to indicate the extent to which they agreed or disagreed with the four items (e.g., “I like new and exciting experiences, even if I have to break the rules”) on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The four items were averaged and higher scores reflected greater sensation-seeking tendencies. The reliability and validity of the BSSS-4 for screening and large-scale surveys have been documented (Stephenson et al., 2003; Vallone et al., 2007). For the present sample, internal consistency reliability was  $\alpha=0.83$ . The sensation-seeking scale was transformed to z scores (i.e., grand-mean centered).

### Covariates

Four time-invariant covariates (age when recruited, race/ethnicity, sex, and college type) all assessed at study entry,

and one time-varying covariate (cigarette smoking), were included in analyses. Participant age when recruited to the project (centered at 18 years) was included to partial out possible cohort effects. Race/ethnicity was dummy coded (i.e., four dummy variables, one for Hispanic/Latino, one for Asian American, one for Black/African American, and one for other race/ethnicity) so that non-Hispanic white participants served as the referent group. Sex (0 = male and 1 = female) and college type were dummy coded (0 = 2-year college and 1 = 4-year college). Finally, current cigarette smoking status (0 = did not smoke cigarettes in the past 30 days and 1 = smoked cigarettes on at least one of the past 30 days) was assessed at all six waves and included in analyses as a time-varying covariate.

### Data Analysis

Data were analyzed using R, version 4.2.2 (R Core Team, 2021). Models were fit using the *lme4* package (Bates et al., 2015) and the *interactions* package, version 1.1.0 (Wickham, 2016) was used to graph interactions in fitted models. We used growth curve models for an accelerated longitudinal design (Duncan et al., 1996) to examine intraindividual changes in frequency of log-ENDS use across young adulthood and to assess the independent and interacting associations of depressive symptoms and sensation seeking on these changes. The accelerated longitudinal design used participant age as the variable to assess change. Participants were aged 18.9 to 26.9 years old at baseline and 22.3 to 30.4 years old at the final wave, and each participant contributed up to 3.5 years of data, based on their exact age at each wave. Thus, the model’s age parameters represent the fitted trend for the entire age range of the sample, 18 to 30 years old across the six waves, on the basis of data contributed from participants with overlapping age ranges. Following recommendations from Singer and Willett (2003), we first fit an unconditional model that included only age as an independent variable. We established the shape of the unconditional growth model by comparing 3 models: a linear age effect, a quadratic age effect, and a log-age effect model, and selected the linear model based on the Bayesian information criterion (BIC). Age was centered at the midpoint of the full age range in the study, 24.5 years, for all models.

After establishing the shape of the model (linear), we evaluated the appropriateness of applying an accelerated design to our data, which comprised eight cohorts (i.e., ages 18 through 26 at recruitment). We implemented an approach recommended by Miyazaki and Raudenbush (2000) to evaluate if a common linear trajectory for all eight cohorts was viable. This approach compares a full model that maximally parameterizes cohorts and represents age as a cohort median age-centered variable with a restricted model, in which participants’ age is the single longitudinal variable

(i.e., an accelerated longitudinal design). Both models contained identical random effects: a random intercept and a random slope for the cohort median age-centered age, which represents cohort variability in the growth trajectory. Using the same random effects in both models allows for model comparisons as the full and reduced models have identical covariance structures. The models were compared using a likelihood-ratio test and the BIC: the full model had a significantly better fit than the restricted model ( $X^2[14] = 37.4$ ,  $p < 0.001$ ) but had a larger BIC (BIC = 18,906) than did the restricted model (BIC = 18,820). We selected the more parsimonious restricted model, the accelerated longitudinal model. However, we accounted for cohort effects in the accelerated longitudinal model by including participant age when recruited to the project as a continuous covariate (Fitzmaurice et al., 2012) as well as the two-way interaction between participant age and age when recruited to the project.

