

# **Real-time antecedents of young adults' vaping and co-vaping of nicotine and cannabis**

Vuong Van Do, Pamela May Ling, Salomeh Keyhani, Gregory M Marcus,  
Johannes Thrul, Nhung Nguyen

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# Real-time antecedents of young adults' vaping and co-vaping of nicotine and cannabis

Vuong Van Do<sup>1</sup> PhD; Pamela May Ling<sup>1</sup> MD, MPH; Salomeh Keyhani<sup>2</sup> MD; Gregory M Marcus<sup>3</sup> MD, MAS; Johannes Thrul<sup>4</sup> PhD; Nhung Nguyen<sup>1</sup> PhD

<sup>1</sup> Center for Tobacco Control Research and Education University of California, San Francisco San Francisco US

<sup>2</sup> Center for Data to Discovery and Delivery Innovation (3DI) San Francisco VA Health Care System San Francisco US

<sup>3</sup> Department of Medicine Division of Cardiology University of California, San Francisco San Francisco US

<sup>4</sup> Department of Mental Health Bloomberg School of Public Health Johns Hopkins University Baltimore US

## Corresponding Author:

Nhung Nguyen PhD

Center for Tobacco Control Research and Education  
University of California, San Francisco  
530 Parnassus Avenue Suite 366  
San Francisco  
US

## Abstract

**Background:** Nicotine and cannabis vaping are common among young adults, potentially leading to adverse health consequences. Identifying real-time antecedents of vaping events may provide insights into intervention targets pertinent to these behaviors.

**Objective:** This study aimed to examine real-time antecedents of nicotine and cannabis vaping and same-moment co-vaping among young adults.

**Methods:** We collected ecological momentary assessments (EMAs) via smartphone app among California young adults (ages 18-29) in 2023-2024. Participants completed four random prompts each day for 30 days. Outcomes were defined as whether participants reported being about to vape nicotine, cannabis, or both substances (same-occasion co-vaping) in a given EMA. We used mixed-effects logistic regression models to examine real-time antecedents of each outcome.

**Results:** Overall, 113 participants (mean age 23.8 years, 63% female) completed 9,001 EMAs. Similar antecedents of all three vaping outcomes were craving and using alcohol. Increased cravings for a given substance were associated with a higher likelihood of vaping that substance or co-vaping. Craving for cannabis vaping was associated with lower odds of reporting nicotine vaping. Feeling happier was associated with higher odds of reporting co-vaping while feeling more stressed was associated with lower odds of vaping nicotine or cannabis. Seeing tobacco advertisements was associated with higher odds of vaping nicotine and co-vaping. Cannabis vaping and co-vaping were more likely to occur in the afternoon and nighttime than in the morning.

**Conclusions:** We found similar antecedents (craving, alcohol use) and unique antecedents (mood, advertising exposure, and time of day) for nicotine vaping, cannabis vaping, and same-occasion co-vaping, suggesting targets for future vaping cessation interventions.

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## Original Manuscript

## **Real-time antecedents of young adults' vaping and co-vaping of nicotine and cannabis**



## ABSTRACT

**Background:** Nicotine and cannabis vaping are common among young adults, potentially leading to adverse health consequences. Identifying real-time antecedents of vaping events may provide insights into intervention targets pertinent to these behaviors. This study aimed to examine real-time antecedents of nicotine and cannabis vaping and same-moment co-vaping among young adults.

**Methods:** We collected ecological momentary assessments (EMAs) via smartphone app among California young adults (ages 18-29) in 2023-2024. Participants completed four random prompts each day for 30 days. Outcomes were defined as whether participants reported being about to vape nicotine, cannabis, or both substances (same-occasion co-vaping) in a given EMA. We used mixed-effects logistic regression models to examine real-time antecedents of each outcome.

**Results:** Overall, 113 participants (mean age 23.8 years, 63% female) completed 9,001 EMAs. Similar antecedents of all three vaping outcomes were craving and using alcohol. Increased cravings for a given substance were associated with a higher likelihood of vaping that substance or co-vaping. Craving for cannabis vaping was associated with lower odds of reporting nicotine vaping. Feeling happier was associated with higher odds of reporting co-vaping while feeling more stressed was associated with lower odds of vaping nicotine or cannabis. Seeing tobacco advertisements was associated with higher odds of vaping nicotine and co-vaping. Cannabis vaping and co-vaping were more likely to occur in the afternoon and nighttime than in the morning.

**Conclusions:** We found similar antecedents (craving, alcohol use) and unique antecedents (mood, advertising exposure, and time of day) for nicotine vaping, cannabis vaping, and same-occasion co-vaping, suggesting targets for future vaping cessation interventions.

