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Temporal associations linking alcohol and cannabis use to cigarette smoking in young adults engaged in a tobacco cessation and relapse monitoring study

Kyle J. Walters [a,*], Noah N. Emery [b], Johannes Thrul [c,d,e], Rachel L. Tomko [a], Kevin M. Gray [a], Erin A. McClure [a,f]

[a] Department of Psychiatry and Behavioral Sciences, Medical University of South Carolina, Charleston, SC, USA
[b] Department of Psychology, Colorado State University, Fort Collins, CO, USA
[c] Department of Mental Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
[d] Sidney Kimmel Comprehensive Cancer Center at Johns Hopkins, Baltimore, MD, USA
[e] Centre for Alcohol Policy Research, La Trobe University, Melbourne, Australia
[f] Hollings Cancer Center, Medical University of South Carolina, Charleston, SC, USA

A B S T R A C T

Young adulthood remains a developmental period in which cigarette smoking initiation and progression to dependence and regular use is common. Moreover, co-use of alcohol and/or cannabis with tobacco is common in this age group and may have detrimental effects on tobacco use rates and cessation outcomes. Although young adults are interested in quitting smoking, achieving abstinence remains difficult, even with evidence-based treatment strategies. Understanding proximal associations between other substance use (e.g., alcohol and cannabis) and smoking may have important treatment implications. This exploratory analysis investigated the role of alcohol and/or cannabis use in contributing to smoking events on the same day or next day among young adults engaged in a smoking cessation and relapse monitoring study. We used ecological momentary assessment (EMA) data from 43 young adults (ages 18–25; 932 observations) who smoked cigarettes daily and agreed to participate in a 5-week study that included a 2-day smoking quit attempt and provision of tobacco treatment in the form of nicotine replacement therapy, brief cessation counseling, and financial incentives for abstinence (incentives were provided only during the 2-day quit attempt). We tested multilevel time-series models of daily associations between alcohol use, cannabis use, and smoking. Consistent with hypotheses, days on which participants were more likely to drink alcohol predicted increased likelihood of smoking the next day (OR = 2.27, p =.003). This effect was significant after controlling for both the one-day lagged effect of smoking (i.e., autoregression) and the concurrent (i.e., same day) effects of drinking and cannabis use. Although there was a positive concurrent effect of cannabis use on smoking (OR = 12.86, p =.003), the one-day lagged effect of cannabis use and the concurrent effect of drinking was not significant, contrary to hypotheses. Results indicate that alcohol use presents a potential threat to successful smoking cessation that extends to the following day. This suggests a risk-window in which treatment could be supplemented with just-in-time interventions and extending the focus on co-use to include this lagged impact on cessation outcomes.

1. Introduction

Adolescence and young adulthood represent developmental periods in which tobacco use is commonly initiated and often progresses to dependence and regular use (Pérez et al., 2021; Sharapova et al., 2020). Smoking remains the leading preventable cause of death in the US (Islami et al., 2018), and most of these deaths (80 %) occur in individuals who began smoking by the age of 18 (U. S. Department of Health and Human Services, 2012; U.S. Department of Health Human Services, 2014). Although young adults (i.e., aged 18 to 24 years) show interest in quitting smoking and are more likely to engage in smoking quit attempts compared to their older counterparts (West et al., 2019), achieving and maintaining abstinence remains difficult (Bancej et al., 2007; Villanti et al., 2020; Watkins et al., 2020). Identifying barriers to successful smoking quit attempts and prevention of relapse among young adults remains an important research focus.

In addition to tobacco use, young adulthood is a developmental period with persistently high levels of alcohol and cannabis use (Cohn et al., 2015). Co-use of these substances among young adults and adolescents is also highly prevalent, which gives rise to particular vulnerabilities during this critical developmental period (Moss et al., 2014). Approximately half of young adults endorsing tobacco use report past 30-day cannabis use (Cohn & Chen, 2022) and up to 98 % of young adult smokers have been reported to currently drink alcohol, with co-use rates greatest among those reporting higher alcohol consumption (Weitzman & Chen, 2005).

* Corresponding author.

