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Associations of Mode of Administration on Cannabis Consumption and Subjective Intoxication in Daily Life

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Abstract

Objective.—As cannabis products are becoming increasingly available and young adults are increasingly using vaporizers to consume cannabis, there is a need to understand how this population is using different modes of administration and the extent to which specific modes are associated with differential cannabis use outcomes. Toward this end, the current study characterized predictors of cannabis mode of administration and examined how consumption levels and subjective intoxication vary as a function of mode of administration in daily life.

Method.—Participants were 106 young adult cannabis and heavy alcohol users (51% female) who completed up to 14 daily diaries ($n = 1,405$ person days). Each day, participants reported whether they used any cannabis and, if any, which mode(s) were used, number of hits used per mode, overall subjective intoxication, and the socio-environmental context in which they used cannabis.

Results.—Across all cannabis use days, Bong-Only and Vape-Only days were the most common, followed by Multimode, Joint-, Pipe-, and Blunt-Only days. Participants reporting a greater proportion of cannabis use days were more likely to report Bong-Only and Multimode days than Vape-Only days. Compared to Vape-Only days, participants reported fewer hits on Bong-Only days and more hits on Blunt-Only, Pipe-Only, and Multimode days. Participants felt more intoxicated on Bong-Only days than Vape-Only days.

Conclusions.—Mode-specific associations with cannabis consumption and subjective intoxication levels suggest assessing modes of administration may be a meaningful way to guide individual and public health intervention efforts.

Keywords

Marijuana; Mode of Administration; Route of Administration; Subjective Intoxication; Daily Diary

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The data reported in this manuscript were collected as part of a larger data collection focused on the consequences of simultaneous alcohol and cannabis use which has been published in a separate manuscript (Linden-Carmichael, Van Doren, et al., 2020). The current manuscript focuses specifically on the day-level associations of mode of cannabis administration which have not been reported or published elsewhere.

Cannabis is the second most widely used regulated substance in the US after alcohol (Miech et al., 2019; Substance Abuse and Mental Health Services Administration, 2019). Recent historical changes in the legality of recreational and medicinal use policies have rapidly altered the landscape of cannabis use. Cannabis has become more accessible and potent, while perceptions of the risks associated with use have decreased and norms have become more accepting (Borodovsky et al., 2016; Prince & Conner, 2019; Russell et al., 2018; Spindle, Bonn-Miller, et al., 2019). The effects of cannabis on health outcomes remain poorly understood in part because there is still no consensus on best practices for measuring cannabis use (National Academies of Sciences Engineering and Medicine, 2017). The tendency to operationalize use solely by frequency (e.g., number of times used per day or number of days used) neglects other defining variables such as quantity (e.g., number of grams or hits used per occasion), potency (e.g., THC concentration), and routes or modes of administration (e.g., smoking, vaping) (Freeman & Lorenzetti, 2020; Lee et al., 2019; Mariani et al., 2011; Prince & Conner, 2019). Adding to the challenge of reconciling this gap, is how quickly routes and modes of administration patterns change over time while also influencing other markers of cannabis use (Johnston et al., 2019; Prince & Conner, 2019). As a result, several agencies and organizations have called for more comprehensive measures of use including the explicit need to “distinguish between different routes of cannabis administration” (National Academies of Sciences Engineering and Medicine, 2017, p. 397; World Health Organization, 2016).

Route and Mode of Cannabis Administration

Route of administration refers to the general process by which a psychoactive substance is consumed: smoked or inhaled, ingested, absorbed transdermally, or injected into the blood stream (Ehrler et al., 2015; Russell et al., 2018). Routes of administration impact the onset, intensity, and duration of drug effects which can, in turn, impact use patterns and consequences. For example, when the psychoactive chemical in cannabis, Δ^9 -tetrahydrocannabinol (THC), is smoked, it enters and leaves the central nervous system more rapidly than when it is ingested, resulting in a faster intoxication onset but shorter duration (Vandrey et al., 2017). Time to intoxication onset is similar for smoking (i.e., applying combustible heat) and vaping (i.e., applying non-combustible heat) cannabis, however, vaping appears to increase subjective intoxication levels and decrease certain toxin exposures relative to smoking the same cannabis plant products (Spindle et al., 2018). Within each route, there are also different modes of administration linked with distinct outcomes. For example, cannabis can be smoked with joints, blunts, bong, or pipes. Smoking cannabis with joints is associated with greater objective (i.e., plasma THC levels) and subjective intoxication levels compared to smoking cannabis with blunts; in contrast, smoking cannabis in blunts (relative to joints) is associated with increased absorption of carbon monoxide - a risk factor for cardiovascular and pulmonary disease (Cooper & Haney, 2009). Finally, the cannabis product used drastically alters the range of potency and toxins. Growing cannabis plants somewhat constrains the potency of the product, while increasing exposure to pesticides (Russell et al., 2018). Concentrates and oils commonly used in vaporizers might reduce pesticide exposure, but exponentially raises the upper potency bound while potentially exposing users to other unregulated toxins that

cause serious adverse events (Budney et al., 2015; Budney & Borodovsky, 2017). Though empirical research is limited, vaporizers modeled after electronic nicotine delivery devices (e.g., e-cigarettes) have been linked to serious adverse health events (He et al., 2017; Schuchat, 2019).