**Keywords:** nicotine vaping, cannabis, marijuana, tobacco, co-use, mHealth



## INTRODUCTION

Using vaporizers to vape nicotine and cannabis (vaping) is common among U.S. young adults (18-29 years old), with 24.1% reporting vaping nicotine and 12.6% reporting vaping cannabis in the past month in 2023 [1]. Co-use of both substances is also common, with 54.6% of young adults who vape nicotine also vaping cannabis [2]. While the long-term effects of vaping are not yet fully understood, evolving evidence has shown that vaping nicotine and cannabis exposes users to toxic chemicals (e.g., propylene glycol, aldehydes, acrolein) that may increase the risk for respiratory and cardiovascular diseases [3-5]. Young adulthood is a critical period for intervention since this developmental period includes transitions from substance use experimentation to established use [6, 7]. Of young people who vape nicotine, over half desire to quit [8]. However, vaping cessation interventions for this population are still scarce.

Young adult vaping exhibits complex behavioral patterns. Young adults may engage in nicotine and cannabis vaping by using each substance on separate days within the same month (same-month co-vaping or single-substance vaping), using both substances on the same day (same-day co-vaping), or using both on the same occasion (same-occasion co-vaping) [9]. Closer temporal proximity of co-vaping was associated with greater intensities of vaping nicotine and cannabis [10], with the pattern of same-occasion co-vaping having the highest vaping consumption compared to other patterns. Understanding predictors of different vaping patterns is critical to informing interventions curbing nicotine and cannabis vaping.

Ecological Momentary Assessment (EMA) has been established as a data collection method to capture fine-grained information on vaping behaviors in daily life [11]. EMA uses mobile devices to repeatedly assess a targeted behavior as it occurs in naturalistic settings. It has been used successfully to investigate antecedents of substance use behaviors while reducing

recall bias and improving ecological validity. This data collection method is ideal for examining subjective and contextual factors that trigger nicotine and cannabis vaping in real-time that could not be captured by using traditional data collection methods [12, 13]. Several EMA studies have examined different behaviors of using tobacco (e.g., exclusive e-cigarette use, exclusive cigarette use, and dual tobacco use) and cannabis among young adults [14-17]. However, it is unclear whether real-time antecedents differ between nicotine and cannabis vaping and less is known about real-time antecedents of same-occasion co-vaping.

To address this gap, we aimed to examine real-time antecedents of nicotine and cannabis vaping and same-moment co-vaping among young adults. Such data might inform the development of interventions to reduce nicotine and cannabis vaping and related harms in this population, such as Just-In-Time Adaptive Intervention (JITAI) which delivers personalized and adaptive supports tailored to antecedents at moments when there is a high likelihood of vaping occurrence.

## **METHODS**

### **Design & Procedures**

The study was conducted in California during June 2023 – January 2024. Details about study design and participant recruitment have been reported elsewhere [10]. Briefly, participants completed an online survey via Qualtrics that asked about their demographics, substance use history, current vaping behaviors, and other characteristics (e.g., perceptions of vaping) at baseline. Participants downloaded the study app to their own smartphones and were guided on using the app to collect EMAs for a 30-day period. Each day, participants were prompted by the study app to complete four random surveys during waking hours and were asked to report

substance vaping at that specific moment. Each EMA required 2-3 minutes to complete and was available only for 30 minutes. All responses were time and date-stamped to allow for a time-specific analysis. To maximize participants' compliance with EMAs, incentives were tied to completed EMA surveys, with higher incentives for better compliance, ranging from \$0 to \$120 gift cards. Those who completed more than 80% of surveys received a bonus incentive of \$60.

## **Participants**

Participants were recruited through Instagram. The advertisement contained a link to the study's screener. Eligible participants were 18-29 years of age, resided in California, owned a smartphone, reported vaping either nicotine or cannabis at least 20 days during the past month, and intended to quit vaping either nicotine or cannabis in the next 6 months. Electronic informed consent was obtained on the study's website. Eligible participants were required to send a picture of their ID to verify their identity. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

## **Measures**

### ***Outcome variables***

We examined three binary vaping outcomes, including momentary nicotine vaping, momentary cannabis vaping, and momentary co-vaping of both nicotine and cannabis on the same occasion. These outcomes were derived from participants' responses to the questions about vaping behaviors in each EMA (e.g., "Are you about to vape right now [yes, no]?" ; If answering "yes," then being asked "What type of vapes? [nicotine, cannabis]"). EMAs that reported both nicotine and cannabis vaping were categorized as same-occasion co-vaping, while those reporting no vaping or single-substance vaping were classified as no same-occasion co-use.