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Although results have been mixed, co-use of other substances (e.g., alcohol, cannabis) may serve as barriers to successful cessation. Among young adults, binge drinking has been associated with more cigarettes smoked per day in addition to increased likelihood of having a failed past quit attempt (Gubner et al., 2016). In both adolescents (Haug et al., 2014; Van Zundert et al., 2012) and adults (Weinberger et al., 2017), alcohol co-use has been associated with poorer smoking cessation outcomes. Drinking during smoking cessation among a sample of adolescents (ages 15–19) was concurrently associated with first lapse after quitting (Van Zundert et al., 2012) and drinking at baseline was associated with a 10 % reduction in odds of abstinence at 6-month follow-up (Haug et al., 2014). However, in a 12-week pharmacotherapy trial of smoking cessation in a sample of youth (ages 14–21), baseline alcohol co-use was not associated with smoking abstinence during treatment (McClure, Baker, et al., 2020). In a sample of heavy drinking adult smokers engaged in smoking cessation treatment, risk of smoking lapse on a drinking day was over five times greater than on non-drinking days (Kahler et al., 2010). In summary, while some conflicting findings exist in the literature, alcohol use seems to be implicated in poorer smoking cessation outcomes.

With regard to cannabis, co-use with tobacco has been associated with decreased motivation to quit tobacco (Hindocha et al., 2016). Moreover, cannabis use has been associated with increases in tobacco smoking (Patton et al., 2005; Rubinstein et al., 2014) and poorer tobacco cessation outcomes (Amos et al., 2004; Ford et al., 2002) in adults. In young adults enrolled in a 3-month smoking cessation intervention, cannabis use was associated with 46 % decreased odds of abstaining from smoking as assessed over 12 months of follow up (Vogel et al., 2018). Similarly, adolescents and young adults who co-used cannabis at baseline in a smoking cessation treatment trial had double the odds of continued smoking throughout the trial compared to those who did not co-use (McClure, Baker, et al., 2020). However, several other studies of adults have found no association between cannabis use and smoking cessation outcomes (McClure, Rabin, et al., 2020). Similar to the association between alcohol use and reduced smoking cessation, cannabis also seems to suppress quitting, though some inconsistent findings are reported in the existing literature.

A potential reason for conflicting findings in the literature investigating substance co-use and tobacco cessation outcomes may lie in the way these behaviors are assessed. Previous studies largely investigated either between-persons effects (e.g., individuals who consume more cannabis on average smoke more on average; Hindocha et al., 2016) or concurrent effects (e.g., drinking today associated with smoking today; Kahler et al., 2010; Van Zundert et al., 2012). However, to our knowledge, less is understood regarding the duration of these effects at the within-person level. There is a gap in the literature in the understanding of dynamic temporal associations between alcohol use, cannabis use, and tobacco use across time, particularly among young adults attempting to quit smoking. That is, to what extent does drinking or using cannabis now have downstream consequences for smoking at relatively proximal temporal levels (e.g., day-to-day)? Consequences of use today (e.g., hangover, guilt, social consequences) may impair self-regulation and increase likelihood of smoking tomorrow, despite intentions to quit smoking. This question is potentially important in the context of treatment. If substance use behaviors today predict smoking lapse risk tomorrow, then interventions could be bolstered to address this risk window.

In the current study, we used ecological momentary assessment (EMA) data to estimate multilevel time series models to examine within-person lagged effects of cannabis and alcohol use on next-day smoking in a sample of young adults (ages 18–25) who smoke cigarettes daily and are interested in quitting and enrolled in a 5-week smoking cessation and monitoring study. We hypothesized that cannabis and alcohol use would increase the probability of smoking the following day, controlling for the autoregressive effect of smoking and concurrent effects of alcohol and cannabis use.