In addition to directly influencing intoxication onset, intensity, and duration, routes or modes of administration may indirectly influence these outcomes via route- or mode-specific use patterns. Users perceive that relative to smoking, vaping cannabis reduces risk of respiratory problems, tastes better, more efficiently delivers doses, and is easier to conceal; this combination of beliefs may increase both the frequency of use occasions and the quantity of cannabis consumed within occasions when vaping compared to smoking (Aston et al., 2019; Borodovsky et al., 2016; Budney et al., 2015). By acutely increasing subjective intoxication, vaping cannabis regularly also may raise tolerance which increases use demands and accelerates the onset of cannabis use disorder relative to smoking (Budney & Borodovsky, 2017; Loflin & Earleywine, 2014; Prince & Conner, 2019). Within smoking routes, users report placing 50–100% more cannabis flower in blunts than joints and pipes; thus, on a given smoking occasion, this tendency may result in greater quantities of cannabis consumed if using blunts rather than other smoking modes (Mariani et al., 2011).

All facets of cannabis use are interrelated and often confounded with person- and day-level characteristics. For example, the quantity of cannabis consumed corresponds to the level of intoxication experienced. Where tolerance is defined as “marked increases in the amount of cannabis required to achieve the desired effect or diminished effects with the same amount” (American Psychiatric Association, 2013), the extent to which cannabis use translates to intoxication on any given occasion is qualified by the person’s use levels preceding that occasion (Colizzi & Bhattacharyya, 2018). Without precise estimates of one’s tolerance or how potent the cannabis they are consuming is in daily life, users rely on what they perceive their general tolerance and acute intoxication levels to be in order to modulate intake or engage in decision-making, such as deciding whether to drive (Freeman & Lorenzetti, 2020; Korf et al., 2007). Social contexts (e.g., whether they are using with others), physical settings (e.g., at home vs. at school or work), other substance use (e.g., alcohol, nicotine), and day of the week (e.g., weekdays vs. weekends) may influence the quantity of cannabis consumed, the routes or modes of administration used, as well as subjective intoxication levels by altering what is physically available and socially acceptable (Buckner et al., 2015, 2019; Lipperman-Kreda et al., 2017).

Person-level factors have also been shown to impact cannabis use patterns and intoxication. Age and sex may influence both the biological absorption of cannabis as well as the overall norms associated with use (Cooper & Haney, 2009; Russell et al., 2018; Streck et al., 2019). In a recent retrospective self-report study, females were more likely to identify joints and hand pipes as their primary mode of administration, while males were more likely to report bongas as their primary mode of administration (Swan et al., 2021). The initial results suggesting that primary bong users reported more frequent risky use behavior (simultaneous alcohol and cannabis consumption) and experienced more harms than primary joint users, were no longer significant after controlling for age, sex, and prior use history (Swan et al., 2021). While this might suggest that person-level factors

are more relevant than the specific modes of administration on cannabis use outcomes, the design conflates factors associated with *whom* is likely to use bongs more often than joints, with the *bong-specific effect* relative to the joint specific effect. Isolating the mode-specific associations with retrospective surveys or experimental designs and between-person analyses is challenging because of how many factors need to be accounted for with sampling and random assignment.

Modeling Cannabis Use Behavior in Daily Life

A notable strength of intensive longitudinal designs (ILD) like daily diary studies is that the data contains information on both between- and within-person differences (Raudenbush & Bryk, 2002). When isolating mode-specific associations, within-person analyses of ILDs can reveal the extent to which each person's behavior or experiences varied on days they used bongs relative to days when they used joints or vaporizers. For example, a body of work suggests that when in the presence of others, young adults are more likely to use cannabis, use greater amounts, and engage in riskier types of use such as co- or simultaneous consumption of other substances (Buckner et al., 2012; Lipperman-Kreda et al., 2018). However, recent qualitative findings suggest that young adults perceive vape pens to be a more convenient and discrete means of consuming cannabis that does not involve the same social 'smoking rituals' seen with other modes of administration (Aston et al., 2019). It is possible that young adults are more prone to vaping alone and engaging in higher levels of use relative to smoking routes/modes of administration. Daily assessments can help clarify what modes are being used in daily life, when, and by whom, as well as mode-specific associations with quantity of consumption and intoxication levels.

To date, only two published papers (derived from the same data) have examined mode-specific associations at the daily level (Hughes et al., 2014; Streck et al., 2019). Blunts, joints, and edibles were assessed as separate modes, while pipes, bongs, water pipes, and vaporizers were assessed as one mode. Researchers examined person- and day-level correlates of the four mode categories and number of mode categories (one vs. more than one). Findings revealed substantial variability in use patterns across levels of analysis: 93% of users reported multimode use across days, but less than 24% of use days involved multiple modes (Hughes et al., 2014; Streck et al., 2019). At the person-level, females reported a greater proportion of Blunt-Only days than males, those with cannabis dependence reported more Joint-Only days than those without dependence, those who typically used cannabis socially reported more multimode use days than those who typically used alone, and those who consumed alcohol regularly reported more combined only days than those who did not report using alcohol regularly (Streck et al., 2019). At the day-level, participants reported feeling more intoxicated when they smoked cannabis with blunts than all other routes or modes combined (joints, pipes/bongs/vaporizers/water pipes; (Hughes et al., 2014). Together, these studies suggest that there may be person- and day-level characteristics associated with selecting a mode of cannabis use as well as mode-specific associations on the quantity of cannabis consumed and the level of intoxication achieved.

While the Hughes et al. (2014) and Streck et al. (2019) findings offer important, preliminary insight into mode-specific associations in daily life, several key gaps in knowledge remain.