### ***Independent variables***

Based on the extant literature on young adult vaping [15, 17, 18], we developed items capturing vaping antecedents. Each EMA asked about both subjective and contextual factors of the situation the participant was in at the time of the survey. Subjective factors included craving and mood. Nicotine and cannabis cravings were measured by asking participants, “*How strong is your urge to vape nicotine/cannabis?*” with the response option on a Likert scale from 0 (not at all) to 6 (very high). Participants’ moods were measured by four separate questions, including stressed, energized, happy, and focused levels (e.g., “*Right now, how [happy, stressed, focused, energized] do you feel?*”). The response for each item ranged from 0-Not at all to 10-Extremely.

Contextual factors included alcohol consumption (yes/no), the presence of specific triggers (e.g., seeing a nicotine/cannabis vaping product or advertisement), time of the day (i.e., morning: 5 am – 12 noon; afternoon: 12 noon – 6 pm; and evening/night: 6 pm – 5 am), and day of the week (weekend vs. weekday). In addition, participants were asked about the presence of other people, and the responses were categorized as alone, with roommate(s)/friend(s), partner, family, and multiple types of people or acquaintances.

### **Baseline characteristics**

Data on demographics included age, biological sex, gender, race/ethnicity, marital status, and educational attainment. In addition, e-cigarette dependence was measured using the Penn State Electronic Cigarette Dependence Index, and the total dependence score (ranging from 0-13) was treated as a continuous variable [19]. Cannabis use disorder was assessed using the short form of the Cannabis Use Disorder Identification Test-Revised (CUDIT-R), with a cutoff score of 13 or greater being categorized as having cannabis use disorder [20].

### **Statistical analysis**

Descriptive statistics were summarized for the vaping outcomes, use of other tobacco and

cannabis products, and other characteristics. Based on previous EMA studies [21, 22] and recommended analytic methods for EMAs [25], we used generalized linear mixed-effects models (GLMMs) to examine real-time antecedents of the vaping outcomes, accounting for repeated EMAs nested within a participant. Separate GLMMs with a logistic link function were used to examine predictors for each of the binary outcomes (i.e., nicotine vaping, cannabis vaping, and same-occasion co-vaping of both substances). Models included random effects for subjects and fixed effects for predictors. All variables were included simultaneously in the models. Baseline covariates, including demographic variables, e-cigarette dependence, and cannabis use disorder were also controlled in the models. We conducted sensitivity analyses among participants who had a compliance rate of at least 75% to assess the robustness of the main findings. All tests were two-tailed with a significance level of  $\alpha$  less than 0.05. Statistical analyses were performed using Stata version 18 (College Station, TX).

## RESULTS

### Sample characteristics

The baseline characteristics of the 113 participants are shown in **Table 1**. The majority were female, single, and had an education attainment of college or higher. Participants had diverse racial and ethnic backgrounds and gender identities. The average e-cigarette dependence score was  $10 \pm 5$ , and most participants met the criteria for cannabis use disorder.

Table 1. Study participant characteristics at baseline survey (n=113)

| Demographic characteristics    | Frequency (%) |
|--------------------------------|---------------|
| Age, mean [SD]                 | 23.8 [3.0]    |
| Sex assigned at birth (Female) | 70 (63)       |
| Gender identity                |               |
| <i>Straight</i>                | 63 (56)       |
| <i>Bisexual</i>                | 31 (27)       |
| <i>Gay or Lesbian</i>          | 11 (10)       |
| <i>Other</i>                   | 8 (7)         |

|                                                         |            |
|---------------------------------------------------------|------------|
| <b>Marital status</b>                                   |            |
| <i>Married/living with partner</i>                      | 34 (30)    |
| <i>Never married</i>                                    | 79 (70)    |
| <b>Race/ethnicity</b>                                   |            |
| <i>NH-Asian</i>                                         | 29 (26)    |
| <i>NH-Black</i>                                         | 3 (3)      |
| <i>Hispanic</i>                                         | 33 (29)    |
| <i>NH-White</i>                                         | 35 (31)    |
| <i>NH- Other/Multi-races</i>                            | 13 (11)    |
| <b>Education</b>                                        |            |
| <i>Less than high school</i>                            | 5 (5)      |
| <i>Completed high school</i>                            | 15 (13)    |
| <i>Some college – no degree or associate degree</i>     | 50 (44)    |
| <i>Completed bachelor's degree or higher</i>            | 43 (38)    |
| <b>E-cigarette dependence index/PS-score, mean [SD]</b> | 10.1 [4.8] |
| <b>Cannabis use disorder</b>                            | 89 (79)    |

SD: Standard Deviation; PS-core: Penn State Electronic Cigarette Dependence Index.

### Ecological momentary assessments of vaping behaviors and real-time factors

A total of 9,001 EMAs (out of 13,560 EMAs) were completed by the participants (**Table 2**) for an average compliance of 66.4%. Nicotine vaping was reported in 35.8% of the total assessments, cannabis vaping was reported in 9.3%, and same-occasion co-vaping of nicotine and cannabis in 6.3%.

