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Marijuana use is associated with alcohol use and consequences across the first 2 years of college

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Abstract

College entry is associated with marijuana initiation, and co-use of alcohol and marijuana is associated with problematic outcomes, including alcohol-related consequences. The present study explored if: 1) use of marijuana on a given day would be associated with greater alcohol use within the same day; 2) use of marijuana within a given week would be associated with increased alcohol-related consequences in that same week; and 3) the association between marijuana use and alcohol consumption and consequences varies across time or by pre-college level of problematic alcohol use. Participants ($N=488$ college student drinkers, 59% female) completed assessments of marijuana use, alcohol use, and alcohol consequences across two years. Analyses revealed: 1) daily marijuana use predicted greater number of daily drinks and estimated breath alcohol concentration; 2) weekly marijuana use predicted more weekly positive and negative alcohol consequences; 3) the effect of daily marijuana use on alcohol use strengthened over time, while the effect of weekly marijuana use on positive alcohol consequences reduced over time; and 4) pre-college level of problematic alcohol use moderated the association between daily marijuana and alcohol use and weekly marijuana use and negative consequences. This study provides the first longitudinal evidence of the association between marijuana use and greater alcohol use and consequences in college students. Future research examining event-level measurement of alcohol and marijuana co-use is important for the prevention of alcohol-related consequences.

Keywords

Alcohol use; marijuana use; co-use; alcohol consequences

Introduction

Alcohol use and alcohol-related consequences are important public health concerns among college students. The transition into college not only represents a period of increasing rates of alcohol use (Stone, Becker, Huber, & Catalano, 2012; White et al., 2006), but also

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consequences from use (Merrill, Kenney, & Barnett, 2017). Thus, it is important to understand the factors contributing to alcohol use and alcohol-related consequences during this period. One potential contributor to the amount of alcohol consumed and the consequences thereof is the co-use (e.g. use of both substances during a given time period, but not necessarily simultaneously) of alcohol with other substances such as marijuana. Rates of marijuana use have doubled in the last two decades (Hasin et al., 2015), and the prevalence of marijuana use among college students is at its highest in 30 years (Schulenberg et al., 2017). Further, entering college is associated with marijuana initiation and increased use (Suerken et al., 2014; White et al., 2006). In large samples of college student marijuana users, 88% report engaging in alcohol use (Suerken et al., 2014), and 69% report heavy or “binge” drinking (defined as 4/5 drinks on a single occasion for females/males) in the past 30 days (Primack et al., 2012).

Compared to using alcohol alone, marijuana and alcohol co-use is associated with a variety of deleterious outcomes. Alcohol and marijuana co-users evidence a potentiated risk for alcohol-related consequences and alcohol use disorders (Brière, Fallu, Descheneaux, & Janosz, 2011; Haas et al., 2015; Hasin et al., 2015; Keith, Hart, McNeil, Silver, & Goodwin, 2015; Shillington & Clapp, 2006; Weiss & Dilks, 2015). Cross-sectional data in both adolescent and adult samples indicate that when marijuana and alcohol are used together, they are associated with higher levels of consumption compared to when either substance is used alone (Brière, Fallu, Descheneaux, & Janosz, 2011; Patrick, Kloska, et al., 2017; Patrick, Veliz, & Terry-McElrath, 2017; Subbaraman & Kerr, 2015). Simultaneous use (i.e., using both substances at the same time so that their effects overlap) is associated with increased incidence of motor vehicle collisions (Ramaekers, Berghaus, Van Laar, & Drummer, 2004; Sewell, Poling, & Sofuoglu, 2009; Terry-McElrath, O’Malley, & Johnston, 2014), injuries (Harrington et al., 2012), and risky sexual behavior (Metrik, Caswell, Magill, Monti, & Kahler, 2016; Parks, Collins, & Derrick, 2012). Even among college students who are moderate alcohol users, co-use of marijuana is associated with more negative alcohol-related consequences, such as blackouts, injury, and driving under the influence (Haas et al., 2015).