First, epidemiological and laboratory studies suggest that joints, pipes, bongs, vaporizers, and water pipes represent distinct routes (vaping vs. smoking) and modes that differentially impact consumption and intoxication levels (Russell et al., 2018). Because modes were analyzed as a single mode category in both studies, it is unknown whether these mode-specific associations emerge in daily life. This approach also makes it unclear the extent to which the prevalence of multimode use was underrepresented at the daily level. Second, data from these prior studies were collected in 2012; prevalence of vaporizers has rapidly increased in more recent years and vaporizers have diversified (Budney et al., 2015; Schulenberg et al., 2019). With changing legislation, older, bulkier devices that vaporized cannabis flower and were difficult to hide or transport, have been supplemented by e-pens that use flavorful, high potency oils or concentrates which can be carried and used more discretely (Schauer et al., 2016). Despite these key design differences and fairly limited safety research or legislative oversight, as a whole vaporizers continue to be perceived as healthier and more effective means of getting intoxicated (Budney et al., 2015; Lee et al., 2016; Malouff et al., 2014). Third, participants in prior studies were selected based in part on their desire to reduce their cannabis use during the study period and their low dependence risk for non-cannabis related substances. Findings may not generalize to the majority of high-risk cannabis users not attempting to regulate their use or are also heavily using other substances like alcohol (Substance Abuse and Mental Health Services Administration, 2019; Yurasek et al., 2017).

Present Study

The current study expands upon prior research by using a 14-day diary study to examine both patterns of cannabis use modes and the mode-specific associations on cannabis use outcomes. Specific aims were to 1) describe person- and day-level correlates of cannabis modes of administration and 2) describe the unique day-level associations among modes of administration with cannabis consumption and subjective intoxication levels. In light of public health concerns regarding the uptick in vaporizer use and the safety of vaporizing cannabis relative to smoking cannabis, we characterized mode-specific differences of each smoking modality (i.e., Blunt-Only, Bong-Only, Joint-Only, Pipe-Only, Multimode use days) relative to Vape-Only use days. At the day level, we expected more Multimode days to occur when using cannabis with others relative to using alone. Given the dearth of literature comparing mono-mode specific contexts further, no additional hypotheses were outlined for Aim 1. For Aim 2, consumption and intoxication levels were hypothesized to be highest on Multimode days, followed by Vape-Only days. The attributes of modern vaporizers making it more discrete to possess and consume both cannabis plants and high potency concentrates suggested Vape-Only days would be more strongly associated with cannabis use relative to all other mono-mode days (i.e., Blunt-Only, Bong-Only, Joint-Only, Pipe-Only). These effects are hypothesized to be robust to the inclusion of person- (e.g., sex, proportion of cannabis use days) and day-level (e.g., use with others; common physical settings, any alcohol use) correlates that may also account for differences in consumption and subjective intoxication levels.

Method

Participants

Participants were recruited from a larger daily diary study of simultaneous alcohol and cannabis users (Linden-Carmichael, Van Doren, et al., 2020). Eligibility criteria for the larger study were 18–25 years of age, any past-month simultaneous use of alcohol and cannabis, any past two-week heavy episodic drinking (4+/5+ drinks in one occasion for females/males), and providing valid contact information in the online survey[dummy_chk similar]. From the larger study ($N = 161$), participants who reported at least 1 day of cannabis use across the two-week period were selected to examine correlates of use versus non-use days ($N = 106$ participants with 1,405 person days). All 642 cannabis use days (42% of total days) were then described, before excluding days where the cannabis consumption metric (i.e., number of hits) was not meaningful (e.g., Edible-Only days) for the primary analyses. This resulted in a final primary analytic sample of 105 participants (51% female; $M_{\text{age}} = 20.28$, $SD_{\text{age}} = 1.49$) across 607 use days. In the final sample, 69% of participants identified as Non-Hispanic (NH) White (69%), 12% identified as NH-Asian, 8% identified as NH-Black, 7% identified as Hispanic-Latinx, and 5% identified as NH-multi-racial.

Procedure

All study procedures were approved by the university Institutional Review Board. Data were collected from October 2018 to March 2019 in a state where cannabis had not been legalized or decriminalized for recreational use. Participants were screened and, if eligible, were immediately prompted to complete an online baseline survey. Shortly thereafter participants were provided with instructions for completing daily surveys for 14 consecutive days. Each day, participants were sent e-mail and text reminders at 9 and 11:30am to report on the prior day's behaviors. Participants received up to \$48: \$10 for baseline, \$2/daily survey, plus a \$10 bonus if they completed 12+ surveys. Compliance rates from the larger study were excellent – 95% of eligible participants completed at least 1 daily survey with participants completing an average of 13.13 ($SD = 1.95$) daily surveys (see Linden-Carmichael, Van-Doren et al., 2020 for additional information).

Measures

Each day, participants were provided a comprehensive list of substances and asked to check all substances used the day prior. If cannabis use was endorsed, participants were asked to report on modes of administration, consumption levels for each mode, and overall subjective intoxication. They were also asked to report on the setting and social context in which they used.

Mode of Administration—Participants were asked to check all the modes used to consume cannabis with the following options: smoked a joint, smoked a blunt, smoked a bong, smoked a pipe, vaped, ate an edible, other (please specify). These responses were collapsed into a single factor mode variable reflecting Bong-Only, Vape-Only, Joint-Only, Pipe-Only, or Blunt-Only days. Edible-Only ($n = 18$) and Other-Only ($n = 17$) days were excluded because the metric of consumption (number of hits) was not meaningful for these

modalities and rarely endorsed. Days when participants used multiple modes were coded as ‘Multimode Days’.

Cannabis Consumption (Number of Hits)—To obtain a behavioral marker of varying cannabis consumption levels across modes of cannabis administration, participants were asked to estimate the number of hits used for each mode endorsed on cannabis use days. For example, if a participant reported both joint and blunt use, they were provided with separate follow-up questions regarding the number of hits used via a joint and the number of hits used via a blunt. The number of hits estimated for each mode was summed to reflect the total number of hits used per day with half hits rounded up to the next fullest integer (e.g., 0.5 was recoded as 1). Number of hits offers an intuitive assessment of consumption levels with consistent scaling to compare differences across smoking and vaping routes of administration (Kosa et al., 2017). At the daily level, number of hits also offers more meaningful variability than the scales used in retrospective surveys (e.g., any use; use frequency).