In almost half of the assessments (49.1%) participants were alone, followed by being with a partner (16.3%), multiple people or someone else (16.3%), family (9.4%), and roommates/friends (8.6%). Participants reported seeing tobacco products in 10.2% and tobacco advertisements in 1.4% of the assessments, while proportions for seeing cannabis products and advertisements were 7.1% and 1.3%, respectively. Alcohol use was reported in 4.5% of the assessments.

Among 65 participants (57.5% of the total sample) who had an EMA compliance rate of 75% or greater, 6,563 EMAs were completed (average compliance of 84%), which included nicotine vaping being reported in 2,481 assessments (37.8%), cannabis vaping in 546 assessments (8.3%), and same-occasion co-vaping in 418 assessments (6.4%). The distribution of

real-time antecedents was slightly different compared to those among the entire sample.

Table 2. Distribution of vaping outcomes and real-time predictors reported in EMA during the study time

| Real-time variables                                                 | All observations<br>(n=9,001) | Compliance rate<br>≥75% (n=6,563) |
|---------------------------------------------------------------------|-------------------------------|-----------------------------------|
| Outcomes                                                            | N (%)                         | N (%)                             |
| Nicotine vaping                                                     | 3,225 (35.8)                  | 2,481 (37.8)                      |
| Cannabis vaping                                                     | 839 (9.3)                     | 546 (8.3)                         |
| Same-occasion co-vaping (vaping both substances at the same moment) | 570 (6.3)                     | 418 (6.4)                         |
| Real-time predictors                                                |                               |                                   |
| Present of people                                                   |                               |                                   |
| <i>Someone else or multiple people</i>                              | 1,466 (16.3)                  | 1,125 (17.1)                      |
| <i>Alone</i>                                                        | 4,421 (49.1)                  | 3,107 (47.3)                      |
| <i>Roommate/Friend</i>                                              | 774 (8.6)                     | 509 (7.8)                         |
| <i>Partner</i>                                                      | 1,491 (16.6)                  | 1,175 (17.9)                      |
| <i>Family</i>                                                       | 849 (9.4)                     | 647 (9.9)                         |
| Product advertisement exposure                                      |                               |                                   |
| <i>Seeing tobacco products</i>                                      | 922 (10.2)                    | 580 (8.8)                         |
| <i>Seeing tobacco advertisement</i>                                 | 129 (1.4)                     | 96 (1.5)                          |
| <i>Seeing cannabis products</i>                                     | 638 (7.1)                     | 284 (4.3)                         |
| <i>Seeing cannabis advertisement</i>                                | 115 (1.3)                     | 73 (1.1)                          |
| Alcohol use                                                         | 407 (4.5)                     | 271 (4.1)                         |
| Time of the day                                                     |                               |                                   |
| <i>Morning (5 am - 12 noon)</i>                                     | 2,114 (23.5)                  | 1,565 (23.9)                      |
| <i>Afternoon (12 noon - 6 pm)</i>                                   | 4,584 (50.9)                  | 3,356 (51.1)                      |
| <i>Evening/night (6 pm- 5 am)</i>                                   | 2,303 (25.6)                  | 1,642 (25.0)                      |
| Weekday (vs. weekend)                                               | 6,587 (73.2)                  | 4,807 (73.2)                      |
| Mood (0-10) <sup>a</sup> : mean [SD]                                |                               |                                   |
| <i>Feeling happy</i>                                                | 5.9 [2.2]                     | 6.1 [2.1]                         |
| <i>Feeling stressed</i>                                             | 3.6 [2.6]                     | 3.4 [2.6]                         |
| <i>Feeling focused</i>                                              | 5.2 [2.2]                     | 5.4 [2.2]                         |
| <i>Feeling energized</i>                                            | 5.3 [2.2]                     | 5.6 [2.2]                         |
| Craving for nicotine (0-6) <sup>b</sup> : mean [SD]                 | 2.9 [1.9]                     | 3.0 [1.9]                         |
| Craving for cannabis (0-6) <sup>b</sup> : mean [SD]                 | 1.7 [1.9]                     | 1.6 [1.9]                         |

<sup>a</sup> The scale for each emotional feeling ranged from 0-Not at all to 10-Extremely.