A series of conditional linear growth curve models assessing intraindividual changes in log-ENDS use were fit next to test the study hypotheses. The base conditional model included all covariates (age, age when recruited, sex, race/ethnicity, type of college attended, and time-varying current smoking status), and time-varying depressive symptoms and sensation seeking as main/independent variables. The base model also included the two-way interaction between age and age when recruited to the project. After fitting the base model, we tested models with two-way and three-way interactions. We sequentially examined possible interacting effects by adding three two-way interactions to the base model: (a) age  $\times$  depressive symptoms, to test whether elevated depressive symptoms would be associated with a faster increase in the rate of change in log-ENDS use across age (hypothesis 3), (b) age  $\times$  sensation seeking, to test whether elevated sensation seeking would be associated with a faster increase in the rate of change in log-ENDS use across age (hypothesis 3), and (c) depressive symptoms  $\times$  sensation seeking, to examine if sensation seeking would moderate the association between depressive symptoms and log-ENDS use (hypothesis 4). To examine if the interactive association between depressive symptoms and sensation seeking on log-ENDS use differed across increasing age, we also tested the three-way interaction of age  $\times$  depressive symptoms  $\times$  sensation seeking (hypothesis 5). Non-significant interaction terms were removed, and models were refit.

### Missing Data

Data from the 1298 participants included in the present study represented a maximum of 7788 observations across the six study waves. Some participants skipped one or more surveys or variables of interest during the study period, generating 6772 complete observations (13% missing of all

observations). Although all models were fit using maximum likelihood estimation, which allows the use of all available data, we conducted a series of generalized linear mixed models to determine if missingness was associated with any of the study covariates including sex, race/ethnicity, type of college attended, and baseline smoking status. Findings indicated that males (odds ratio [OR] = 1.40, 95% confidence interval [CI] = 1.06, 1.84) and those reporting current smoking at baseline (OR = 1.33, 95% CI = 1.01, 1.76) were respectively more likely than females and non-smoking peers to have missing data. However, the ORs were in the small effect size range (Chen et al., 2010), and both sex and baseline smoking status were included in all models, which bolsters the missing at random assumption and reduces non-response bias (Gelman & Hill, 2007).

### Results

Before assessing study hypotheses, we examined descriptive statistics of the study variables across the six study waves (see Table 1). On average, young adults used ENDS on fewer than 5 days per month; the mean number of days ENDS were used in the past 30 days was highest at the last wave in spring 2019 (5.3) and lowest in spring 2017 (2.9). Moreover, the frequency of ENDS use appeared to increase across the six waves. Approximately one-third of participants reported current cigarette smoking, but the prevalence of smoking appeared to decrease from a high of 38.9% of participants at baseline in fall 2015 to a low of 28.3% at the last wave in spring 2019. Regarding mean depressive symptoms and sensation seeking, neither appeared to vary across the six waves.

Results from the unconditional accelerated growth model (see Table 2) with only age as an independent variable indicated that there was a significant age effect on log-ENDS use ( $\gamma = 0.04$ ,  $p < 0.001$ ); thus, ENDS use frequency increased as young adults aged (hypothesis 1). Results from the base conditional model (see Table 2), indicated that depressive symptoms and sensation seeking were not independently associated with log-ENDS use (hypothesis 2). However, the covariates of age, age when recruited, sex, race/ethnicity, and current smoking were significantly associated with log-ENDS use. Age when recruited was negatively associated with log-ENDS use indicating that older cohorts used ENDS less frequently throughout the study period. The age  $\times$  age when recruited interaction was not significant indicating that while older participants used ENDS less frequently, ENDS use became more frequent across increasing age at the same rate for all participants. Additionally, women reported less frequent ENDS use than men, and young adults reporting Hispanic, Asian American, and Other race/ethnicity reported less frequent ENDS use than non-Hispanic white young

**Table 2** Frequency of ENDS use regressed onto age, age when recruited to the project, race, sex, and time-varying current cigarette smoking, depressive symptoms, and sensation seeking

	Unconditional model <i>Estimate (standard error)</i>	Model without interactions <i>Estimate (standard error)</i>	Model with interaction <i>Estimate (standard error)</i>
Intercept	0.78 (0.03)***	1.22 (0.11)***	1.22 (0.11)***
Age in years	0.04 (0.01)***	0.08 (0.01)***	0.08 (0.01)***
Age when recruited to the project		−0.06 (0.02)***	−0.06 (0.02)***
Age × age when recruited		−0.00 (0.00)	−0.00 (0.00)
Female sex		−0.19 (0.04)***	−0.19 (0.04)***
Hispanic (vs. White)		−0.24 (0.05)***	−0.24 (0.05)***
Black (vs. White)		−0.17 (0.09)	−0.17 (0.09)
Asian (vs. White)		−0.22 (0.06)***	−0.22 (0.06)***
Other (vs. White)		−0.18 (0.08)*	−0.18 (0.08)*
Four- (vs. two-) year college		−0.07 (0.08)	−0.07 (0.08)
Current cigarette smoking		0.18 (0.03)***	0.18 (0.03)***
Depressive symptoms		0.02 (0.01)	0.02 (0.01)
Sensation seeking		0.02 (0.01)	0.02 (0.01)
Depressive symptoms × sensation seeking			0.03 (0.01)*