2. Methods

2.1. Participants

As part of the parent study (McClure et al., 2023; Walters et al., 2023), we recruited young adults (aged 18–25) from the Charleston, South Carolina community from April 2017 through May 2019 who were daily smokers and were interested in quitting. Participants were recruited via social media advertisements, fliers, word of mouth, and friend referrals and had to meet the following inclusion criteria: (1) smoke at least 5 cigarettes daily for at least 3 months, (2) be willing to limit or abstain from other tobacco products, and if applicable, limit or abstain from using cannabis during the study, (3) be willing to engage in a 48-hour quit attempt, and (4) having interest in quitting smoking (defined as 5 or above on a 10-point scale).Young adults who primarily used electronic nicotine delivery system (ENDS) were included in the final six months of study enrollment. Over the course of the study, all ENDS users also smoked some cigarettes. Thus, we retained ENDS participants ($N = 7$) in the final analysis.[1] Of 62 participants who consented and were screened for eligibility, 46 were eligible and enrolled in the study. Three participants were excluded from this analysis due to having insufficient data to conduct lagged analyses. The final analytic sample for the current secondary analysis ($N = 43$) was 44 % female, 9 % black, and 12 % more than one race or not reported. Fourteen percent identified as Latino/Hispanic. At baseline, 23 participants (53.4 %) reported using any cannabis in the past 30 days ($M = 13.1$ days, $SD = 12.1$). Thirty participants (69.8 %) reported any alcohol use in the past 30 days ($M = 8.1$ days, $SD = 6.9$). De-identified data are available upon written request to the corresponding author and with the execution of a data use agreement.

2.2. Procedures

Participants were trained to use an EMA app to complete: (1) self-initiated cigarette use logs (event-based assessments), (2) EMA assessments (up to four per day), and (3) an evening report daily for 35 consecutive days. Days consisted of participant-selected 12-hour blocks within which sessions were prompted. Participants were asked to log cigarettes smoked in the app in real time. Following the first two self-initiated cigarette use logs, participants were prompted with EMA assessments. In addition, two non-smoking semi-random EMA sessions were prompted each day, at least 30 min apart. Thus, participants could answer up to four EMA prompts daily (two after self-initiated cigarette logs; two semi-randomly and not immediately after a cigarette use log). In addition to alcohol and cannabis use, EMA prompts assessed contextual factors surrounding that occasion, which were not the focus of the present but are included here in order to provide data on overall protocol adherence (presented in results). More detail regarding EMA assessment of contextual factors is provided in Walters et al. (2023). Evening reports asked about cigarette entries not logged in addition to alcohol and cannabis that day.

Participants were asked to make a 48-hour smoking quit attempt starting on the morning of Day 7. To prepare for their upcoming quit attempt, participants were given a combination of nicotine replacement therapy (NRT; patches and lozenges) and brief counseling to support their quit attempt. In addition, financial incentives for abstinence were provided during the 48-hour smoking quit attempt. Participants also completed weekly study visits, which included additional assessments and brief counseling for the parent study. The primary outcome paper describes randomization groups, which were largely methodological

[1] Sensitivity analyses were conducted to determine the extent to which observed relationships differ when ENDS users were excluded from the analysis. In that model that excluded ENDS users ($N = 37$, $n = 844$), the pattern of associations and pattern of statistical significance remained largely unchanged.

and include remote vs. in-person biochemical verification of smoking and abstinence, which has been described elsewhere (McClure et al., 2023).

2.3. Measures

2.3.1. Baseline

Demographics (i.e., age, biological sex), smoking history, and ENDS use (i.e., past 30-day use via Timeline Follow-Back procedures) were assessed at baseline (Lewis-Esquerre et al., 2005; Sobell et al., 1988) to determine eligibility.

2.3.2. EMA assessments

Smoking was assessed by self-initiated cigarette use logs. Evening reports included assessments of additional cigarettes smoked (i.e., cigarettes that were not logged in self-initiated event-based assessments), other nicotine use, alcohol use, and cannabis use. Semi-random prompts also asked participants to report cannabis use and alcohol use. Any day in which smoking was endorsed (i.e., either self-imitated use log, evening report, or semi-random prompt) was coded as a smoking day. Likewise, any day in which cannabis use and/or alcohol use was endorsed (i.e., by either evening assessment or semi-random prompt) was coded as a cannabis use and/or drinking day. Person-level cannabis and alcohol use were the proportion of study days in which the particular substance was used.