Subjective Cannabis Intoxication—Consistent with prior work (Bravo et al., 2017; Quinn & Fromme, 2011), on days participants indicated any cannabis use, they were asked to rate their subjective level of cannabis intoxication (i.e., “How high did you feel yesterday?”) on a 0 (*not at all*) to 100 (*highest I have ever felt*) scale. This rating was requested separately from an item administered on days participants indicated any alcohol use to capture subjective levels of alcohol intoxication (i.e., “How drunk did you feel yesterday?”).

Proportion of Cannabis Use Days—To account for potential between person differences in use frequency when estimating subjective intoxication, a proxy variable was calculated as the ratio of days each participant used any cannabis during the assessment period divided by the total number of days data were reported, with higher ratios indicating more use days. Specifically:

$$PCU = \frac{\# \text{ of Days Used Any Cannabis}}{\text{Total \# of Days with Data}}$$

Additional Covariates

Social Context.: On cannabis use days, participants were asked if they used with others (1 = *Yes/Social*; 0 = *No/Used Alone*). This binary variable is consistent with prior literature (e.g., Buckner et al., 2012), addresses the current study aims (controlling for social effects on increased use levels/subjective intoxication), and reflects the relative distribution of responses available to detect a statistically significant effect (i.e., 41.1% used alone vs. 58.9% used with 1+ others). If participants endorsed social use, they were asked about their relationship to anyone present (*Friends, Significant Other, People I Don’t Know/Don’t Know Well, Parents/Relatives, Other*). As relationships were assessed using ‘Check all that apply’, each category was recoded to reflect endorsement (1) or non-endorsement (0).

Physical Setting.: Participants who endorsed cannabis use were asked where they had used (*Home, Work, Friends' House, Restaurant, Bar/Club, Car, Outdoors/While Walking, Other*). As physical setting was assessed using 'Check all that apply', each setting was recoded to reflect endorsement (1) or non-endorsement (0).

Any Nicotine Use.: Any nicotine use was indicated by participants reporting that they had used cigarettes, cigars, cigarillos, hookah, or e-cigs. Although assessed separately, they were combined to create a single dichotomous variable reflecting any nicotine use (1) or no nicotine use (0).

Alcohol Use.: Each day that participants indicated consuming any alcohol, they were provided examples of standard alcoholic drinks for reference and asked the number of standard alcoholic drinks they consumed for each type of alcohol (e.g., beer, wine, liquor). Number of drinks were summed across all types of alcoholic beverages to create a composite score.

Day of the Week.: Thursday to Saturday were coded as weekend days (1); Sunday to Wednesday were coded as weekdays (0) (Del Boca et al., 2004).

Analytic Approach

Continuous variables with extreme univariate outliers outside of the 3 *SD* range were winsorized to match the next highest value and if they still violated normality assumptions, they were transformed (Barnett & Lewis, 1994). As the number of hits variable was skewed, values 3+ *SD* above the original mean (39.96) were rounded to 40+ hits, then all values were log transformed to meet normality assumptions. The pre-log transformed data are presented in descriptive statistics and used in analyses where hits are used as a covariate. Log-transformed data were used when hits was the outcome variable¹. Missing data were minimal (< 2%) and addressed via pairwise deletion resulting in slightly varying number of days reported in table notes. Next, a series of chi-square tests were conducted to describe the associations between person-level and day-level variables with cannabis use days (vs. non-use days) and modes used within use days.

Given the nested nature of the data and uneven number of daily observations for each individual, multilevel modeling (MLM) with maximum likelihood estimators were used to address Aims 1 and 2. For both Aims, the intraclass correlation coefficients (ICCs) were calculated from the unconditional means model to assess the percentage of variance at the within- (Level 1) and between- (Level 2) person levels (Ene et al., 2015). To calculate the ICC when mode of administration was the categorical outcome, a slightly modified formula was used assuming a Level-1 residual of 3.29 (Ene et al., 2015).

Mode was included as a single factor variable with Vape-Only days as the reference. Thus, significant findings can be interpreted as the likelihood of using each mode relative to Vape-Only days (Aim 1) and the linear increase in the log number of hits taken and

¹Because analyses were restricted to only use days, the hits variable did not have a true 0 and was therefore treated as a continuous outcome variable in the primary analyses rather than a count variable.

subjective intoxication levels when using each mode, relative to Vape-Only days (Aim 2). Level 2 predictors (i.e., proportion of cannabis use days) were grand mean centered to draw between-person comparisons and Level 1 predictors were person-centered to draw within person comparisons. Person-level sex (female = 0, male = 1) and proportion of cannabis use days as well as day-level Number of Alcoholic Drinks, Any Nicotine Use (No Use = 0; Any Use = 1), Social Context (Alone = 0; 1+ People Present = 1), Day of the Week (Weekday = 0; Weekend = 1), and Home Use (0 = Not at Home; 1 = At Home) were tested simultaneously as covariates for all MLMs. Day-level number of hits was also included as a covariate for models predicting subjective intoxication as the most prominent predictor of day-level intoxication (Aim 2). For example, the MLM specified below tests whether individuals felt more subjectively intoxicated (Intoxication_{di}) on Bong-Only days (Bong_{di}) relative to Vape-Only days while controlling for the number of hits taken ($\# \text{ Hits}_{di}$), whether they drank alcohol (AnyAlcohol_{di}), whether they used with others (SocialUse_{di}), or whether it was a weekend day (Weekend_{di}) at Level 1. Here, days (d) are nested within individuals (i), and the Level-2 model estimates of proportion of cannabis use days (PCU_i).

