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An ecological momentary assessment study to examine covariates and effects of concurrent and simultaneous use of electronic cigarettes and marijuana among college students

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ABSTRACT

Introduction: The prevalence of concurrent and simultaneous use of e-cigarette and marijuana among college students is high. Yet, the literature was mainly based on cross-sectional surveys with emphasis on the smoking route. This is the first ecological momentary assessment (EMA) study that examined the vaping route of nicotine-marijuana co-use and the associated short-term psychological effects.

Methods: This study recruited 686 college student e-cigarette users to participate in an on-line survey and 7-day EMA. Frequent marijuana users (247) – using marijuana weekly or daily – were compared with infrequent/non-users (439) on academic performance, e-cigarette use patterns, and dependence and respiratory symptoms. EMA data from the frequent users were used to study the association between marijuana vaping and e-cigarette consumption and the short-term psychological effects of e-cigarette and marijuana use.

Results: The results show that e-cigarette users who frequently used marijuana tended to have lower academic performance, be involved in higher-risk use patterns, and have higher levels of e-cigarette dependence, marijuana problems, and respiratory symptoms, compared to infrequent/non-users. Marijuana vaping was associated with a higher level of e-cigarette consumption. E-cigarette use and marijuana use were both associated with higher levels of positive affect, physiological sensation, and craving for e-cigarettes. While marijuana use was linked to a lower level of negative affect, e-cigarette use did not have a significant effect. Further, none of the interaction effects between e-cigarette and marijuana use on psychological states were significant.

Conclusions: The results showed *additive effects* of e-cigarette and marijuana use although the hypothesized *synergistic effects* were not supported.

1. Introduction

The past-30-day prevalence of e-cigarette use among college students in the U.S. was about 10 %; among e-cigarette users, 46 % also used marijuana in the past 30 days. (Buu et al., 2020) A survey on marijuana-using college students found that 17 % were involved in concurrent use (in the same time period) of cigarettes/e-cigarettes and marijuana, whereas 22 % reported simultaneous use (in close temporal proximity so the effects overlap). (Ruglass et al., 2020) Although the literature has demonstrated adverse health effects associated with e-cigarette use or marijuana use alone such as respiratory symptoms and cognitive impairment, (Seiler-Ramadas et al., 2021; Volkow et al., 2014) the literature on health effects of co-use is relatively limited and mostly from research on combustible tobacco. A college survey found that the students who smoked tobacco and marijuana concurrently/simultaneously tended to have a lower GPA than those using only one substance. (Hernández-Serrano et al., 2018) Further, a national survey on adult tobacco users in the U.S. showed that concurrent marijuana use was associated with lower odds of attempts to quit tobacco and a higher probability of reporting a history of respiratory diseases. (Strong et al.,

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2018) Another survey also found concurrent marijuana use to be related to more severe dependence on e-cigarettes. (Mayorga et al., 2020) Recently, the COVID-19 pandemic has escalated the concern of e-cigarette-marijuana co-use because such behavior was linked to higher odds of reporting COVID-19 symptoms especially among intermediate/frequent users. (Merianos et al., 2022) Thus, e-cigarette-marijuana co-use is an important public health issue that requires more studies on its covariates and effects.

Some important covariates for co-use of tobacco and marijuana among young adults have been identified in the literature. A mixed method study identified four reasons for tobacco-marijuana co-use: (1) instrumentality, indicating synergistic effects; (2) displacement, indicating using one product to reduce/quit the other; (3) social context, indicating use in different settings/social situations; and (4) experimentation. (Berg et al., 2018) The same study also showed that higher scores on the instrumentality and social context scales were associated with more frequent marijuana use. Furthermore, certain places and social contexts have been linked to simultaneous use such as private settings and a higher perceived percentage of intoxicated people. (Lipperman-Kreda et al., 2018).