<sup>b</sup> Craving score ranged from 0-Not at all to 6-Very high

### Real-time antecedents of nicotine vaping

Nicotine craving was positively associated with the odds of vaping nicotine, whereas, craving for cannabis was negatively associated with vaping nicotine (adjusted odds ratio [AOR] =0.87, 95% CI: 0.82-0.92) (**Table 3**). Feeling stressed (AOR=0.95, 95% CI: 0.91-0.98) and energized (AOR=0.93, 95% CI: 0.88-0.98) were negatively associated with the likelihood of

vaping nicotine. Participants were more likely to vape nicotine when being alone (AOR=2.81, 95% confidence interval [CI]: 2.27-3.46) or with roommates/friends (AOR=2.06, 95% CI: 1.55-2.72) or a partner (AOR=2.98, 95% CI: 2.32-3.82) compared to being with multiple types of people or acquaintances (Table 3). Seeing tobacco products (AOR=6.56, 95% CI: 5.01-8.59) and tobacco advertisements (AOR=3.09, 95% CI: 1.48-6.46) increased the odds of vaping nicotine. Alcohol use was associated with higher odds of vaping nicotine (AOR=1.55, 95% CI: 1.13-2.12). Participants tended to vape nicotine more on weekends than on weekdays (AOR=1.25, 95% CI: 1.09-1.45), but the time of the day was not associated with vaping nicotine.

Table 3. Factors associated with momentary nicotine vaping behaviors among young adults

| Real-time Factors                        | All observations (n=8,911)      |                                 |                                             |
|------------------------------------------|---------------------------------|---------------------------------|---------------------------------------------|
|                                          | Nicotine Vaping<br>AOR (95% CI) | Cannabis Vaping<br>AOR (95% CI) | Same Occasion Co-<br>Vaping<br>AOR (95% CI) |
| <b>Mood <sup>a</sup></b>                 |                                 |                                 |                                             |
| <i>Feeling happy</i>                     | 1.02 (0.96-1.08)                | 1.07 (0.98-1.15)                | <b>1.13 (1.01-1.27)*</b>                    |
| <i>Feeling stressed</i>                  | <b>0.95 (0.91-0.98)**</b>       | <b>0.91 (0.86-0.97)**</b>       | <b>0.89 (0.82-0.97)**</b>                   |
| <i>Feeling focused</i>                   | 1.03 (0.99-1.09)                | 1.00 (0.94-1.08)                | 1.01 (0.92-1.11)                            |
| <i>Feeling energized</i>                 | <b>0.93 (0.88-0.98)*</b>        | 1.00 (0.93-1.08)                | 0.93 (0.84-1.03)                            |
| <b>Craving for nicotine <sup>b</sup></b> | <b>2.38 (2.25-2.53)***</b>      | 0.96 (0.87-1.05)                | <b>1.22 (1.07-1.38)**</b>                   |
| <b>Craving for cannabis <sup>b</sup></b> | <b>0.87 (0.82-0.92)***</b>      | <b>2.33 (2.15-2.53)***</b>      | <b>2.21 (1.98-2.47)***</b>                  |
| <b>Present of people</b>                 |                                 |                                 |                                             |
| <i>Someone else or multiple people</i>   | REF                             | REF                             | REF                                         |
| <i>Alone</i>                             | <b>2.81 (2.27-3.46)***</b>      | <b>2.24 (1.59-3.16)***</b>      | <b>1.65 (1.06-2.56)*</b>                    |
| <i>Roommate/Friend</i>                   | <b>2.06 (1.55-2.72)***</b>      | <b>1.97 (1.24-3.12)**</b>       | <b>2.35 (1.28-4.29)**</b>                   |
| <i>Partner</i>                           | <b>2.98 (2.32-3.82)***</b>      | <b>2.29 (1.53-3.44)***</b>      | <b>1.71 (1.02-2.86)*</b>                    |
| <i>Family</i>                            | 0.97 (0.73-1.31)                | 1.04 (0.63-1.72)                | 1.21 (0.66-2.23)                            |
| <b>Product/advertisement exposure</b>    |                                 |                                 |                                             |
| <i>Seeing tobacco products</i>           | <b>6.56 (5.01-8.59)***</b>      | <b>1.50 (1.03-2.20)*</b>        | <b>1.72 (1.01-2.93)*</b>                    |
| <i>Seeing tobacco advertisement</i>      | <b>3.09 (1.48-6.46)**</b>       | 1.64 (0.62-4.33)                | <b>4.15 (1.18-14.52)*</b>                   |
| <i>Seeing cannabis products</i>          | 0.86 (0.61-1.21)                | <b>3.68 (2.58-5.25)***</b>      | <b>3.90 (2.29-6.68)***</b>                  |
| <i>Seeing cannabis advertisement</i>     | 0.97 (0.45-2.11)                | 0.81 (0.37-1.77)                | 0.72 (0.27-1.93)                            |
| <b>Alcohol use (Yes vs. No)</b>          | <b>1.55 (1.13-2.12)**</b>       | <b>1.87 (1.24-2.80)**</b>       | <b>2.25 (1.40-3.62)**</b>                   |
| <b>Time of day</b>                       |                                 |                                 |                                             |
| <i>Morning (5 am - 12 noon)</i>          | REF                             | REF                             | REF                                         |