Level 1 (Day-Level):

$$\text{Intoxication}_{di} = \beta_{0i} + \beta_{1i} * (\text{Bong-Only}_{di}) + \beta_{2i} * (\text{Weekend}_{di}) + \beta_{3i} * (\text{SocialUse}_{di}) + \beta_{4i} * (\text{NumberOfAlcoholicDrinks}_{di}) + \beta_{5i} * (\text{AnyNicotineUses}_{di}) + \beta_{6i} * (\# \text{ Hits}_{di}) + \epsilon_{di}$$

Level 2 (Person-Level):

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{PCU}_i) + u_{0i}$$

$$\beta_{1i} = \gamma_{10}$$

$$\beta_{1i} = \gamma_{20}$$

$$\beta_{1i} = \gamma_{30}$$

$$\beta_{1i} = \gamma_{40}$$

$$\beta_{1i} = \gamma_{50}$$

Results

Descriptive Statistics

As shown in Table 1, a greater proportion of cannabis use days were reported by males than females, on weekdays relative to weekends, on days alcohol was consumed relative to days alcohol was not consumed, and on days nicotine was used relative to days nicotine was not used. Of all 642 use days (45.7% of total days), participants reported a range of 1 to 5 modes with the majority reporting one mode type per day ($n = 514$ or 80.0% of person-days).

After excluding non-cannabis use days and the 35 Edible-Only or Other-Only days, there were 105 participants reporting a range of 1 to 14 use days ($M = 5.78$, $SD = 4.32$) and 7 – 100% proportion of cannabis use days ($M = .46$, $SD = .32$). As shown in Table 2, there were 607 days in total and the majority of days involved exactly one mode type (n

= 479 or 78.9% of person-days). Bong-Only (30.3%) days were most common, followed by Vape-Only (24.1%), Multimode (21.1%), Joint-Only (11.2%), Pipe-Only (7.6%), and Blunt-Only (5.8%) days.

As shown in Table 3, mode of use was associated with person-level sex and day-level social context and home use, but not day of the week, alcohol use, nicotine use, nor use at friends' homes or outdoors. As the relative distribution of whom participants used with and physical settings outside of their home were fairly limited across mode use days, these variables were not included in the subsequent MLMs.

Aim 1: Describe Person- and Day-level Correlates of Cannabis Modes of Administration

Multinomial MLMs tested the likelihood of using each mode relative to Vape-Only days. The ICCs indicated the majority of variance was accounted for by between-person variability for Bong-Only (69.3%), Blunt-Only (96.1%), Joint-Only (95.5%), Pipe-Only (96.7%), and Multimode (61.7%) comparisons relative to Vape-Only days. This left 30.7%, 3.9%, 4.5%, 3.3%, and 36.9% of respective variance to be accounted for by within-person variation. As shown in Table 4, at the person-level, participants who used cannabis on a greater proportion of days overall were more likely to report Bong-Only and Multimode days than Vape-Only days. At the day-level, on days participants used nicotine they were more likely to report a Blunt-Only day and less likely to report a Joint-Only day than a Vape-Only day. On days participants used cannabis at home, they were less likely to report a Blunt-Only day than a Vape-Only day.

Aim 2: Describe Day-Level Associations Between Mode of Use, Cannabis Consumption and Subjective Intoxication

Based on calculated ICCs, 60.4% of the total variance in the number of hits was attributable to between-person and 39.6% to within-person variation. For subjective intoxication, 31.7% was attributable to between-person and 68.3% to within-person variation.

Table 5 presents the unstandardized, fixed linear effects predicting log number of hits and subjective intoxication². Exponentiating the intercept for log number of hits revealed that, on the average Vape-Only day, participants reporting an average proportion of cannabis use days took 3.9 hits. Compared to Vape-Only days, participants took 15.6% fewer hits on Bong-Only days and 43.3% more hits on Blunt-Only days, 27.1% more hits on Pipe-Only days, and 89.7% more hits on Multimode days. A similar number of hits were taken on Vape-Only and Joint-Only days. Exponentiating the statistically significant covariate fixed effects also revealed that for each alcoholic drink above the persons average there was a 2.0% decrease in the number of hits taken. Participants who reported a higher proportion of cannabis use days took more hits of cannabis on average than those reporting a lower proportion of cannabis use days.

²Participant sex and day of the week were also tested as predictors of day-level cannabis consumption and subjective intoxication levels. As neither were statistically associated with either outcome and findings were substantively similar when excluded, the more parsimonious model excluding these variables were reported.

The unstandardized intercept of 38.79 reflects the expected level of subjective intoxication on the average Vape-Only days for participants reporting an average proportion of cannabis use days. Compared to Vape-Only days, participants subjective intoxication was 6.09 and 7.99 units higher on Bong-Only and Multimode days, respectively. Subjective intoxication on Vape-Only days did not differ from Blunt-Only, Joint-Only, or Pipe-Only days. Each additional cannabis hit taken was associated with a 1.33-unit increase in subjective intoxication, but subjective intoxication levels were not significantly associated with number of alcoholic drinks consumed, whether nicotine was used, whether cannabis was used at home, nor whether cannabis was used with others. The proportion of cannabis use days participants also was not associated with their average level of subjective intoxication after adjusting for daily number of cannabis hits.