The literature of tobacco-marijuana co-use reviewed above was based on cross-sectional survey research that is vulnerable to recall biases, particularly for studying simultaneous use and the associated contexts. Ecological momentary assessment (EMA) is a better alternative because this approach repeatedly collects behavioral samples from participants in real-time and real-life. (Buu et al., 2021) An EMA study examining the effects of simultaneous tobacco and marijuana use on working memory found significant main effects – working memory was poorer with marijuana use and yet better with tobacco use – but a nonsignificant interaction between the two substances. (Schuster et al., 2016) Though interesting, that study only investigated the smoking route of simultaneous use. It is crucial to fill the current knowledge gap in the vaping route because of the high prevalence of e-cigarette-marijuana co-use among college students (Buu et al., 2020; Ruglass et al., 2020) and marijuana vaping among young adults. (Schulenberg et al., 2021) Particularly, a study comparing the physiological effects of marijuana vaping and marijuana smoking among infrequent users found that marijuana vaping was associated with pronounced drug and adverse effects with the same dosage of THC. (Spindle et al., 2018) Given the convenience and potentially high prevalence of co-use with marijuana among e-cigarette users, it is imperative to investigate the interaction between these two substances through the vaping route.

Another important gap is in the short-term psychological effects of co-using e-cigarettes and marijuana. For example, although nicotine has been used for emotion regulation among cigarette and e-cigarette users, (Buu et al., 2021) it is unclear whether marijuana may promote or hinder this function when simultaneous use is involved. According to the smoking literature, cigarette-marijuana co-use may have synergistic effects on physiological sensation (Berg et al., 2018; Reboussin et al., 2021) and mood. (Kendall et al., 2022) These psychological effects, however, have not been investigated through the vaping route. Studying these effects could inform future development of just-in-time adaptive interventions (JITAIs) (Nahum-Shani et al., 2018).

This study aims to fill the knowledge gaps by conducting an EMA study on a cohort of college student e-cigarette users. Frequent marijuana users – using marijuana weekly or daily/almost daily – were compared with infrequent/non-users of marijuana in terms of academic performance, e-cigarette use patterns, and dependence and respiratory symptomatology. The EMA data from frequent marijuana users were analyzed to study e-cigarette-marijuana co-use. Three research hypotheses were examined. First, frequent marijuana users were hypothesized to adopt higher-risk use patterns and have worse outcomes, including lower GPA and greater levels of e-cigarette dependence and respiratory symptomatology than infrequent/non-users of marijuana. Second, marijuana vaping was hypothesized to be associated with higher consumption of e-cigarettes at the event level. Third, simultaneous use of e-cigarettes and marijuana captured by EMA data was hypothesized to have synergistic effects on psychological states including positive affect, negative affect, physiological sensation, and craving.

2. Method

2.1. Study sample

This study recruited 686 participants from one 4-year college campus in Indiana and two campuses in Texas, based on five inclusion criteria: (1) e-cigarette use at least once per week in the last 4 weeks; (2) no intention to quit e-cigarette use in the next 30 days; (3) 1st to 3rd year undergraduates; (4) ownership of a smartphone; and (5) using a cartridge, tank, pod mod, or new-generation disposable e-cigarette. Study flyers were distributed to the student populations through email listservs, social media, online classified advertising sites, bulletin boards, and tabling events. The recruitment period was Fall 2019-Fall 2021.

2.2. Study design & procedure

This EMA study assessed participants' e-cigarette and polysubstance use through an on-line survey and 7-day EMA via a smart phone app in each of four consecutive semesters (the longitudinal data collection spans Fall 2019-Spring 2023). The study protocol was approved by the Institutional Review Board (IRB) of the University of Texas Health Science Center at Houston (HSC-SPH-19–0391). Every eligible college student who signed up for the study was scheduled a baseline assessment during which he/she provided informed consent, filled out demographic information, completed a lifetime measure of substance use, and received a training session on EMA protocol and a payment of $20. The participant was also offered the opportunity to earn an extra $20 by providing a saliva cotinine sample. Due to public health concerns related to the COVID pandemic, some of the baseline assessments were conducted virtually and the bio-sample data collection was suspended from March 2020 to May 2022.

After the baseline assessment, an email was sent to the participant with a link to an on-line survey ($20 for participation) that measured average/typical consumption of substances and related outcomes. The survey also inquired about the student's typical wake-up time and bedtime on weekdays and weekend, which determined the individualized period of computer-initiated prompts during the 7-day EMA data collection starting on the following day. The same procedure of administering the on-line survey and EMA was repeated in the following 3 semesters. In this paper, we restricted analyses to the on-line survey and EMA data from the semester during which each student was initially recruited (i.e., Wave 1) to ensure participants were vaping at least once per week.