\*  $p < .05$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$

Age in years is time-varying and assessed at all six waves. Age when recruited to the project is time invariant. Both age when recruited and the age × age when recruited interaction were included to account for cohort effects. Non-significant interactions are not shown

adults. Being a current cigarette smoker was associated with more frequent ENDS use.

Hypotheses 3 to 5 were tested by adding two-way and three-way interactions among age, depressive symptoms, and sensation seeking to the base model. Only one interaction was significant: depressive symptoms × sensation seeking (hypothesis 4). The two-way interactions between age and depressive symptoms and between age and sensation seeking, and the three-way interaction among age, depressive symptoms, and sensation seeking were not significant. Depressive symptoms and sensation seeking were not associated with the rate of escalation in ENDS use frequency across age (hypothesis 3) nor did sensation seeking moderate the strength of association between depressive symptoms and the rate of escalation in ENDS use frequency across age (hypothesis 5). Non-significant interactions were not included in our final model (see Table 2).

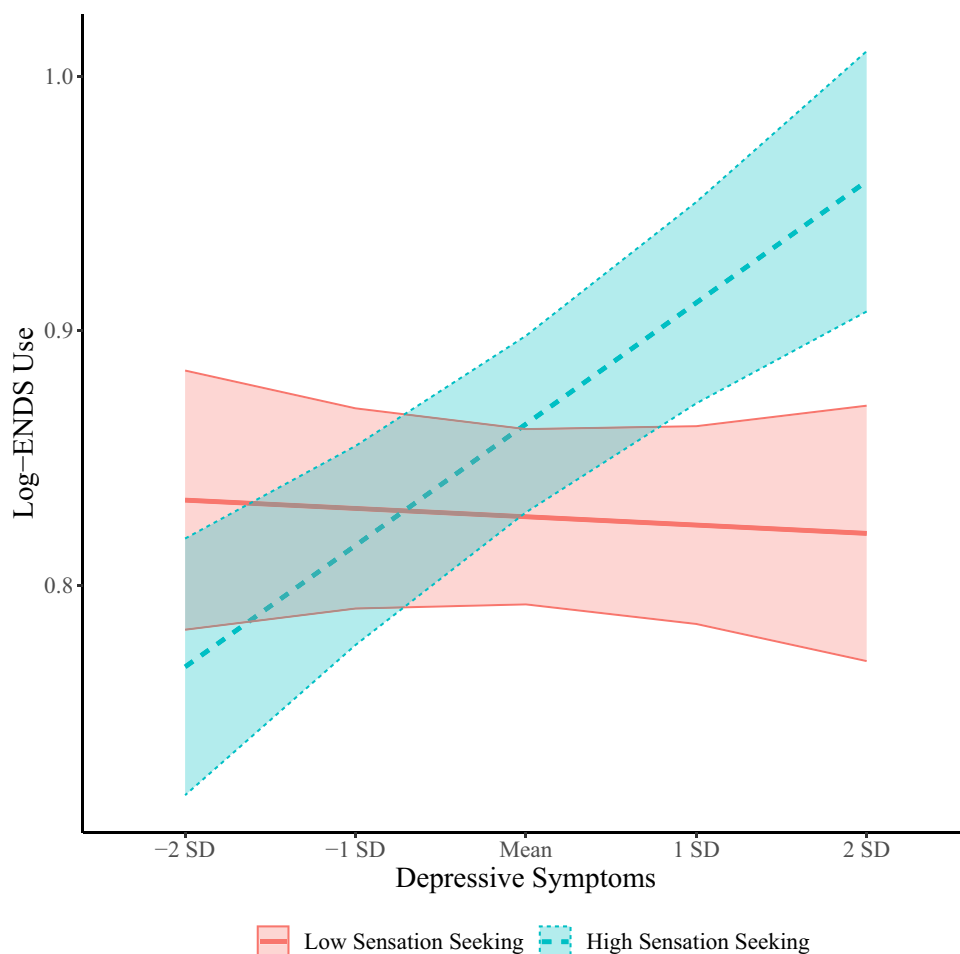
To determine the nature of the depressive symptoms × sensation-seeking interaction, post-hoc analyses were conducted. Because depressive symptoms were a continuous variable, two points (one standard deviation [SD] below and one SD above the mean) were selected to probe the interaction effect across the entire age range of the study (Aiken et al., 1991). Figure 1 illustrates the significant two-way interaction between depressive symptoms and sensation seeking on ENDS use frequency (hypothesis 4). As shown in Table 2 and Fig. 1, the association between depressive symptoms and frequency of