Discussion

The current study aimed to 1) describe person- and day-level correlates of cannabis modes of administration and 2) describe the specific modes of administration associations with cannabis consumption and subjective intoxication levels at the daily level. Within cannabis use days, Bong-Only and Vape-Only days were the most commonly reported, followed by Multimode, Joint-, Pipe-, and Blunt-Only days. Participants who used cannabis more often overall were more likely to report Bong-Only and Multimode days relative to Vape-Only days. Relative to Vape-Only days, participants took fewer hits on Bong-Only days, and more hits on Blunt-Only, Pipe-Only, and Multimode days. Participants also reported greater subjective intoxication on Bong-Only and Blunt-Only days relative to Vape-Only days. Notably, findings were robust to several, potentially key confounds, including participant sex, level of cannabis consumption, number of alcoholic drinks, whether they also used nicotine, whether others were around when they used, whether they used at home, and the day of the week. The current study extends a small but growing body of work characterizing cannabis use in daily life and is one of the first to demonstrate mode-specific associations on daily cannabis use outcomes.

Descriptively, a greater proportion of cannabis use days were reported by males relative to females, on weekdays relative to weekends, on days they used alcohol relative to days they did not use alcohol, and on days they used nicotine relative to days they did not use nicotine. That young adults in this sample overall tended to use exactly one mode of administration within cannabis use days, while young adults reporting a greater proportion of use days were more likely to report multiple modes, is also consistent with both diary and retrospective survey work (Hughes et al., 2014; Streck et al., 2019; Swan et al., 2021). That Bong-Only (30.3%) and Vape-Only (24.1%) use days were more prevalent than Joint- (11.2%), Pipe- (7.6%), and Blunt- (5.8%) Only use days, is consistent with emerging historical trend data. Smoking routes as a whole remain popular, blunts and joints as specific modes are less commonly used, and vaporizer use is increasing in popularity (Cranford et al., 2016; Knapp et al., 2019).

Descriptively, the proportion of type of mode use days appeared to differ across sex, however, in the subsequent multilevel models, person-level sex did not influence the day-level odds of using any modes compared to Vapes-Only. Further, engaging in any alcohol

use, using cannabis in the presence of others, and day of the week were not associated with proportion of type of mode use days nor odds of using a particular mode relative to Vapes-Only. Based on prior work, it is possible that sex is more strongly associated with overall patterns of use and preferences formed across longer periods of time (Streck et al., 2019; Swan et al., 2021). Day-level variables such as alcohol use or day of the week also may be less relevant in choosing how cannabis is being consumed, while still playing a larger role in levels of cannabis consumption. Given the major methodological differences from prior work in terms of design, measuring mode of administration, and sampling participants, there is a need for more work characterizing the decision to use a given mode, how preferences form over time, as well as how decisions and preference formation might vary as a function of person-level traits such as sex.

Relative to Vape-Only days, participants took fewer hits on Bong-Only days, and more hits on Blunt-Only, Pipe-Only, and Multimode days. In lieu of a standardized measurement of cannabis quantity or potency, number of hits offers a clear, behavioral marker of use quantity and consistent scaling to compare across smoking and vaping routes of administration (National Academies of Sciences Engineering and Medicine, 2017; Zeisser et al., 2011). As such, findings offer preliminary insight into how young adults may behaviorally alter their level of cannabis consumption when using different modes of administration. For example, bongs are generally designed to be larger to increase the amount of smoke that is inhaled. Young adults may reduce the number of hits when smoking bongs because it takes fewer hits to achieve the same subjective intoxication levels, the increased smoke may feel more unpleasant, or it might burn through more product more quickly. Nevertheless, number of hits alone is an imperfect measure of consumption that does not capture other key metrics. It is possible that participants modified their consumption and subjective intoxication levels as a function of the *products* or *potency*, rather than mode of administration (Prince & Conner, 2019). As higher potency concentrates are more commonly used in vaporizers, it is possible that participants systematically reduced the number of hits on Vape-Only days to accommodate higher potency products that reduced their subjective intoxication levels. Combined with the rapid changes in product formulations that are associated with distinct risk outcomes, future research should consider more comprehensive daily measures of cannabis use (Budney et al., 2015).

Participants also reported greater subjective cannabis intoxication on Bong-Only days relative to Vape-Only days. Though other diary studies noted different day-level rankings of subjective intoxication levels (Hughes et al., 2014), this is the first diary study to assess bongs, vaporizers, and pipes separately. Our interpretation of these results as mode of administration specific differences in subjective cannabis intoxication, rather than potential polysubstance use confounds, is strengthened by the study design. First, consistent with prior work, each day participants were asked to rate how high they felt as a function of their cannabis use separately from how drunk they felt as a function of their alcohol use (Bravo et al., 2017; Quinn & Fromme, 2011). Second, the effects were robust even after statistically controlling for participants' use of alcohol and nicotine – neither of which were statistically associated with subjective cannabis intoxication. Findings reinforce that these are distinct modes of administration that should continue to be assessed separately and regularly to better characterize use outcomes. For example, there has been widespread speculation that

vaping cannabis may increase risk for long-term problems by increasing consumption and subjective intoxication levels (Budney et al., 2015; Solowij, 2018). In the current study, this would have translated in Vape-Only days having the greatest number of hits and subjective intoxication levels. Instead, Vape-Only days were generally associated with similar or lower consumption and intoxication levels. Thus, rather than vaping cannabis or concentrates to increase subjective intoxication in perpetuity, findings align more closely with the idea that young adults are vaping to achieve similar intoxication levels in fewer or similar hits (Aston et al., 2019; Lau et al., 2015).

Together, this work can be used to help address common myths about specific mode of administration effects on consumption and intoxication levels to better inform public health priorities (Aston et al., 2019; Cooper & Haney, 2009; Fairman, 2015; Mariani et al., 2011). Findings also may inform harm-reduction interventions to help redirect clients away from dangerous products or help clients better titrate and reduce their levels of cannabis consumption (Russell et al., 2018). Critically, as the current study did not evaluate acute consequences, persisting use-related problems, nor motives for vaporizer use, future research addressing these limitations is needed.