2.4. Analysis plan

Multilevel times series analysis was conducted using Stata 15.1 (StataCorp, 2018). This approach disaggregates between and within-person effects and accounts for autocorrelation, thus providing a robust test of within-person effects of alcohol and cannabis use on next-day smoking, controlling for the autoregressive effect of smoking and concurrent effects of alcohol and cannabis use.

Multilevel models were estimated in two stages following the approaches of Simons et al. (2018) and Walters & Simons (2023). The first stage involves estimating residualized scores, which allows estimation of lagged within-person effects. This approach is similar to person-mean centering, but it also takes time trends into account. These scores have a person-mean of zero and reflect deviations from the person's expected score on a given day. In the first stage, multilevel logistic regression models were estimated separately for smoking, drinking, and cannabis (i.e., constructs varying across time and people) with days (Level 1) nested in persons (Level 2). These models included day in the study (time) and six orthogonal day-of-the-week dummy coded indicators as predictors. We also include time^2 to account for potential curvilinear effects. Random intercepts were included in each model, and random slopes for time were included where possible. Residual scores produced for each model reflect the deviations from the individual's expected scores based on time and day of the week.

In the second stage, these estimated residuals were used as predictors of smoking. Thus, the regression of observed smoking at time t on the residual of smoking at time $t-1$ (i.e., previous day) represents the autoregressive effect controlling for the effects of time and day of the week t. The drinking and cannabis residual scores at time t and at time $t-1$ were included as predictors of smoking at time t. In addition, the drinking and cannabis residual scores at time t were included to account for concurrent effects. The stage 2 model also included time in the study and six day-of-the-week indicators as time-varying covariates. Biological sex and age were included as time invariant covariates. The model was specified to have a random intercept and random slope variance components were tested sequentially for each time-varying predictor. Random slopes that were able to be estimated with substantial variance were included in the final model. Smoking was modeled as a logistic outcome. The advantage of this approach is that the estimated residuals from the first stage have a mean of zero and also reflect deviations from the person's expected value (i.e., likelihood of smoking) on a given day in their time series. Thus, the lagged residual effects of cannabis and drinking on smoking will reflect the unique within-person effects of cannabis and drinking on next day smoking controlling for the autoregressive effect of smoking, time, and concurrent effects. See Fig. 1 for an illustration of the proposed model.

3. Results

3.1. Descriptive statistics

Our analysis sample consisted of 43 participants and 932 observations[2]. Participants provided between 3 and 34 days ($M = 24.4$) of data. Participants demonstrated adequate compliance with the protocol, completing 75.5 % of evening assessments and 73.3 % of random prompts. Given the lagged effects of the proposed model, only consecutive days could be used in the final analysis. That is, observations could not be used if preceded by a missing observation. Nonetheless, over half (55 %) of the sample had useable data for at least two thirds (21 days) of the sampling period Almost half of the sample (48 %) consumed all three substances (i.e., tobacco, alcohol, cannabis) over the course of the study. Ninety three percent of participants consumed either alcohol or cannabis. Eighty eight percent consumed alcohol and tobacco and 56 % consumed cannabis and tobacco over the course of the study. We estimated empty models of smoking, drinking, and cannabis use to derive intraclass correlation coefficients (ICC). Less than half the variance in smoking was at the between-person level (ICC = 0.42) while approximately half of the variance in drinking was between-persons (ICC = 0.51). Eighty percent of the variance in cannabis use was a the between-person level (ICC = 0.80). Table 1 provides descriptive statistics and correlations for Level 1 and Level 2 variables.