Positive consequences of substance use are important to investigate; recent work has highlighted the importance of examining positive consequences related to alcohol use given they occur more frequently (Barnett et al., 2014; Park, 2004) and have been shown to significantly contribute to increased and sustained alcohol use (Lee, Maggs, Neighbors, & Patrick, 2011; Usala, Celio, Lisman, Day, & Spear, 2014). Though understudied, there are likely also positive consequences of alcohol and marijuana co-use. Indeed, young adults endorse a variety of motives for engaging in simultaneous alcohol and marijuana use, including enhanced positive subjective effects and social motives (Patrick, Fairlie, & Lee, 2017). These motives likely derive from positive consequences experienced as a result of simultaneous use (e.g., “having a good time”). Whether marijuana use increases positive consequences attributed to drinking (in turn potentially augmenting the reinforcing value of either or both substances) is unknown.

Alcohol and marijuana co-use also has implications for alcohol intervention efficacy. Within college samples, students who reduce their alcohol use following brief interventions tend to

be those who do not use marijuana or who also reduce marijuana use (White et al., 2015). Similarly, recent work in community samples suggests that use of marijuana during treatment for alcohol use disorder (AUD) may result in negative outcomes, particularly decreased likelihood of alcohol abstinence and increased problems related to alcohol use (Mojarrad, Samet, Cheng, Winter, & Saitz, 2014; Subbaraman, Metrik, Patterson, & Swift, 2017). Therefore, marijuana use appears to be an important predictor of alcohol consumption, consequences, and clinical outcomes. Despite this compelling body of work regarding the association between marijuana use and alcohol-related outcomes, less is known about how the level of problematic alcohol use may moderate the link between marijuana and alcohol use and consequences at the event-level or across time.

Two distinct theories of co-use posit that alcohol and marijuana act as either: (a) substitutes (i.e., individuals use marijuana in order to substitute for the effects of alcohol); or (b) complements (i.e., individuals use marijuana [or alcohol] to enhance intoxication). Evidence for the *substitution* hypothesis arises from treatment outcome research. Abstinence from marijuana while in treatment for problematic alcohol use is associated with greater alcohol craving and consumption (Peters & Hughes, 2010). In contrast, evidence also exists for the *complementarity* hypothesis. For example, using six months of timeline follow back data in a sample of veterans, Metrik and colleagues (2018) found that heavy alcohol use is more likely on marijuana use days, particularly for individuals with a current AUD. In a recent review attempting to elucidate these competing theories, Subbaraman (2016) found compelling evidence that individuals engage in both substitution and complementarity of alcohol and marijuana use. Several moderators of these competing theories have also been highlighted, including person-level factors (e.g., age (Wen, Hockenberry, & Cummings, 2015). Additional person-level moderators, such as problematic substance use, may have important implications for intervention and prevention efforts. For instance, recent work has shown that individuals with an AUD are more likely to report binge drinking on days when marijuana is used (Metrik et al., 2018), suggesting these individuals may be at increased risk for alcohol-related consequences when using marijuana. Longitudinal studies examining co-use of alcohol and marijuana at the daily level and subsequent consequences would provide clarity about the nature of these associations.

Three studies have examined marijuana/alcohol use associations at the daily level, of which two (Hughes et al., 2014; O'Hara, Armeli, & Tennen, 2016) focused on the effect of alcohol use on marijuana use rather than the effect of marijuana use on alcohol use. These studies found evidence for the complementary hypothesis, such that alcohol use predicted a greater likelihood of marijuana use (O'Hara et al., 2016) and self-reported marijuana intoxication (Hughes et al., 2014). In an analysis examining the effect of marijuana use on alcohol outcomes, Mallett et al. (2017) found that third-year college students reported significantly more alcohol-related consequences on occasions in which they used marijuana in the same day (Mallett et al., 2017). However, this data collection consisted of a brief assessment window (i.e. two consecutive weekends in each semester) and did not examine whether marijuana use predicted increased alcohol consumption at the daily level. More research using ecologically valid studies is needed to examine whether marijuana use contributes to increased alcohol use at the daily level.