ENDS use is significant at higher levels (one SD above the mean) of sensation seeking ( $\beta = 0.05$ , 95% CI = [0.01, 0.08]), but not at lower levels (one SD below the mean) of sensation seeking ( $\beta = -0.00$ , 95% CI = [−0.04, 0.03]). Findings indicate that sensation seeking exacerbated the effect of depressive symptoms on ENDS use frequency. Young adults with more depressive symptoms tended to use ENDS more frequently, but only if they were high in sensation seeking.

## Discussion

This longitudinal study examined intraindividual changes in the frequency of ENDS use across young adulthood among a sample of students recruited from colleges, and determined if depressive symptoms and sensation seeking, independently and in interaction with one another were associated with these changes. Consistent with prior research with adolescents (Audrain-McGovern et al., 2021; Bold et al., 2018; Harrell et al., 2021), findings indicated that there was an upward linear increase in the frequency of ENDS use across young adulthood. Although depressive symptoms and sensation seeking were not independently associated with ENDS use frequency either concurrently or longitudinally, there was an interaction between the two. We found that sensation seeking exacerbated the association between depressive symptoms and frequency of ENDS use, such that young adults with elevated

**Fig. 1** Sensation seeking as a moderator of the association between depressive symptoms and frequency of ENDS use. *Note.* Low sensation seeking assessed at 1 standard deviation below the mean and high sensation seeking assessed at 1 standard deviation above the mean. Shaded areas represent 1 standard error above and below the fitted slopes



depressive symptoms used ENDS more frequently across young adulthood, but only when they had high levels of sensation seeking. These findings are unique and add to the growing body of research on young adults' ENDS use by moving beyond examination of ENDS use as a binary outcome (i.e., use vs. not use) to examine frequency of use and by examining both independent and interactive associations of depressive symptoms and sensation seeking with longitudinal changes in ENDS use. Findings indicate that young adults with depressive symptoms are a heterogeneous population and that those at elevated risk for more frequent ENDS use may also report elevated levels of sensation seeking.

To our knowledge, the present study is the first to describe the trajectory of the frequency of ENDS use from ages 18–30. The increasing frequency of ENDS use across young adulthood is concerning because it may indicate that some young adults are developing symptoms of nicotine dependence, such as tolerance (Chesaniuk et al., 2019), although additional research tracking young adults into adulthood is needed to determine if and who develops dependence to ENDS. Of note, the increasing trajectory of ENDS use across young adulthood appears to be different from that for

cigarette smoking, which decreases or remains at levels set in early young adulthood (Barrington-Trimis et al., 2020; Hair et al., 2017).

Contrary to expectations, findings indicated that neither depressive symptoms nor sensation seeking were independently associated with ENDS use frequency. Findings are both inconsistent and consistent with a longitudinal study of ENDS use frequency among adolescents conducted by Audrain-McGovern et al. (2021), who reported that depressive symptoms were associated with escalations in the frequency of ENDS use, but sensation seeking was not. One explanation for the discrepancy in findings between the Audrain-McGovern et al. study and our own is that depressive symptoms may be more powerful predictors of escalations in frequency of ENDS use during adolescence when depressive symptoms continue to increase rather than young adulthood when they peak and decline (Kwong et al., 2019). The consistent finding between the Audrain-McGovern et al., study and our own regarding the lack of association between sensation seeking and ENDS use frequency may confirm research indicating that sensation seeking plays a role in the initiation of ENDS and cigarette use, but not in

the continued or escalating use of these products (Case et al., 2017a, b; Perkins et al., 2000; Wilkinson et al., 2012).