Three types of EMA data were collected: (1) *random prompts*, which were initiated by the study app 5 times per day throughout a participant's waking hours; (2) two *participant-initiated event reports* – one in the morning (wake-up to 1 pm) and the other in the afternoon (1–8:30 pm) – about the most recent e-cigarette use event; and (3) an *end-of-day summary report* initiated by the participant before bedtime. A reminder was generated by the app for each of the three participant-initiated reports. Participation in each assessment was rewarded with $2. To encourage high compliance, we offered an entry to win an Amazon gift card of $50 as a "bonus payment" if the participant completed more than 80 % of all EMA reports during the 7-day period. The chance of winning was 5 %.

2.3. Measures

Marijuana user groups. In the on-line survey, participants were asked about the frequency of marijuana use in the past 3 months. About 30 % identified themselves as nonusers; 34 % as infrequent users (i.e., once, twice, or monthly); and 36 % as frequent users (i.e., weekly or

daily/almost daily). Because preliminary analyses showed that the nonusers and infrequent users were similar on the academic and health outcomes of interest, we aggregated them together as a comparison group to the frequent users.

Academic and health outcomes. In the on-line survey, participants reported their GPA in the past semester and also responded to questions in the following well-validated scales: (1) the Penn State Electronic Cigarette Dependence Index (PS-ECDI (Foulds et al., 2015) for e-cigarette dependence; (2) the 6 items in Alcohol, Smoking, and Substance Involvement Screening Test (ASSIST (Group WAW, 2002) for marijuana problems; and (3) the American Thoracic Society Questionnaire (ATSQ (Comstock et al., 1979) that has a comprehensive coverage of chronic bronchitis symptoms found in adolescent e-cigarette and cigarette users. (Cassidy et al., 2015; McConnell et al., 2017).

E-cigarette use patterns and motivation to use. In the on-line survey, participants responded to a retrospective e-cigarette consumption measure about the quantity/frequency, device features, nicotine concentration, flavor, co-use, situational contexts, and reasons of use in the past 30 days, which could be associated with e-cigarette dependence. (Wong et al., 2019).

EMA measures. The following two sets of variables collected from the *random prompts* were used in the analysis: (a) their current psychological states including positive affect (excited, enthusiastic), negative affect (sad/unhappy, anxious/worried/stressed, angry/irritated), craving (thinking about vaping, want to use an e-cigarette), and physiological sensation (buzzed/dizzy) on a 7-point scale; and (b) whether they have used e-cigarettes or marijuana in the past hour (Y/N). Furthermore, we used the following items in the *participant-initiated event reports* in the analysis: the quantity of e-cigarette use (the number of puffs), the type of marijuana vaped (not use any; dried leaves/herbs; CBD-laced e-liquid; CBD wax; CBD oil; THC-laced e-liquid; THC wax; THC oil; and not sure), the flavor (tobacco, menthol, fruit, etc.), and contexts of use including where (residence, campus-outdoor, campus-indoor, car, and other), with whom (alone, with others vaping, with others smoking, with others drinking, with others not vaping/smoking/drinking).

2.4. Statistical analysis

Frequent marijuana users were compared with infrequent/non-users of marijuana to test the first hypothesis that frequent marijuana users would adopt higher-risk use patterns and have worse outcomes, including lower GPA and greater levels of e-cigarette dependence and respiratory symptomatology than infrequent/non-users of marijuana. Two-sample t tests and Chi-square tests were used to examine group differences.

EMA data from the frequent marijuana users, whose co-use events were more likely to be captured in the 7-day period, were analyzed to test the second and third hypotheses. To test the second hypothesis that marijuana vaping would be associated with higher consumption of e-cigarettes, a generalized linear mixed model (GLMM) with the log link function (Poisson) was used to model the number of puffs drawn on an e-cigarette as a function of marijuana vaping, adjusting for the effects of e-cigarette flavor, when, where, and presence of other(s). A random intercept was employed to handle the correlation among event reports within each participant. The GLMM can deal with missing assessments under the missing-at-random assumption, (Diggle et al., 2002) by weighting the contributions from participants based on data completion rates and borrowing information from other participants if an assessment was missed. The analysis was carried out using the R packages: lme4 and lmerTest. (Bates et al., 2015; Kuznetsova et al., 2017).