|                                   |                           |                            |                           |
|-----------------------------------|---------------------------|----------------------------|---------------------------|
| <i>Afternoon (12 noon - 6 pm)</i> | 1.04 (0.89-1.22)          | <b>1.52 (1.16-1.98)**</b>  | <b>1.59 (1.14-2.22)**</b> |
| <i>Evening/night (6 pm- 5 am)</i> | 1.16 (0.96-1.40)          | <b>1.95 (1.45-2.63)***</b> | <b>1.84 (1.26-2.71)**</b> |
| <b>Weekend vs. weekday</b>        | <b>1.25 (1.09-1.45)**</b> | 0.92 (0.74-1.15)           | 0.86 (0.65-1.13)          |

AOR: Adjusted odds ratio; CI: Confidence interval; REF: Reference; \* P<0.05, \*\* P<0.01, \*\*\* P<0.001

All models were controlled for study day (1-30) and baseline covariates, including age (years), biological sex (male vs. female), gender (non-straight vs. straight), cannabis use disorder, e-cigarette dependence score, race/ethnicity (NH-White, Hispanic, and NH-Other), and education levels

<sup>a</sup> The scale for each emotional feeling ranged from 0-Not at all to 10-Extremely.

<sup>b</sup> Craving score ranged from 0-Not at all to 6-Very high

### Real-time antecedents of cannabis vaping

Craving for cannabis was a significant antecedent (AOR=2.33, 95% CI: 2.15-2.53) of cannabis vaping. Regarding mood, participants were less likely to vape cannabis as they felt more stressed (AOR=0.91, 95% CI: 0.86-0.97). Participants were more likely to report cannabis vaping when they were alone (AOR=2.24, 95% CI: 1.59-3.16), with a roommate(s)/friend(s) (AOR=1.97, 95% CI: 1.24-3.12) or a partner (AOR=2.29, 95% CI: 1.53-3.44) compared to being with other people. Seeing tobacco products (AOR=1.50, 95% CI: 1.03-2.20), seeing cannabis products (AOR=3.68, 95% CI: 2.58-5.25), and alcohol use (AOR=1.87, 95% CI: 1.24-2.80) were also significant antecedents of cannabis vaping. Participants were more likely to vape cannabis in the afternoon (AOR=1.52, 95% CI: 1.16-1.98) and in the evening (AOR=1.95, 95% CI: 1.45-2.63) compared to the morning, but there was no statistically significant difference between weekdays and weekends.

### Real-time antecedents of same-occasion co-vaping of nicotine and cannabis

Both cravings for nicotine (AOR=1.22, 95% CI: 1.07-1.38) and cannabis (AOR=2.21, 95% CI: 1.98-2.47) were associated with higher increased odds of co-vaping. The higher levels of feeling happy were positively associated with co-vaping (AOR= 1.13, 95% CI: 1.01-1.27), while higher levels of feeling stress were negatively associated with co-vaping. Similar to nicotine vaping and cannabis vaping, participants were more likely to co-vape when they were alone, with roommates/friends, or with a partner compared to being with other people. Likewise,

seeing tobacco products, seeing tobacco advertisements, seeing cannabis products, and alcohol use were other real-time antecedents of co-vaping. Similar to cannabis vaping, participants were also more likely to co-vape both substances in the afternoon or evening compared to the morning time, but there were no statistical differences in the likelihood of co-vaping between weekends and weekdays.

### Sensitivity analyses

Results of the sensitivity analyses with the subset of 65 participants (57.5% of the total sample) who had a compliance rate of 75% or greater are shown in **Table 4**. The results were mostly the same for vaping nicotine and vaping cannabis outcomes. Some associations turned to non-significant in the model for co-vaping, but the direction of most associations remained the same with results from analyzing observations from the entire sample.

Table 4. Sensitivity analyses of factors associated with momentary nicotine vaping behaviors among young adults completing at least 75% of EMA surveys during the study period