Current Study

The current study extends this body of work by examining daily associations between marijuana and alcohol use and weekly associations between marijuana use and alcohol-related consequences in college students using a rich two-year longitudinal dataset. The assessment windows included 36 bi-weekly repeated measures of daily marijuana use, daily alcohol use, and weekly alcohol-related consequences over a two-year period in a large sample ($N = 488$) of college students with a history of marijuana use. The use of weekly reports over an extended time period increases reliability of reporting, provides valuable insight regarding complementary versus substitution hypotheses, and allows for the examination of change and patterns of daily co-use over time. We hypothesized: (1) use of marijuana on a given day would be associated with greater alcohol use (i.e., number of drinks; estimated blood alcohol concentration [eBAC]) within the same day; (2) use of marijuana within a given week would be associated with increased negative alcohol-related consequences in that same week; and (3) the effect of marijuana on daily alcohol consumption and weekly negative consequences would be stronger for individuals with higher level of problematic alcohol use upon entering college. Finally, we examined two exploratory aims: (1) the association between marijuana use within a given week and positive alcohol-related consequences, and (2) how the association between marijuana and alcohol consumption and consequences may change over time.

Method

Participants

Participants were drawn from a larger 2-year naturalistic longitudinal study ($N = 1,053$) examining changes in alcohol use patterns among students in their first and second years of college. Participants were recruited from three universities in southern New England prior to arriving for their first year of college. See (Hoepfner et al., 2012) and (Barnett et al., 2014) for details about the universities from which the sample was recruited. Students were eligible to participate if they were: (1) enrolled at one of the three participating universities; (2) under 21 years of age; (3) intended to be enrolled full time; (4) planned to live on campus during freshman year; and (5) not international students. The current study focuses on a subset of students ($N = 488$) who reported consuming at least one alcoholic drink and using marijuana at least once during data collection (see below). Participants were, on average, 18.4 ($SD = 0.41$) years of age at baseline, 59% female, and 69% white. The percentage of study participants self-identifying as white was greater than the parent study; thus, we control for race in all analyses. No other significant differences were identified between those included in this study and the larger sample.

Procedures

Incoming students received letters inviting them to enroll in the study during the summer prior to the start of college (43% recruitment rate). Parents of minors received a similar letter and their consent was required for their child to participate. Using information provided from the universities, a sex-stratified sample of students, oversampling for racial/ethnic minority status, received an invitation to participate and \$5 for considering participation. Participants completed the baseline assessment battery before arriving to campus.

Participants then received biweekly emails containing links to an online survey beginning the first week after arriving to campus. To minimize response burden over the two years of the study, participants were randomly assigned to one of two biweekly alternating assessment groups. That is, in any given week, half of participants were asked to complete surveys. Surveys were available for completion for one week and participants reported on data for the seven days prior to the response day. Surveys were collected during the academic year only, excluding summer breaks due to potential differences in patterns of substance use (e.g. increased use during academic breaks) during these times, to limit external contextual differences, and to reduce participant burden. Participants earned \$20 for completing the baseline (pre-college) survey. At the end of the semester, participants received \$2 for each completed biweekly assessment and \$20 for 85% completion of biweekly surveys in each semester. After completing each biweekly survey, participants had a 1 in 50 chance of winning \$100. Response rates ranged from 77% - 91% across the 36 weeks. All procedures were approved by the Institutional Review Boards of the respective institutions.

Measures

Baseline Survey

Demographics.: Participants reported sex, age, and race.

Alcohol Use, Problems, Dependence.: The 10-item Alcohol Use Disorders Identification Test (AUDIT: Saunders et al., 1993) questions screened for alcohol use, problems, and dependence. A sum score was created for the present analyses, ranging from 0-10. Cronbach's α in the present sample = .76. The AUDIT was completed in the baseline assessment (before students arrived on campus), and queried alcohol-related problems over the past year.