3.2. Multilevel models

Models were estimated using the melogit command in Stata version 15.1. Smoking was a dichotomous variable modeled with a logistic reference distribution. The model included the 1-day lagged residual for smoking (i.e., the autoregressive effect). It also included 1-day lagged residual scores of drinking and cannabis use, concurrent residual scores of alcohol and cannabis use, six day-of-the week indicators, elapsed time since initiating the study, and a time squared term as Level 1 covariates. Grand mean centered trait alcohol and cannabis use (i.e., subject means), biological sex, and age were included as Level 2 covariates. The model included a random intercept and a random slope for concurrent cannabis use. This was the only random effect large enough to be estimated by Stata with these data. Results are presented in Table 2. Consistent with hypotheses, there was a significant effect of drinking on next day smoking. That is, drinking at time $t-1$ was positively associated with smoking at time t. Given that the drink residual at time $t-1$ is akin to a person-centered binary predictor, it can be interpreted as such. The odds ratio (OR) of 2.27 indicates that, controlling for the residuals of cannabis use and smoking at time $t-1$ (i.e., the autoregressive effect), the residuals of cannabis use and drinking at time t, time, days of the

[2] Stata uses listwise deletion in regression analyses. As a consequence of including both lagged and concurrent effects for drinking and cannabis, there were more opportunities for observations to be omitted than if just lagged effects or concurrent effects were included. We estimated a model that included only lagged effects for drinking and cannabis ($N = 1061$) and a model that included only concurrent effects of drinking and cannabis ($N = 1054$). In addition, we estimated a model with only cannabis use as predictors (lagged and concurrent) and a model with only drinking (lagged and concurrent as predictors. Effects in these models were consistent with the final model that included both lagged and concurrent effects of cannabis use and drinking (See Supplemental Tables).

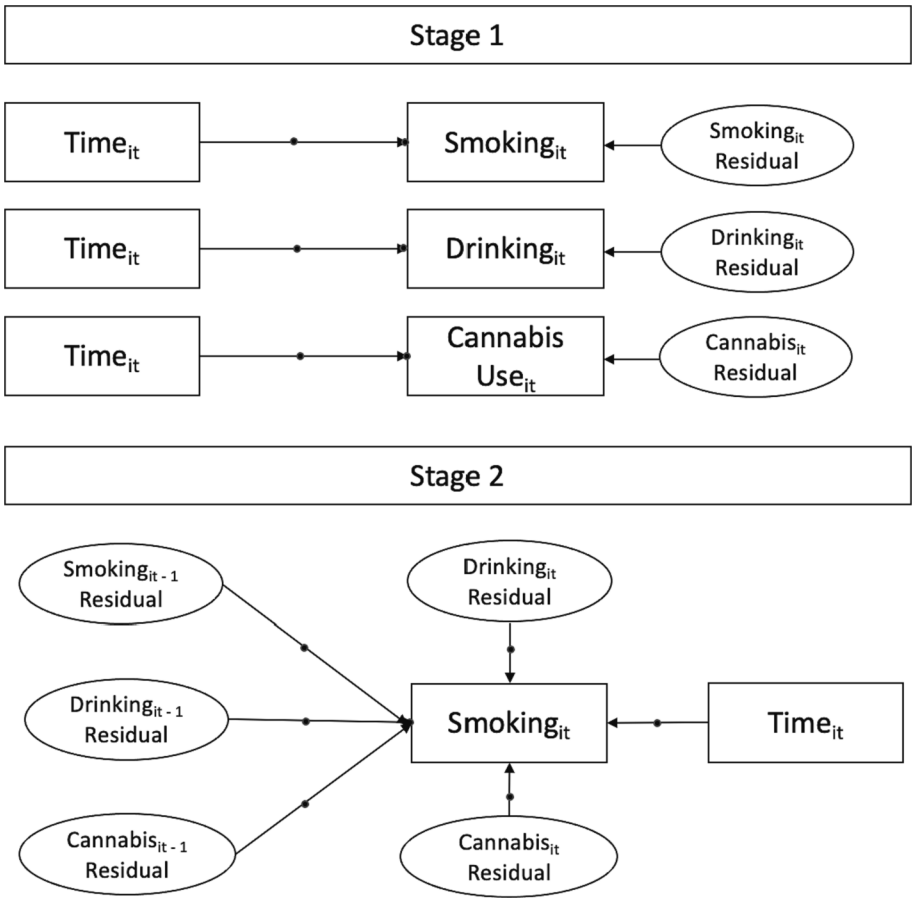

Fig. 1. *Conceptual Diagram of Analytic Approach. Note.* The "i" subscript stands for individual and the "t" subscript stands for time (days) since initiating study. The "it-1" subscripts denote lagged effects. Solid dots are random slopes and intercepts. Some covariates are omitted for clarity (i.e., time^2, day of the week indicators, sex, age, and between person drinking and cannabis use).