The third hypothesis – simultaneous use of e-cigarettes and marijuana would have synergistic effects on psychological states – was tested using data from the random prompts of EMA including e-cigarette and marijuana use within the past hour, as well as psychological states at the moment. The means of the corresponding items of psychological states were calculated as the composite scores for positive affect, negative affect, physiological sensation, and craving. Because the sample distributions of these composite scores were right-skewed, they were log-transformed. A GLMM with the identity link and a random intercept was used to model each of these log-transformed variables as a function of e-cigarette use, marijuana use, and their interaction.

3. Results

Table 1 shows the descriptive statistics of demographic background, academic performance, e-cigarette use patterns/reasons, and dependence/respiratory symptoms for the 247 frequent marijuana users and the 439 infrequent/non-users, as well as the hypothesis testing results of group differences. Compared to infrequent/non-users, the frequent users tended to be White or Black, and had lower GPA. In terms of e-cigarette use patterns, frequent users reported higher percent of time involving simultaneous use of e-cigarettes and marijuana, higher concentration of nicotine, shorter duration from waking-up to 1st puff, and lower percent of time using e-cigarettes alone. Frequent users also tended to endorse "to feel good or get high" and "hooked" as most important reasons for e-cigarette use. Furthermore, frequent users reported higher levels of e-cigarette dependence and marijuana problems. Concerning respiratory health, frequent users reported higher frequencies for 7 out of the 8 symptoms on ATSQ compared to infrequent/non-users.

Among the 247 frequent marijuana users, 207 (84 %) provided some participant-initiated event reports in EMA and were all included in the analysis. The median compliance rate was 71 % (out of 14 prompts). Table 2 depicts the results of a GLMM of the number of puffs taken from e-cigarettes as a function of marijuana vaping and use contexts. Because the log link function was employed to deal with the count outcome, the regression coefficients were exponential-transformed (i.e., incident risk ratio [IRR]) to facilitate interpretation. Preliminary analyses did not find CBD and THC products to be associated with e-cigarette consumption differently and thus marijuana vaping was treated as a binary variable. Vaping marijuana was associated with an increase in e-cigarette consumption Although e-cigarette use quantity did not differ between weekday and weekend, the quantity consumed in the morning was less than that in the afternoon. Both the menthol and fruit flavors were associated with a larger quantity of e-cigarette use. Being around other people was associated with a higher level of e-cigarette consumption. Further, being on campus or in the car was associated with an increase in e-cigarette consumption.

Among the 247 frequent marijuana users, 200 (81 %) responded to some random prompts in EMA and were all included in the analysis. The median compliance rate was 44 % (out of 35 prompts). Table 3 shows the fitted GLMM of the effects of e-cigarette and marijuana use on psychological states. The regression coefficients were also exponential-transformed to facilitate interpretation because the outcomes were log-transformed. Unlike the participant-initiated event reports that focused on marijuana vaping, the item about "marijuana use" in the random prompts did not specify the route of administration. Using e-cigarettes in the past hour was associated with higher levels of positive affect, physiological sensation, and craving for e-cigarettes. Using marijuana was also associated with higher levels of the above psychological states, as well as a lower level of negative affect. No interaction effects between e-cigarette and marijuana use were found so they were not included in the final models. On the weekend, the level of positive affect tended to be higher, whereas the level of negative affect was lower. In comparison to the morning, the level of positive affect tended to be higher in the afternoon; the levels of positive affect, physiological sensation, and craving were all higher in the evening.

4. Discussion

This is the first EMA study that examined the vaping route of nicotine and marijuana co-use, as well as the short-term psychological effects of

Table 1
The differences between e-cigarette using college students who used marijuana frequently and those who did not.