Biweekly Surveys

Daily Alcohol Use.: Participants reported number of standard drinks consumed and the length of time spent drinking on each day during the past week using a calendar grid. We calculated estimated blood alcohol concentration (eBAC) from drinking information, sex, and weight (reported at least annually), for each day of drinking with the following formula: $BAC \text{ (in g/dl)} = [(number \text{ of standard drinks}/2) \times (\text{sex constant of } 9.0 \text{ for females or } 7.5 \text{ for males/weight in pounds})] - (0.017 \text{ g/dl for the rate of alcohol metabolism per hour} \times \text{time in hours from first sip of alcohol})$ (Matthews & Miller, 1979).

Daily Marijuana and Cigarette Use.: Participants indicated if they smoked marijuana (yes/no) and reported number of cigarettes smoked ("how many cigarettes did you smoke on this day"; cigarettes were defined as including: tobacco cigarettes, clove cigarettes, kreteks, bidis) for each of the seven days prior to completing the survey.

Weekly Alcohol-related Consequences.: Participants who endorsed alcohol use were asked if they experienced any of 13 negative consequences or 11 positive consequences during or after drinking alcohol in the past week. Alcohol-related consequences were not assessed at the daily level in order to reduce response burden for participants. Positive and negative

consequences were chosen from well-established measures of consequences of alcohol use (Fromme, Katz, & Rivet, 1997; Fromme, Stroot, & Kaplan, 1993; Hurlbut, & Sher, 1992; Kahler, Strong, & Read, 2005; Leigh & Stacy, 1993; Noar, Laforge, Maddock, & Wood, 2003; Saunders et al., 1993) and had acceptable internal reliability in our sample (average biweekly $\alpha = .81$). Negative alcohol-related consequences included: being physically sick, not remembering part of the night, saying something that you later regretted, feeling sad or depressed, disappointing others, regretted sexual activity, problems at school/work, passing out, being physically injured, drinking and driving, getting into trouble with authorities/police, accidentally physically hurting someone, or getting into a flight. Positive consequences included: having a good time, talking to someone you were sexually attracted to, feeling less/more relaxed, enjoying sex more, feeling more energetic, having an easier time socializing, feeling like a part of a group, feeling more self-confident, feeling sexier, being able to take your mind off of problems, and expressing thoughts/feelings more easily. Consequences were recorded only for participants who reported one or more drinking days in the week¹. We computed weekly sums for number of negative and positive alcohol-related consequences (see Table 1 for descriptive statistics).

Data Analysis

Analytic Plan—We conducted a series of generalized linear mixed models (GLMMs; Hedeker, 2005) using *lme4* (Bates, Mächler, Bolker, & Walker, 2015) in R 3.43 (R Core Team, 2013), which we chose for their appropriateness in modeling our outcome distributions and data structures. At the daily level, we regressed alcohol use, operationalized as daily number of standard alcoholic drinks consumed (Model 1a) or daily eBAC (Model 1b), onto subject-level covariates, daily time-varying covariates, and a binary variable indicating daily marijuana use. Separate models were run to assess these two unique operationalizations of alcohol consumption because: (1) they reflect different aspects of drinking; and (2) eBAC may be a more robust measure of level of intoxication, as it accounts for the passage of time and gender. To examine if the relationship between daily marijuana use and alcohol use was moderated by subject-level problematic alcohol use (measured at baseline), we included the cross-level interaction of the AUDIT with daily marijuana use in both models. In the Model 1b (eBAC as the dependent variable), we removed the covariate of sex, as this was accounted for in the calculation of the outcome variable. AUDIT scores were mean centered. Additionally, to examine if the relationship between daily marijuana and alcohol use changed over time, we include an interaction between daily marijuana use and study day.