Table 1
Descriptive Statistics and Bivariate Correlations.

	M (SD)	Sex	Age	Smoking	Drinking	Cannabis Use
Sex	56 % M	1.00				
Age	21.53 (2.07)	-0.37*	1.00			
Smoking	0.75 (0.43)	0.45**	-0.04	1.00	-0.01	0.10**
Drinking	0.32 (0.46)	-0.23	0.11	-0.08	1.00	0.04
Cannabis Use	0.14 (0.35)	-0.07	0.05	-0.09	0.21	1.00

Note: $N = 43$. Sex is coded 0 = male, 1 = female. Smoking, Drinking, and Cannabis use are the person-level proportion of days in which each substance was used. Within-person correlations are above the diagonal. * $p < .05$ ** $p < .01$.

week, and Level 2 covariates, compared to non-drinking days, drinking days were associated with a 127 % increase in odds of smoking the following day. In addition, as hypothesized, the concurrent residual of cannabis use was positively associated with smoking, such that compared to non-cannabis use days, cannabis use days were associated with an almost 13 times increase in odds of same day smoking ($OR = 12.86$). Contrary to hypotheses, the lagged effect of cannabis use and the concurrent effect of drinking was not significant. Lastly, there was a significant effect for sex, suggesting females exhibited a greater proportion of smoking days during the sampling period. However, no other between-person trait effects were observed.

4. Discussion

Informed by research on the effect of alcohol and/or cannabis use impacting smoking lapse during a quit attempt (Amos et al., 2004; Haug et al., 2014; Van Zundert et al., 2012), we examined within-person lagged effects of cannabis and alcohol use on next-day smoking in a sample of young adults enrolled in a 5-week cessation and monitoring study. Our goal was to determine to what extent drinking or using cannabis use now (e.g., today) has downstream consequences for smoking at relatively proximal temporal levels (e.g., day-to-day) among those trying to quit. To accomplish this, we used multilevel time series modeling to test the one-day lagged effects and concurrent effects of alcohol and cannabis use on smoking in a sample of young adults attempting tobacco cessation. We hypothesized that days in which participants were more likely to use alcohol or cannabis would be associated with increased likelihood of smoking the following day, controlling for the autoregressive effect of smoking and concurrent effects of alcohol and cannabis use.

Our findings add to a growing body of literature on the risk-inducing effects of other substance use on smoking and relapse during a quit attempt. As hypothesized, days in which individuals were more likely to use alcohol were associated with increased odds of next-day smoking,

Table 2
Multilevel Model of Smoking.

Variable	*b*	*SE*	*p*	95 %CI	*OR*
Within-person (L1; time varying)					
Drinking resid *t* −1	0.82	0.28	0.003	0.28, 1.37	2.27
Drinking resid *t*	−0.26	0.27	0.342	−0.79, 0.28	0.77
Cannabis use resid *t* −1	−0.54	0.38	0.157	−1.30, 0.21	0.58
Cannabis use resid *t*	2.55	0.87	0.003	0.85, 4.26	12.86
Smoking resid *t* −1	1.56	0.23	<0.001	1.10, 2.01	4.74
Time	−0.49	0.44	0.263	−1.36, 0.37	0.61
Time^2	0.07	0.13	0.568	−0.18, 0.33	1.08
Day of week covariates					
Monday	−0.05	0.35	0.896	−0.75, 0.65	0.95
Tuesday	−0.24	0.36	0.507	−0.95, 0.47	0.79
Wednesday	−0.69	0.36	0.054	−1.40, 0.01	0.50
Thursday	0.41	0.37	0.266	−0.31, 1.14	1.51
Friday	0.40	0.38	0.285	−0.34, 1.15	1.50
Saturday	0.21	0.37	0.576	−0.52, 0.94	1.23
Between-person (L2; time invariant)					
Drinking	0.78	0.73	0.309	−0.72, 2.27	2.17
Cannabis use	0.73	0.92	0.431	−1.08, 2.54	2.07
Age in years	0.05	0.12	0.657	−0.18, 0.28	1.05
Sex	1.42	0.49	0.004	0.46, 2.38	4.14
Intercept	−0.88	2.94	0.765	−6.65, 4.89	0.42
Random Variance (covariance)					
Cannabis use resid *t*	4.64	3.20		1.21, 17.91	
Intercept	1.67	0.46		0.96, 2.88	
(Cannabis use resid *t*, Intercept)	2.58	1.21	0.033	0.21, 4.95	