Variables	% or mean (standard deviation) Frequent marijuana users [a] (N = 247)	Infrequent/non–users (N = 439)	p-value
Demographics & academic performance			
Age	19.70 (1.37)	19.89 (1.34)	0.068
Male	46.2 %	50.3 %	0.330
Race: White	74.1 %	67.7 %	0.038
Black	6.5 %	3.9 %	
Asian	12.6 %	19.4 %	
Other race	6.9 %	9.1 %	
Hispanic	12.6 %	12.8 %	1.000
GPA	3.39 (0.46)	3.47 (0.42)	0.016
E-cigarette use patterns in past 30 days			
Number of days vaping	25.01 (7.69)	25.17 (7.17)	0.788
Number of times vaping per day	1.57 (0.73)	1.53 (0.72)	0.508
% time simultaneously using e-cigarettes & marijuana	37.74 (30.07)	4.14 (12.02)	<0.001
Using pod (instead of tank or cartridge)	79.8 %	83.3 %	0.300
Concentration level of nicotine (mg/ml)	48.93 (13.01)	45.42 (15.50)	0.006
Using tobacco flavor	6.9 %	9.1 %	0.396
Using menthol flavor	71.3 %	68.6 %	0.526
Using fruit flavor	59.9 %	59.3 %	0.939
Number of minutes to 1st puff after waking up	30.51 (28.22)	36.95 (30.01)	0.006
Percent of e-cigarette use alone	47.11 (25.40)	53.51 (26.42)	0.002
How difficult to refrain in forbidden places (1–5)	2.58 (1.18)	2.58 (1.15)	0.961
Dollars spent on e-liquid/cartridge	56.07 (45.12)	64.83 (77.26)	0.104
Most important reasons for e-cigarette use			
To help quitting regular cigarette	4.9 %	6.0 %	0.636
Regular cigarette use is not permitted	2.8 %	5.8 %	0.116
To have good time with friends	43.7 %	44.4 %	0.925
To relax or relieve tension	68.4 %	65.3 %	0.465
Look cool	9.7 %	15.6 %	0.042
Boredom, nothing else to do	40.9 %	39.8 %	0.837
Tastes good	32.8 %	35.1 %	0.597
To experiment, to see what it's like	14.6 %	21.6 %	0.032
To feel good or get high	39.3 %	30.2 %	0.021
Hooked	50.2 %	41.2 %	0.028
Dependence symptoms			
PS-ECDI (e-cigarette dependence)	10.15 (4.83)	9.17 (4.94)	0.013
ASSIST (marijuana problems)	17.76 (7.84)	3.45 (4.36)	<0.001
Respiratory symptoms (1–5)			
Coughing first thing in the morning	1.74 (0.99)	1.58 (0.83)	0.020
Cough frequently throughout the day	2.13 (1.11)	1.91 (0.98)	0.008
Wheezing	1.41 (0.81)	1.28 (0.60)	0.017
Shortness of breath when walking	1.80 (1.02)	1.77 (1.00)	0.756
Shortness of breath exercise/walking upstairs	2.31 (1.25)	2.12 (1.15)	0.050
Phlegm/mucous when coughing	1.81 (1.11)	1.41 (0.80)	<0.001
Pain or tightness in the chest	1.69 (0.89)	1.55 (0.81)	0.037
Get very tired in a short time	2.22 (1.19)	1.92 (1.14)	0.002

[a] E-cigarette users who reported using marijuana weekly or daily/almost daily.

each substance and their interactions. Consistent with the first hypothesis, the results show that e-cigarette users who frequently used marijuana tended to have lower academic performance, be involved in higher-risk use patterns (e.g., simultaneous use), and have more severe symptomatology including e-cigarette dependence, marijuana problems, and respiratory symptoms. The finding that marijuana vaping

Table 2
Generalized linear mixed model with the log link function (Poisson) for examining the association of marijuana vaping and contexts with the number of puffs taken during vaping events among e-cigarette users who used marijuana weekly or daily/almost daily (N = 207).