At the weekly level, we regressed positive (Model 2a) and negative (Model 2b) alcohol use consequences onto subject-level covariates, weekly time-varying covariates, and past-week number of marijuana use days. As in Models 1a and 1b, we included a cross-level

¹Participants were assigned scores of 0 for number of consequences for drinking weeks on which they did not experience alcohol-related consequences. Number of consequences were coded as missing for weeks on which no drinking was reported. We chose not to enter zero for consequences on non-drinking weeks, as these two scenarios (0 consequences because one did not drink and 0 consequences on weeks when one did drink) are qualitatively different. Further, entry of 0 for consequences on weeks when participants had 0 drinks might inflate the strength of the association tested (due to perfect correlations between drinking and consequences on all non-drinking weeks). This approach is consistent with existing publications with data from this project (Merrill et al., 2017).

interaction between marijuana use and AUDIT and an interaction between time (i.e., biweekly period) and marijuana use. Both AUDIT scores and past-week number of marijuana use days were mean centered. Random intercepts were estimated in all models. We computed intra-class correlations for all models to evaluate the proportion of variance in dependent variables accounted for by clustering (non-independence) in daily or weekly observations by participant.

Covariates

Subject-level: Covariates included: participant school and survey group (i.e. which alternating-week surveys administered); self-reported age, sex, race (white vs. nonwhite). In order to control for between-subject variance in marijuana use severity, we controlled for percent marijuana use days (computed as # of days of marijuana use / # days of survey responses by participants).

Time-varying – Daily: Time was controlled for with two variables: 1) each participant's day in the study (number of days since first report); and, 2) a binary indicator of weekday vs. weekend (i.e., Thurs, Fri, Sat). Daily cigarette use was controlled for using a binary variable (yes / no).

Time-varying – Weekly: Time was controlled for with a numeric indicator of biweekly assessment period, ranging from 0-17 and 26-43 in freshman and sophomore years respectively. Assessments were not administered during the summer months between years (i.e., biweekly periods 18–25). We computed average daily cigarettes per day (CPD) from daily data (total number of cigarettes in given week / 7). We also computed a weekly average number of alcoholic drinks per drinking day (number of alcoholic drinks in given week / number of drinking days that week).

Results

Participants provided an average of 30.5 (SD = 8.6) surveys (out of 36 biweekly surveys in the academic years). See Table 1 for sample descriptive statistics.

Effect of Daily Marijuana use on Alcohol Use

Results from the GLMMs predicting daily number of alcoholic drinks or eBAC from time (study day), marijuana use, AUDIT scores, the interaction between marijuana use and AUDIT score, the interaction between marijuana use and time, and subject-level and time-varying covariates are presented in Table 2. Consistent with hypotheses, on days on which participants used marijuana, they also consumed more drinks and attained a higher eBAC. Baseline AUDIT scores were associated with higher daily number of drinks and eBAC. However, this effect was qualified by a significant positive interaction between AUDIT scores and daily marijuana use. Specifically, participants with higher AUDIT scores demonstrated a stronger relationship between daily use of marijuana and daily number of drinks or eBAC than those with lower scores (see Figure 1). Furthermore, study day significantly negatively predicted daily number of drinks and eBAC (i.e., drinking decreased over time). However, the significant positive interaction between daily marijuana use and

study day in both models indicated that marijuana use at the daily level was associated with more drinking and higher eBACs over the course of the study. These findings were observed in the context of controlling for significant covariates of sex, weekend days, and subject level marijuana use, cigarette use. Of note, while marijuana use at the daily level positively predicted daily alcohol use, subject level marijuana use negatively predicted daily number of drinks and eBAC. Clustering accounted for 8.6% of variance in daily number of alcohol drinks and 10.0% of variance in eBAC.