| Real-time Factors                        | Compliance rate $\geq$ 75% (n=6,473) |                                 |                                         |
|------------------------------------------|--------------------------------------|---------------------------------|-----------------------------------------|
|                                          | Nicotine Vaping<br>AOR (95% CI)      | Cannabis Vaping<br>AOR (95% CI) | Same Occasion Co-vaping<br>AOR (95% CI) |
| <b>Mood <sup>a</sup></b>                 |                                      |                                 |                                         |
| <i>Feeling happy</i>                     | 0.97 (0.91-1.04)                     | 1.11 (0.99-1.24)                | <b>1.16 (1.01-1.35)*</b>                |
| <i>Feeling stressed</i>                  | <b>0.92 (0.87-0.96)***</b>           | <b>0.88 (0.81-0.96)**</b>       | 0.91 (0.82-1.01)                        |
| <i>Feeling focused</i>                   | 1.05 (0.99-1.11)                     | 1.06 (0.97-1.16)                | 1.07 (0.96-1.20)                        |
| <i>Feeling energized</i>                 | <b>0.91 (0.86-0.98)**</b>            | 1.01 (0.92-1.11)                | 0.97 (0.86-1.09)                        |
| <b>Craving for nicotine <sup>b</sup></b> | <b>2.48 (2.30-2.66)***</b>           | <b>0.87 (0.77-0.98)*</b>        | 1.11 (0.95-1.30)                        |
| <b>Craving for cannabis <sup>b</sup></b> | <b>0.87 (0.81-0.93)***</b>           | <b>2.53 (2.27-2.82)***</b>      | <b>2.35 (2.04-2.71)***</b>              |
| <b>Personally staying with</b>           |                                      |                                 |                                         |
| <i>Someone else or multiple people</i>   | REF                                  | REF                             | REF                                     |
| <i>Alone</i>                             | <b>2.67 (2.09-3.41)***</b>           | 1.58 (1.02-2.45)*               | 1.13 (0.65-1.96)                        |
| <i>Roommate/Friend</i>                   | <b>2.01 (1.43-2.81)***</b>           | 1.87 (1.02-3.42)*               | 2.13 (0.96-4.76)                        |
| <i>Partner</i>                           | <b>3.35 (2.51-4.46)***</b>           | 2.21 (1.34-3.64)**              | 1.59 (0.85-2.97)                        |
| <i>Family</i>                            | 1.05 (0.75-1.48)                     | 0.79 (0.42-1.45)                | 0.86 (0.41-1.80)                        |
| <b>Product/advertisement exposure</b>    |                                      |                                 |                                         |
| <i>Seeing tobacco products</i>           | <b>6.76 (4.88-9.37)***</b>           | <b>2.06 (1.17-3.61)*</b>        | 2.34 (1.04-5.26)*                       |
| <i>Seeing tobacco advertisement</i>      | <b>4.16 (1.47-11.75)**</b>           | 1.76 (0.41-7.50)                | 3.08 (0.39-24.06)                       |

|                                      |                            |                            |                            |
|--------------------------------------|----------------------------|----------------------------|----------------------------|
| <i>Seeing cannabis products</i>      | 1.00 (0.61-1.66)           | <b>3.10 (1.77-5.44)***</b> | <b>4.68 (1.93-11.34)**</b> |
| <i>Seeing cannabis advertisement</i> | 0.28 (0.07-1.66)           | 0.59 (0.12-2.82)           | 0.86 (0.10-7.46)           |
| <b>Alcohol use</b>                   | 1.37 (0.93-2.04)           | 1.42 (0.83-2.42)           | 1.64 (0.89-3.02)           |
| <b>Time of day</b>                   |                            |                            |                            |
| <i>Morning (5 am - 12 noon)</i>      | REF                        | REF                        | REF                        |
| <i>Afternoon (12 noon - 6 pm)</i>    | 1.06 (0.88-1.28)           | <b>1.42 (1.02-1.98)*</b>   | 1.38 (0.93-2.07)           |
| <i>Evening/night (6 pm - 5 am)</i>   | 1.22 (0.97-1.53)           | <b>1.84 (1.26-2.70)**</b>  | <b>1.75 (1.10-2.78)*</b>   |
| <b>Weekend vs. weekday</b>           | <b>1.37 (1.15-1.62)***</b> | 0.99 (0.74-1.31)           | 0.97 (0.69-1.35)           |

AOR: Adjusted odds ratio; CI: Confidence interval; REF: Reference; \* P<0.05, \*\* P<0.01, \*\*\* P<0.001

All models were controlled for study day (1-30) and baseline covariates, including age (years), biological sex (male vs. female), gender (non-straight vs. straight), cannabis use disorder, e-cigarette dependence score, race/ethnicity (NH-White, Hispanic, and NH-Other), and education levels

<sup>a</sup> The scale for each emotional feeling ranged from 0-Not at all to 10-Extremely.

<sup>b</sup> Craving score ranged from 0-Not at all to 6-Very high

## DISCUSSION

### Principal Findings

This smartphone-based study EMA revealed real-time antecedents of vaping behaviors, including nicotine vaping, cannabis vaping, and especially same-occasion co-vaping. To the best of our knowledge, this is the first study that examines the antecedents of same-occasion co-vaping of nicotine and cannabis among young adults, a high-risk behavioral pattern for vaping dependence [10]. Our study identified both common and unique antecedents across the vaping behavioral patterns (e.g., craving and alcohol use were shared predictors for both nicotine and cannabis vaping behaviors while feeling happy was a unique antecedent for same-occasion co-vaping). The findings suggest there may be different targets for cessation programs to help young adults quit vaping nicotine, cannabis, or same-occasion co-vaping.