Future Directions and Limitations

There are several limitations that should be noted. First, subjective cannabis intoxication was assessed with a single item broadly referring to how high participants felt the prior day. Recent survey and experimental findings suggest that qualities of the subjective intoxication experience are more nuanced and variable across modes of administration, age, and gender (Ewusi-Boisvert et al., 2020; Spindle, Cone, et al., 2019). Future research designed to capture this variability with multiple items and more specific instructions (e.g., asking about peak intoxication) is clearly needed; this work also may benefit from incorporating more contemporary language adopted by regular cannabis users (Linden-Carmichael, Masters, et al., 2020). Second, results were based on self-reports of prior day cannabis use and daily diary design; while a reliable and valid means of assessing substance use that minimizes retrospective reporting biases (Simons et al., 2015), there may have been persisting recall concerns. For example, it may have been difficult to accurately rate subjective intoxication on days involving multiple cannabis use events (i.e., spaced out with sufficient time to return to a non-intoxicated state). More intensive longitudinal designs such as ecological momentary assessments could reduce recall biases even further by capturing use patterns and intoxication experiences in real-time (e.g., time to peak intoxication, total duration of intoxication). Third, there were relatively few Blunt-Only, Pipe-Only, and Joint-Only days endorsed in the current sample which may have impacted our power to detect statistically significant within-person differences. Larger samples assessed over longer periods of time may be needed to test for differences among these modes of administration. Lastly, our sample was predominantly NH-White (69%); more diverse samples that consider systemic factors are needed to better characterize why certain modes of administration are used (e.g., access; policing possession of paraphernalia) as well as the subsequent impact on the associations among modes of use, levels of cannabis consumption, subjective intoxication, and consequences (Lipperman-Kreda et al., 2014, 2018).

Conclusions

Several organizations have called for research that better characterizes and accounts for modes of cannabis administration (NASEM, 2017; WHO, 2016). The current study adds to this effort by being one of the first to characterize mode-specific correlates and associations with cannabis use outcomes at the daily level. On days when participants vaped cannabis, they took more hits compared to days on which they used bong, but fewer hits compared to days they used blunts. While participants felt equally intoxicated on days they vaped or used blunts, they felt more intoxicated on days they used bong. Notably, the mode-specific associations with cannabis consumption and subjective intoxication were robust to number of cannabis use days, participant sex, as well as day-level cannabis consumption levels, alcohol use, social context, and physical setting. Future research is needed to fully characterize contemporary features of cannabis use and associated consequences. Nevertheless, future policy and interventions should consider mode-specific correlates and use outcomes to improve treatment response among young adults.

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Public Health Significance Statement:

The current study found that cannabis consumption increased when vaping cannabis compared to smoking cannabis from bong, but decreased compared to smoking it from blunts. Subjective intoxication was higher when young adults smoked cannabis from bong or more than one mode, but similar across days they vaped and smoked blunts, joints, and pipes. As cannabis use becomes decriminalized across the United States and products are more available, the current findings reinforce the need to understand how young adults are consuming in everyday life to better guide tailored interventions and appropriate public policies.

Table 1.

Chi-Square Tests to Compare Cannabis Use vs. Non-Use Days

Categorical Correlates	Days <i>n</i>	Cannabis Days <i>n</i> (%)	χ^2
Total	1,405	642 (45.7%)	
Sex			3.95*
Male	686	332 (48.4%)	
Female	719	310 (43.1%)	
Day of Week			4.91*
Weekend	402	165 (41.0%)	
Weekday	1003	477 (47.6%)	
Alcohol Use			27.60***
Any Use	497	274 (55.1%)	
No Use	908	368 (40.5%)	
Nicotine Use			6.19*
Any Use	329	170 (51.7%)	
No Use	1,076	472 (43.9%)	

Note. *N* = 1,405 person-days. χ^2 tests whether the proportion of cannabis use days relative to non-use days differed by sex, day of the week, or alcohol use.

* $p < .05$

*** $p < .001$

Table 2.
Means and Standard Deviations of Cannabis Consumption and Subjective Intoxication by Each Type of Mode Day

Variable	Bong-Only (<i>n</i> = 184 days)		Vape-Only (<i>n</i> = 146 days)		Joint-Only (<i>n</i> = 68 days)		Pipe-Only (<i>n</i> = 46 days)		Blunt-Only (<i>n</i> = 35 days)		Multimode (<i>n</i> = 128 days)		Total (<i>n</i> = 607 days)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
^a Number of Hits	5.63	4.85	6.08	5.01	7.03	8.09	6.41	5.84	9.09	5.49	17.10	10.05	8.56	8.10
Subjective Intoxication Level	43.37	16.30	39.01	19.45	36.46	20.53	40.52	19.66	49.09	16.51	46.66	19.94	42.36	18.93

Notes: Findings report on *N* = 607 person-days.

^a *n* = 597 after accounting for missing data on this variable only.

Table 3. Categorical Context and Person-Level Variable Differences across Each Type of Mode Use Day