Effect of Weekly Marijuana Use on Alcohol Consequences

Results from the GLMMs predicting weekly positive and negative alcohol use consequences from past-week marijuana use days, time (biweekly period), AUDIT scores, interactions between marijuana use and AUDIT score and time, and subject-level and time-varying covariates are presented in Table 3. Consistent with hypotheses, number of past-week marijuana use days were positively associated with both weekly positive and negative alcohol use consequences (controlling for significant covariates of sex and race). As expected, AUDIT scores were associated with negative but not positive alcohol use consequences. However, a significant interaction between AUDIT scores and past-week marijuana use days on negative consequences was also found; such that participants with higher AUDIT scores were more likely to experience more negative alcohol use consequences on heavier marijuana use weeks (Figure 2). AUDIT scores did not interact with the association between past-week marijuana use days and weekly positive alcohol use consequences. Biweekly assessment period negatively predicted positive and negative alcohol consequences. Further, the relationship between past-week marijuana use days and positive alcohol use consequences was qualified by a significant interaction with biweekly period such that this effect was attenuated over the study period. A similar trending ($p = .062$) effect was observed for negative consequences. Clustering accounted for 43.2% of variance in positive and 22.0% of variance in negative weekly alcohol use consequences.

Discussion

The present study extends the current literature on alcohol and marijuana co-use by examining marijuana's association with alcohol consumption and alcohol consequences in a rich longitudinal data set of college students. This is the first study to examine patterns of alcohol and marijuana use at the daily level in a longitudinal design. We found that on days in which marijuana was used, participants reported a higher number of drinks consumed and higher eBAC. Additionally, we found a significant time by marijuana interaction on alcohol use, suggesting that as time went on, students were increasingly more likely to drink more on marijuana use days, suggesting positive reinforcement from co-use. Interestingly, we also found a negative association between an individual's overall percent of marijuana use days and daily alcohol consumption. This effect suggests that individuals who are overall heavy marijuana users generally drink less, but that marijuana users may be more likely to drink more on co-use days. Although only studies that assess timing of substance use (e.g. using ecological momentary assessment) would be able to test directional hypotheses, the present results support the complementary hypothesis of substance co-use, in that participants reported using more alcohol on days when marijuana is also used. This finding is consistent

with existing retrospective (Metrik et al., 2018) and event-level research (Hughes et al., 2014; O'Hara et al., 2016) showing that marijuana use at the daily level is associated with heavy (binge) alcohol use.

The present study is also first to examine marijuana's association with alcohol-related consequences at the weekly level within the same sample across an extended period of data collection (two years). We found that more marijuana use in a given week was associated with increased number of negative alcohol consequences experienced that week. These results are consistent with the only event-level study examining the relationship between marijuana use and alcohol-related consequences (Mallett et al., 2017), which found alcohol-related consequences were more likely on co-use days. Our findings extend these results by confirming the positive relationship between weekly marijuana use and negative alcohol consequences over a two-year period of assessment in college students. Interestingly, we found that individuals were less likely to experience both positive and negative consequences over time.

This is the first study to examine the relationship between marijuana use and positive alcohol consequences. We found that weekly marijuana use predicted higher endorsement of positive consequences, suggesting that individuals who use marijuana more in a given week are more likely to experience positive alcohol consequences. Additionally, we found a significant negative time by marijuana interaction on positive alcohol consequences, suggesting that as time went on, students were less likely to experience positive alcohol consequences on weeks when they were engaged in more alcohol and marijuana co-use. However, this interaction was not significant for negative consequences. Therefore, although positive consequences decline and negative consequences are sustained over time, we did not observe reduced co-use over time. Importantly, the main effect of weekly marijuana use on positive consequences was not moderated by baseline problematic alcohol use. This suggests that positive consequences experienced may partially explain motivation for engaging in maintenance of co-use behaviors, especially in the absence of experiencing problems from alcohol use.

Finally, this is the first study to examine how problematic alcohol use before entering college (as measured with the AUDIT) affects the associations between marijuana and alcohol use and consequences with longitudinal event-level data. Notably, the associations between marijuana use and alcohol use (at the daily level) and negative consequences (at the weekly level) were more pronounced for individuals who reported higher levels of problematic alcohol use before entering college. In other words, these individuals consumed even more alcohol on marijuana use days and incurred more negative consequences during weeks in which they consumed marijuana more frequently. These findings suggest that for those with more problematic alcohol use, marijuana may be particularly problematic (i.e., lead to more drinking). This finding is consistent with research using a retrospective report design (Metrik et al., 2018).