Note. $N = 932$ (43 persons), Log likelihood = -380.5400. Time is elapsed days since starting the study. Time was scaled for estimation (i.e., divided by 5) such that the variance was between 1 and 10. Resid = residual, t −1 is a one-day lag. *t* is a concurrent effect. Sex is coded 0 = male, 1 = female. Day of the week effects represent the day's effect compared to Sunday. Between-person drinking is the person-rate of drinking and between-person cannabis use the person-rate of cannabis use. Between-person drinking and cannabis use were grand-mean centered. Bold denotes significance.

controlling for the autoregressive effect of smoking, concurrent effects of drinking and cannabis use, elapsed time in the study, day of the week, and between-person covariates (Level 2; i.e., trait drinking, trait cannabis use, age, and sex). Interestingly, the concurrent effect of drinking was not significant but there was a concurrent effect of cannabis use on smoking. Contrary to hypotheses, the lagged effect of the within-person residual of cannabis use was not significant.

The lagged effect of drinking on next day smoking suggests that effects of drinking endure beyond the specific drinking episode and may compromise one's quit attempt well beyond that specific episode's time frame. While research has detailed the acute effects of drinking on a smoking quit attempt (e.g., Van Zundert et al., 2012), these results reveal a risk window that extends beyond what has been previously documented. This result is particularly striking given up to 98 % of young adults who smoke also drink alcohol (Weitzman & Chen, 2005). Though the exact mechanisms driving this extension of the risk window are unclear, there are a few possible candidates. This could be the result of lingering physiological symptoms of heavy drinking (e.g., hangover, withdrawal), which have been shown to have implications for self-regulation (Devenney et al., 2019). Indeed, hangover onsets when blood alcohol concentration approaches zero (van Schrojenstein Lantman et al., 2016) and is characterized by impairments in executive functioning (Gunn et al., 2020; Scholey et al., 2019), which have been inversely associated with tobacco cessation success (Brega et al., 2008). Likewise, alcohol withdrawal develops in the 6–24 h after discontinuation of alcohol consumption and is characterized by irritability and confusion among a host of uncomfortable physical symptoms like hangover (Mirijello et al., 2015), all likely to impact the success of a quit attempt. In addition, even in the absence of hangover, guilt about excess alcohol use or limit violations the previous day can result in poor self-regulation (Muraven et al., 2005) and may contribute to subsequent lapses. Taken together, it is not surprising that alcohol use contributes to extended risk window for subsequent smoking lapse.