Categorical Correlates	Total (n = 607 days)	Bong-Only (n = 184 days)	Vape-Only (n = 146 days)	Joint-Only (n = 68 days)	Pipe-Only (n = 46 days)	Blunt-Only (n = 35 days)	Multimode (n = 128 days)	χ^2
Column %								
Sex								17.33 ^{***}
Males	52.4	46.2	44.5	69.1	63.0	54.3	57.0	
Females	47.6	53.8	55.5	30.9	37.0	45.7	43.0	
Day of the Week								9.71
Weekday	74.8	77.7	76.0	83.8	65.2	62.9	71.1	
Weekend	25.2	22.3	24.0	16.2	34.8	37.1	28.9	
Alcohol Use								8.74
Any Use	42.2	42.4	35.6	38.2	37.0	48.6	51.6	
No Use	57.8	57.6	64.4	61.8	63.0	51.4	48.4	
Nicotine Use								10.24
Any Use	27.7	31.5	22.6	19.1	19.6	34.3	33.6	
No Use	72.3	68.5	77.4	80.9	80.4	65.7	66.4	
Social Context								16.84 ^{***}
Used with 1+ People	58.9	62.5	48.0	53.7	78.3	65.7	60.2	
Used Alone	41.1	37.5	52.1	46.3	21.7	34.3	39.8	
Who Used With								-
^a With Friends vs. Not	90.2	92.2	88.6	97.3	69.4	100.0	92.2	
^a With Sig Others vs. Not	16.2	17.4	17.1	10.8	36.1	4.4	10.4	
^a With Strangers vs. Not	15.6	8.7	25.7	27.0	19.4	13.0	10.4	
Physical Setting								20.95 ^{***}
At Home vs. Not	73.3	79.4	66.4	61.8	82.6	57.1	79.7	
At Friends vs. Not	31.6	26.6	34.9	30.9	21.7	42.9	35.9	
Outdoors vs. Not	4.5	0.5	6.2	7.4	4.4	2.9	7.0	

Note. N = 607 person days. Overall χ^2 tested whether the proportions of each type of mode day differed by the categorical correlates. ‘.’ indicates insufficient variability for testing.

n = 357 only assessed on social use days; assessed using 'check all that apply' so endorsements are not mutually exclusive to each other.

p < .05
**
p < .01

p < .001

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Table 4.

Multilevel Multinomial Model Predicting the Likelihood of Each Type of Mode Day Occurring Relative to Vape-Only Mode Days

Predictors	Bong-Only		Blunt-Only		Joint-Only		Pipe-Only		Multimode	
	OR	(CI)	OR	(CI)	OR	(CI)	OR	(CI)	OR	(CI)
Intercept	0.59	(0.24, 1.49)	<0.01	(<0.01, <0.01)	<0.01	(<0.01, 0.06)	<0.01	(<0.01, 0.01)	0.19	(0.08, 0.48)
Level 1										
Number of Drinks	0.99	(0.90, 1.09)	1.03	(0.88, 1.20)	1.18	(1.00, 1.40)	1.06	(0.91, 1.25)	1.05	(0.95, 1.16)
^a Nicotine Use	0.92	(0.26, 3.24)	33.71	(1.58, 719.19) [*]	0.02	(<0.01, 0.32) ^{**}	0.43	(0.03, 5.68)	2.59	(0.72, 9.27)
^b Social Context	1.41	(0.57, 3.52)	1.59	(0.20, 12.34)	0.43	(0.10, 1.92)	1.13	(0.27, 4.69)	0.81	(0.33, 2.02)
^c Day of the Week	0.75	(0.34, 1.64)	1.74	(0.41, 7.47)	0.42	(0.11, 1.67)	2.51	(0.74, 8.55)	1.25	(0.58, 2.70)
^d Home Use	0.81	(0.26, 2.49)	0.01	(<0.01, 0.18) ^{**}	0.19	(0.04, 1.04)	1.92	(0.29, 12.68)	0.79	(0.25, 2.47)
Level 2										
^d _{Sex}	1.11	(0.23, 5.42)	0.61	(0.02, 19.57)	5.10	(0.25, 102.34)	0.89	(0.04, 18.02)	1.33	(0.32, 5.48)
Proportion of Cannabis Use Days	18.18	(1.25, 264.60) [*]	0.08	(<0.01, 40.96)	0.02	(<0.01, 1.90)	0.06	(<0.01, 11.52)	160.98	(12.36, >999) ^{***}

Note. N = 606 cannabis use days nested within 105 individuals; OR = odds ratios; CI = 95% Confidence Intervals.

^aNicotine Use: 1 = Cigarettes, cigars, cigarillos, hookah, or e-cigarettes used; 0 = No cigarettes, cigars, cigarillos, hookah, or e-cigarettes used

^bSocial Context: 1 = 1+ people present; 0 = alone or 0 people present

^cHome Use: 1 = at home; 0 = not at home

^dSex: 1 = Male, 0 = Female.

^{*} $p < .05$

^{**} $p < .01$

^{***} $p < .001$

Table 5.

Multilevel Models of Mode Type Predicting Cannabis Use Outcomes

Fixed Effects	Log Number of Hits		Level of Intoxication	
	<i>b</i>	<i>SE</i>	<i>b</i>	<i>SE</i>
Intercept	1.37	0.07***	38.79	1.97***
Level 1: Type of Mode Day				
Vape-Only (Reference)	-	-	-	-
Bong-Only	-0.17	0.08*	6.09	2.24**
Blunt-Only	0.36	0.12**	5.45	3.51
Joint-Only	0.20	0.10	2.32	2.91
Pipe-Only	0.24	0.11*	0.52	3.16
Multimode	0.64	0.08***	7.99	2.40***
Level 1: Covariates				
Number of Hits	-	-	1.33	0.15***
Number of Drinks	-0.02	0.01**	0.04	0.16
^a Nicotine Use	0.03	0.07	1.95	2.16
^b Social Context	0.08	0.05	1.67	1.60
^c Home Use	-0.01	0.07	-2.37	2.13
Level 2: Person				
Proportion of Cannabis Use Days	1.10	0.17***	-2.00	4.21

Note. *n* = 596 days nested within 105 individuals.

^aNicotine Use: 1 = Cigarettes, cigars, cigarillos, hookah, or e-cigarettes used; 0 = No cigarettes, cigars, cigarillos, hookah, or e-cigarettes used

^bSocial Context: 1 = 1+ people present; 0 = alone or 0 people present

^cHome Use: 1 = at home; 0 = not at home.

*
p < .05

**
p < .01

p < .001