Despite the lack of independent associations, this study demonstrated that the interaction between depressive symptoms and sensation seeking was associated with ENDS use frequency such that high levels of sensation seeking exacerbated the depressive symptoms—ENDS use association. This finding corroborates limited research indicating that sensation seeking and depression interact to predict cigarette smoking (Carton et al., 1994), and confirms expectations that young adults with elevated depressive symptoms are a heterogeneous population. According to self-medication models (Fluharty et al., 2017; Khantzian, 1997), individuals may use ENDS to cope with the negative affect associated with elevated depressive symptoms. The nicotine in ENDS provides temporary relief of negative affect (Brandon, 1994), but not everyone who experiences depressive symptoms uses ENDS. Rather, those with concurrently high levels of sensation seeking may use ENDS more frequently than their counterparts low in sensation seeking because they expect more negative affect reduction from nicotine (Doran et al., 2006; Lee et al., 2011) and attribute less risk associated with nicotine use (Doran et al., 2011). Although we did not find that the interaction between depressive symptoms and sensation seeking was associated with the rate of change in ENDS use frequency across increasing age, we did show that the interaction was consistently associated with more frequent ENDS use across young adulthood. Given the limited work examining the interaction between depressive symptoms and sensation seeking in relation to ENDS use frequency, additional research replicating these findings with other samples of young adults is needed.

This study has a number of strengths including examination of the frequency of ENDS use across 3.5 years, from ages 18–30, among a large and demographically diverse sample. However, there are limitations. Participants were recruited from colleges and frequency of ENDS use may be lower among college students compared with young adults in the general population (e.g., Sargent et al., 2022). Similarly, examination of socio-demographics indicates that our sample may over-represent non-Hispanic white and Asian American college students and under-represent African American college students attending the 24 colleges from which they were drawn. Thus, results may not generalize to other college students or to young adults more broadly. Moreover, we included biological sex as a covariate to capture differences between males and females, but sexual orientation and gender identity were not included despite known disparities in ENDS use among young adults reporting a sexual and gender minority (SGM) identity (Hinds et al., 2017). Future research should assess the

role of depressive symptoms and sensation seeking in the ENDS use trajectory of a representative sample of young adults and should consider the role of SGM identity in that trajectory. Another limitation is that the current study did not assess clinical diagnosis of depression. However, elevated scores on screening tests, such as the CES-D-10, predict elevated risk for clinical diagnoses of depression and are valid and economical ways of measuring depressive symptoms on a continuum among large community samples (Lewinsohn et al., 1997). Finally, although we examined longitudinal changes in the frequency of all types of ENDS used over a 3.5-year period, given the variety of ENDS products and the difficulty of measuring ENDS use behaviors (Amato et al., 2016), we could not determine the quantity and severity of nicotine consumption on those ENDS using days. Future research should continue to follow young adults as they transition into adulthood to longitudinally capture changes in varying levels of nicotine consumption from ENDS use behavior.

In sum, this study indicates that the frequency of ENDS use increases across young adulthood, from ages 18–30. Findings also indicate that young adults with depressive symptoms are a heterogeneous population, with some at higher risk for using ENDS more frequently. In particular, young adults with elevated depressive symptoms tend to use ENDS more frequently when they are also high in sensation seeking. As such, prevention and cessation messages that target young adults who are high in depressive symptoms and sensation seeking have the most potential to interrupt the escalation of ENDS use.

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**Data Availability** All data, analysis code, and research materials are available upon request to the first author. This study's design and its analysis were not pre-registered.

## Declarations

**Ethics Approval** All study procedures adhere to the tenets of the Declaration of Helsinki and were approved by the Institutional Review Board (IRB) at the University of Texas at Austin (2013–06-0034).

**Consent to Participate** Informed consent was obtained from all participants in this study.

**Conflict of Interest** The authors declare no competing interests.

**Disclaimer** The content of this manuscript is solely the responsibility of the author(s) and does not necessarily represent the official views of the NCI, the National Institutes of Health (NIH), or the FDA.



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