	Coefficient (Standard error)	Incident risk ratio (IRR)	*p*-value
Intercept	1.708 (0.062)	5.517	<0.001
Marijuana vaping	0.069 (0.028)	1.071	0.013
When			
Day (1–7)	0.017 (0.004)	1.017	<0.001
Weekend	−0.006 (0.017)	0.994	0.710
Morning (reference: afternoon)	−0.746 (0.019)	0.474	<0.001
Flavor			
Tobacco flavor	−0.178 (0.100)	0.837	0.074
Menthol flavor	0.244 (0.042)	1.276	<0.001
Fruit flavor	0.195 (0.032)	1.215	<0.001
Company (reference: alone)			
With others not using tobacco/alcohol	0.135 (0.035)	1.145	<0.001
With others vaping/smoking/drinking	0.263 (0.022)	1.301	<0.001
Where (reference: residence)			
Campus – outdoor	0.131 (0.041)	1.140	0.001
Campus – indoor	0.151 (0.047)	1.163	0.001
Car	0.140 (0.034)	1.150	<0.001
Other places	−0.179 (0.049)	0.836	<0.001

Note: This set of analysis was based on the participant-initiated event reports (in the morning and afternoon) in the EMA data.

was associated with higher e-cigarette consumption was also consistent with the second hypothesis. Although our results showed *additive effects* of e-cigarette and marijuana use on positive affect, physiological sensation, and craving, the insignificant interaction effects did not support the hypothesized *synergistic effects* of the two substances (the third hypothesis). This finding based on more fine-grained EMA data has contributed to the co-use literature because of our focus on simultaneous use that is different from concurrent use usually investigated in survey research. (Berg et al., 2018; Reboussin et al., 2021) Although a recent EMA study examined the effect of simultaneous use of marijuana on nicotine-related mood boost, that was a study on combustible cigarettes. (Kendall et al., 2022) Thus, the contribution of the present study is unique.

The results based on EMA data from the frequent marijuana users suggest that marijuana use may potentially have *short-term* promoting effects on not only the quantity of e-cigarette use but also the level of craving for e-cigarettes. This frequent user group may also have *long-term* health consequences including medium e-cigarette dependence and moderate risk of marijuana-associated problems. Importantly, at this young age, they already experienced almost all the chronic bronchitis symptoms more frequently than the infrequent/non-users of marijuana. Such a group difference in respiratory symptoms is unlikely to stem from the potential confounding effect of cigarette smoking, as the two marijuana user groups were not different on the percentage of current smokers (13 % vs 13 %, $p \gg 0.05$) or the percentage of endorsing quitting regular cigarettes as the most important reason for e-cigarette use (4.9 % vs 6.0 %, $p \gg 0.05$). Vaping devices have served as a convenient tool for simultaneous use of e-cigarettes and marijuana, which has been linked to respiratory conditions. (Stratton et al., 2018) In fact, the outbreak of the e-cigarette, or vaping, product use-associated lung illness (EVALI) in early 2020 was connected to an additive, vitamin E acetate, in illicit THC-containing vaping products. (Bonner et al., 2021) Although law enforcement had seized relevant products in the black market, the states that have legalized marijuana should consider restricting such additives

Table 3
Generalized linear mixed models (with log-transformed outcomes) for examining the effects of e-cigarette use and marijuana use on psychological states among e-cigarette users who used marijuana weekly or daily/almost daily (N = 200).

	Positive affect		Negative affect		Physiological sensation		Craving	
	β(se)	exp(β)	β(se)	exp(β)	β(se)	exp(β)	β(se)	exp(β)
Intercept	0.820	2.271***	0.675	1.965***	0.296	1.345***	0.808	2.242***
	(0.037)		(0.034)		(0.037)		(0.039)	
Substance use[a]								
Using	0.181	1.198***	0.013	1.013	0.158	1.171***	0.201	1.222***
e-cigarette	(0.019)		(0.018)		(0.021)		(0.021)	
Using marijuana[b]	0.167	1.181***	−0.079	0.924***	0.249	1.282***	0.065	1.067**
	(0.021)		(0.02)		(0.024)		(0.023)	
When								
Day (1–7)	−0.012	0.988**	−0.003	0.997	−0.015	0.986***	−0.017	0.983***
	(0.004)		(0.004)		(0.004)		(0.004)	
Weekend	0.040	1.041*	−0.042	0.959**	0.009	1.009	0.003	1.003
	(0.016)		(0.015)		(0.018)		(0.017)	
Afternoon[c]	0.120	1.127***	−0.003	0.997	−0.026	0.975	0.036	1.037
	(0.019)		(0.018)		(0.022)		(0.021)	
Evening[c]	0.114	1.121***	−0.026	0.974	0.046	1.047*	0.063	1.065**
	(0.020)		(0.018)		(0.022)		(0.021)	