Finding that marijuana use at the daily level was associated with higher alcohol consumption may be explained by a desire for increased subjective effects from simultaneous use. Recent work examining simultaneous alcohol and marijuana use motives in a young adult

population found that among several motives, positive effects for simultaneous use were the most strongly endorsed (Patrick et al., 2017). For example, motives such as “cross-faded effects are better” and “to get a better high”, suggest that participants may engage in co-use (and increased drinking) for the synergistic effects on impairment. This finding may also be explained by reduced inhibitory control caused by marijuana or its synergistic effects with alcohol (Chait & Perry, 1994; Metrik et al., 2012; Ramaekers et al., 2006). That is, acute effects may lead to poor control over drinking, as reduced inhibitory control has been shown to increase ad libitum alcohol consumption in laboratory studies (Jones et al., 2013; Weafer & Fillmore, 2008).

However, our finding that these associations were pronounced for students higher in problematic alcohol use are not consistent with those of O’Hara et al. (2016), who found that individuals more likely to use substances to cope were less likely to use cannabis as alcohol use increased. This pattern of findings might be due to methodological differences, namely the directionality of the co-use hypothesis. Whereas O’Hara et al. (2016) found that greater alcohol use predicted lower odds of using marijuana among those higher in drinking to cope motives, we found that marijuana use predicted greater alcohol use for those with higher levels of problematic alcohol use. This highlights the importance of studying the directionality of these effects through more temporally-sensitive, daily-level analyses, as done in this study.

Limitations

The current research should be interpreted in the context of its limitations. First, all variables were assessed with self-report measures, and could be subject to recall biases and demand characteristics. However, assessments were conducted for the past week in an effort to reduce limitations of memory recall biases and to increase reliability of reporting. Second, given consequences were only assessed weekly, we were unable to isolate consequences at the daily level, which precludes a conclusion that marijuana use at the daily level was directly associated with the alcohol consequences experienced. However, isolating problems experienced at the weekly level across two years is novel and important, as previous work is limited to cross-sectional studies showing individuals who co-use are more likely to experience consequences (Brière et al., 2011; Haas et al., 2015; Hasin et al., 2015; Keith et al., 2015; Shillington & Clapp, 2006; Weiss & Dilks, 2015). Future work should utilize ambulatory assessment data collection methods to examine the direct relationship between marijuana use and alcohol-related consequences at the daily or even event-level. Third, our measure of marijuana use asked participants if they had “smoked” marijuana. Since these data were collected, alternative methods for consuming marijuana (vaping, edibles) have increased; the method of consumption may alter findings. Further, we only assessed whether or not participants used marijuana on each day. A more comprehensive assessment (i.e. amount, type, potency) of marijuana would have provided depth to our understanding of the association between daily marijuana use and alcohol consumption. For instance, it may be that the effect on alcohol consequences is qualified by heavier marijuana use days. Additionally, we only measured alcohol-related consequences specifically, but were unable to examine consequences that may have arisen from co-use or marijuana use alone. Finally, we are unable to make causal inferences based on the nature of the present data. In order to

further elucidate the true nature of the association between alcohol and marijuana (substitution versus complementarity), detailed assessment, including timing of use, is necessary. Furthermore, future studies would benefit from examining other patterns of co-use behaviors (e.g. marijuana and tobacco co-use) in event-level studies, and their effect on alcohol consumption and related consequences.