### Interpretation of Results and Comparison With Prior Work

We found that higher craving levels of a given substance were not only associated with an increased likelihood of vaping that substance but also co-vaping. Young adults may vape both substances on the same occasion to seek combined pharmacological effects from the

combination of substances [23, 24]. The co-vaping behavior may increase the amount of vaping nicotine and cannabis, putting young adults at an increased risk for nicotine and cannabis dependence [10]. On the other hand, we found that craving for cannabis was associated with lower odds of vaping nicotine while craving for nicotine was not associated with vaping cannabis. This finding does not support substitution effects between nicotine and cannabis (e.g., using one product to replace/substitute the other [25]). A behavioral economic study among adults who use both cannabis and tobacco also found that cannabis joints and cigarettes had an independent relationship [26]. These mixed findings about substitution effects are probably due to cannabis and tobacco having both overlap and unique salient purposes of use [27].

Our participants were less likely to vape nicotine and cannabis as they had higher levels of stress, which contrasts with previous studies indicating stress as a common reason for nicotine vaping among young adults [28-32]. However, previous studies measured vaping and stress within 30 days and examined the between-person association between stress and vaping [28, 29, 32], while our study measured stress levels and the vaping outcomes at a specific moment and examined this association as a within-person variation. Thus, differences in the measurement of exposures and outcomes could be attributed to the difference between our findings and other studies' findings. Some studies even indicate that nicotine vaping can increase anxiety symptoms and stress levels [33, 34]. Feeling happy, in contrast, was positively associated with the likelihood of co-vaping among young adults in our study. When participants feel happy, they may reward themselves by vaping both nicotine and cannabis on the same occasion to "get the buzz" of the effect of cannabis to enhance their positive mood [25, 35]. Future studies should further examine mood variation and vaping behaviors to better understand potential mechanisms underlying the influence of mood and vaping.

We also found that alcohol use was significantly associated with all the vaping outcomes, which is consistent with previous studies [36, 37]. Alcohol, tobacco, and cannabis can potentiate rewarding properties of each other [24, 38, 39], which may increase the use and dependence on each substance. Thus, a single substance use cessation program may not work effectively without considering the concurrent use of multiple substances. In addition, a previous study indicated that vaping nicotine and cannabis occur more in social events (e.g., attending bars or parties) [36], but we found that vaping nicotine, cannabis, and co-vaping consistently occurred more frequently not only when young adults were staying with their roommates/friends or a partner but also when they were alone compared to when staying with multiple types of people/acquaintances. This finding underscores the dynamic nature of vaping behaviors depending on context and social setting.

Seeing tobacco products and advertisements was associated with higher odds of vaping nicotine and same-occasion co-vaping, which is consistent with previous studies [40, 41]. Likewise, seeing cannabis products was also associated with cannabis vaping and co-vaping. This finding highlights the need to address exposures to nicotine/cannabis products and advertisements and guide young adults to avoid these triggers to accommodate their vaping cessation goals.

In our study, time of the day was not associated with vaping nicotine, but cannabis vaping and co-vaping were more likely to occur in the afternoon or evening. Young adults may be chained to vaping nicotine as a habit while vaping cannabis for certain purposes (e.g., sleep aid or pain management) [42, 43], which may partly explain the observed differences in the timing of their vaping behaviors. In addition, while nicotine vaping was associated with weekends (vs. weekdays), neither cannabis nor co-vaping was associated with weekends. These findings have

implications for delivering cessation interventions at the right times to tailor content and timing of messages targeting each vaping behavior. Just-in-time adaptive interventions are grounded in the idea that timing, identified through states of vulnerability and opportunity, plays a critical role in determining the most beneficial moments to deliver support [44]. This type of intervention offers a promising approach to address vaping cessation [45].

### **Limitations**

Limitations to this study include a convenience sample and online recruitment of young adults in California. Substantial proportions of our sample had educational attainment of college or higher, cannabis use disorders, and high e-cigarette dependence. Thus, it is unclear how our findings are generalized to other samples of young adults. In addition, our participants were interested in quitting, so results are not generalizable to those who are not interested in quitting vaping nicotine or cannabis.

### **Conclusions**

In conclusion, this EMA study revealed how subjective and contextual factors differentially predicted nicotine vaping, cannabis vaping, and same-occasion co-vaping among young adults. In addition to similar antecedents for vaping behaviors, we also found unique antecedents for each vaping outcome, informing the development of just-in-time adaptive interventions to help young adults quit vaping nicotine and cannabis. As the overlap between nicotine and cannabis vaping is increasing, future research should address co-vaping of both substances and develop dual cessation treatment among young populations.

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