Note: This set of analysis was based on the random prompts in the EMA data.
[a] None of the interaction effects of e-cigarette and marijuana use were significant so they were not included in the models.
[b] The item about "marijuana use" in the random prompts did not specify the route of administration.
[c] The reference is morning.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

in THC-containing vaping products. Furthermore, given that more states have legalized marijuana and the perceived risk of marijuana use has been declining among young adults in recent years, (Schulenberg et al., 2021) health messages targeting this population is needed to raise awareness of potential risks found in this study including poor academic performance, addiction, and respiratory symptomatology.

Findings from our EMA data indicate that college student e-cigarette users who used marijuana frequently tended to consume more e-cigarettes on campus, in a car (compared to residence), and when others were around including nonusers. Although the universities where we recruited our study participants have all implemented tobacco-free policies, such policies may not be effective towards this high-risk group who tended to be rule-breakers. In fact, a prior study has shown that around half of college student e-cigarette users stealth vaped (i.e., discrete use of e-cigarettes in places where the use is known to be prohibited) on campus in past 30 days. (Russell et al., 2022) These stealth vapers engaged in special techniques such as deep inhale, blowing a hit into one's clothes, and swallowing a hit that are harder to be detected. (Russell et al., 2022) These use patterns in social contexts may pose a health risk to not only themselves but also others exposed to secondhand aerosol, which seems to be "invisible" and yet contains ultrafine particles that are easier to enter into the secondhand vaper's deep lung. (Su et al., 2021).

Analyses of our EMA data also reveal that although the tobacco flavor was not associated with higher consumption of e-cigarettes, the menthol or fruit flavors were. This is consistent with the result of a prior study showing that the menthol or fruit flavors may lessen bitterness and harshness of nicotine and e-cigarette aerosol. (Leventhal et al., 2020) The U.S. FDA has implemented a policy to ban flavors except for menthol and tobacco in tank- and cartridge-based e-cigarettes. The agency has also been discussing about the possibility of further regulating the menthol flavor. Our study has provided empirical evidence to support such a change in policies.

This study has limitations. First, the online survey and EMA data were self-reported and thus were subject to biases. Furthermore, given that the online survey collected retrospective reports of average/typical use patterns and potential consequences and the participant-initiated event report in EMA inquired about the use pattens and contexts in *the most recent event*, the resulting data cannot establish the temporal ordering (e.g., whether marijuana use affected e-cigarette use or the other way around) and thus the results in Tables 1-2 can only be used to infer associations. Nevertheless, the random prompts in EMA asked the participants about their *current* psychological states (i.e., real-time) and e-cigarette or marijuana use *in the past hour*, so the temporal ordering of substance use and psychological states can be established through this set of analysis. Hence, the short-term effects of substance use on psychological states can be inferred from the results in Table 3. Second, the participant-initiated event reports did not quantify marijuana use because of the challenge of measuring and equating the concentration/quantity across different vaping products. Third, although our study sites covered both urban and rural settings, the findings may not be generalizable to the entire college student population in the U.S. Fourth, the COVID pandemic may have negatively impacted the compliance of EMA. Thus, the findings may need to be further verified during an ordinary period.

Despite the above limitations, this study has made a unique contribution to the literature by conducting the first EMA study to demonstrate the potential promoting effect of simultaneous use of marijuana on e-cigarette consumption, as well as the short-term psychological effects of e-cigarette and marijuana use. The EMA data also made it possible to identify important contexts in which higher e-cigarette consumption is likely to occur. Further, this study found possible negative consequences of frequent co-use of e-cigarettes and marijuana including poor academic performance and more severe symptomatology. These use contexts and potential effects may be targeted for future health messages.

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Contributors

Buu, Yang, and Lin conceived the study and drafted the manuscript. Buu and Lin secured the grant funding. Ou, Nam, and Suh conducted data collection and literature review. Yang conducted statistical analysis. All authors contributed to and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data will be deposited to ICPSR after the study is completed

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