The concurrent effect of cannabis use on smoking on the same day suggests that using cannabis may increase the likelihood of a smoking lapse. This is consistent with research demonstrating that cannabis use has been associated with increases in smoking (Patton et al., 2005; Rubinstein et al., 2014) and poorer smoking cessation outcomes (Amos et al., 2004; Ford et al., 2002; McClure et al., 2020; Vogel et al., 2018). However, these previous findings consist largely of either between-persons effects (e.g., individuals who consume more cannabis on average smoke more on average, monthly cross-sectional associations) or macro-longitudinal effects (e.g., 12-month prospective follow-up). It should be noted that the large concurrent effect of cannabis use in this study is accompanied by a large standard error and wide confidence intervals. Additionally, this large effect may be an artifact of infrequent cannabis use in the sample. Among the limited cannabis use days in this study (14 % of days), 86 % were concurrent with smoking days. This suggests that the large effect of concurrent cannabis use on smoking was driven by a small number of individuals/days where smoking only occurred on cannabis use days. Thus, interpretations of this effect should be made with caution and future work should investigate this in larger samples with more cannabis use. Interestingly, the lagged effects of cannabis use and the concurrent effect of drinking, however, were not significant. The reasons for this could be due, in part, to the context of typical use. That is, perhaps the locations where cannabis use occurs have high exposure to smoking cues and availability to smoke (cigarettes), thus increasing risk for cigarette use. On the other hand, many bars and restaurants are now smoke-free, limiting co-use of alcohol and tobacco. However, unlike cannabis, the aftereffects of alcohol may be enough to trigger smoking when it is available (e.g., the following day). Although the null concurrent effect of alcohol use appears inconsistent with work showing increased perceived reward of cigarettes when drinking alcohol (Gubner et al., 2018; Thrul et al., 2021; Thrul et al., 2019), these studies either looked at cross-sectional between-person effects or did not model the autoregressive effect of smoking. Indeed, we found evidence of an autoregressive carryover effect of smoking such that smoking yesterday increased the odds smoking the following day. While not surprising, this result is consistent with the transition from an initial lapse to relapse (Shiffman et al., 1996), which suggests re-exposure to an addictive substance itself sets up the conditions for resumption of regular use. In sum, this study's results highlight the importance of modeling within-person temporal trends of smoking and substance co-use.

Several limitations of the current study should be noted. First, as described in Footnote 2, the inclusion of both lagged and concurrent effects resulted in more opportunities for missing data (Stata uses list-wise deletion). However, sensitivity analyses showed that omitting concurrent effects of alcohol use and cannabis use resulted in a similar pattern of lagged effects. This coupled with protocol adherence that is consistent with adherence in most EMA substance use studies (Jones et al., 2019) tempers our concerns related to missing data. However, given the relatively small sample and exploratory nature of the current analysis, results should be interpreted with caution. We also tested several additional models (see Supplemental Tables) with different combinations of predictors (e.g., all lagged, all concurrent, only drinking, only cannabis use) and results were robust across models. As such, we report effects of the originally hypothesized model in Table 2. Our inability to model between-person variation of the effects of all predictors (i.e., random slopes) is also a limitation. It is likely that there are some individuals for whom drinking is associated with greater likelihood of smoking the following day, and others for whom there is no association or perhaps even an inverse association. Future work with larger samples should explore this further. Also, our analyses did not consider quantity of drinking, which will be important to explore in future studies to better understand hypothesized mechanisms for why drinking would led to increased likelihood of next day smoking (e.g., because of hangover or regret).In addition, although all participants

enrolled in this study were interested in quitting and attempted a quit attempt during the sampling window, these results only capture smoking in general and not lapse episodes specifically. Thus, interpretation regarding how alcohol and cannabis use affect cessation lapses should be made with caution.

Results from this secondary analysis reflect potentially important clinical implications worth further pursuit. The lagged effect of drinking on smoking presents potential opportunities for timely intervention. Individuals receiving treatment for smoking cessation can monitor their alcohol use in real-time and smart phone apps can deliver just-in-time interventions to prevent lapse (Hébert et al., 2018). Future work should incorporate higher density assessment within days in order to adequately model the complex dynamics of substance co-use at more proximal temporal windows. In addition, future work could investigate whether longer lagged effects (e.g., two days, weeks) of drinking and cannabis use exist.

*Note.

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CRediT authorship contribution statement

Kyle J. Walters: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Noah Emery:** Conceptualization, Writing – original draft, Writing – review & editing. **Johannes Thrul:** Conceptualization, Writing – original draft, Writing – review & editing. **Rachel Tomko:** Writing – review & editing, Data curation. **Kevin M. Gray:** Supervision, Resources, Funding acquisition, Writing – review & editing. **Erin A. McClure:** Conceptualization, Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

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

Data availability

The final dataset will be made available to qualified requestors in accordance with NIH Data Sharing Policies and with an executed data use agreement between MUSC and the requestor.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2023.107902.

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