Implications

These findings have important clinical implications for preventing alcohol-related consequences among emerging adults, especially for those experiencing or at-risk for AUDs. Results suggest that marijuana use in this population is associated with higher levels of alcohol use and alcohol-related consequences. Results are consistent with studies indicating that marijuana use leads to poorer alcohol treatment outcomes (Aharonovich et al., 2005; Mojarrad et al., 2014; Subbaraman et al., 2017) and provides further evidence that individuals in treatment for AUDs should abstain from marijuana use. This is particularly relevant when thinking about AUD treatment in the context of the increasing legalization of marijuana use. As the public's perception of the harmfulness of marijuana decreases in line with recent changes to medicinal and recreational marijuana legislation (Keyes et al., 2016), this may have implications for the increased prevalence of co-use in treatment seeking individuals with AUDs who may also perceive marijuana use to be low risk. In addition, our results provide important information regarding positive alcohol consequences experienced on weeks when marijuana is used. Although individuals with alcohol problems may experience increased negative consequences, they may also simultaneously experience positive consequences (e.g. increased positive subjective effects and social effects) when using marijuana. Understanding these motivations for the co-use of marijuana and alcohol will aid clinicians in working collaboratively with individuals who co-use marijuana and should be a focus of future research efforts. Examining time-dependent measurement of alcohol and marijuana co-use is an important future direction for research examining alcohol-related risks associated with marijuana use.

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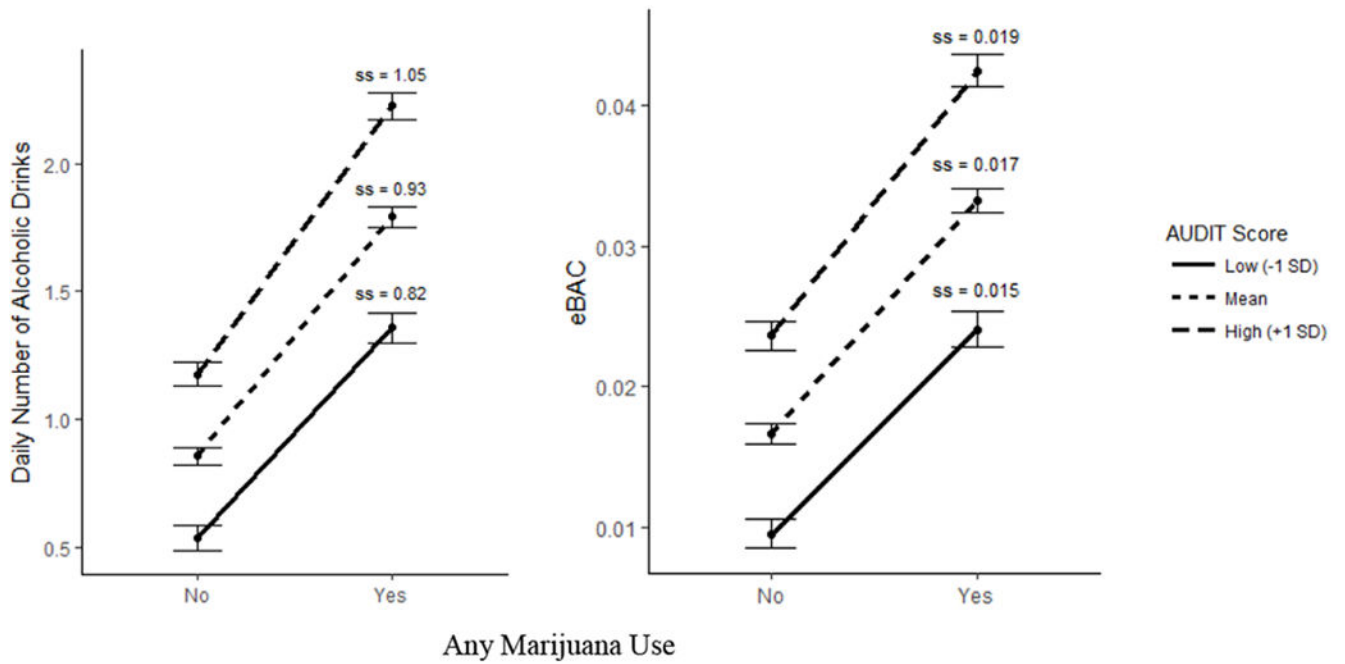


Figure 1.
 Relationship between daily marijuana use and daily number of alcoholic drinks and eBAC for levels of AUDIT
Note. Error bars represent standard errors around fitted estimates. SS = simple slope.

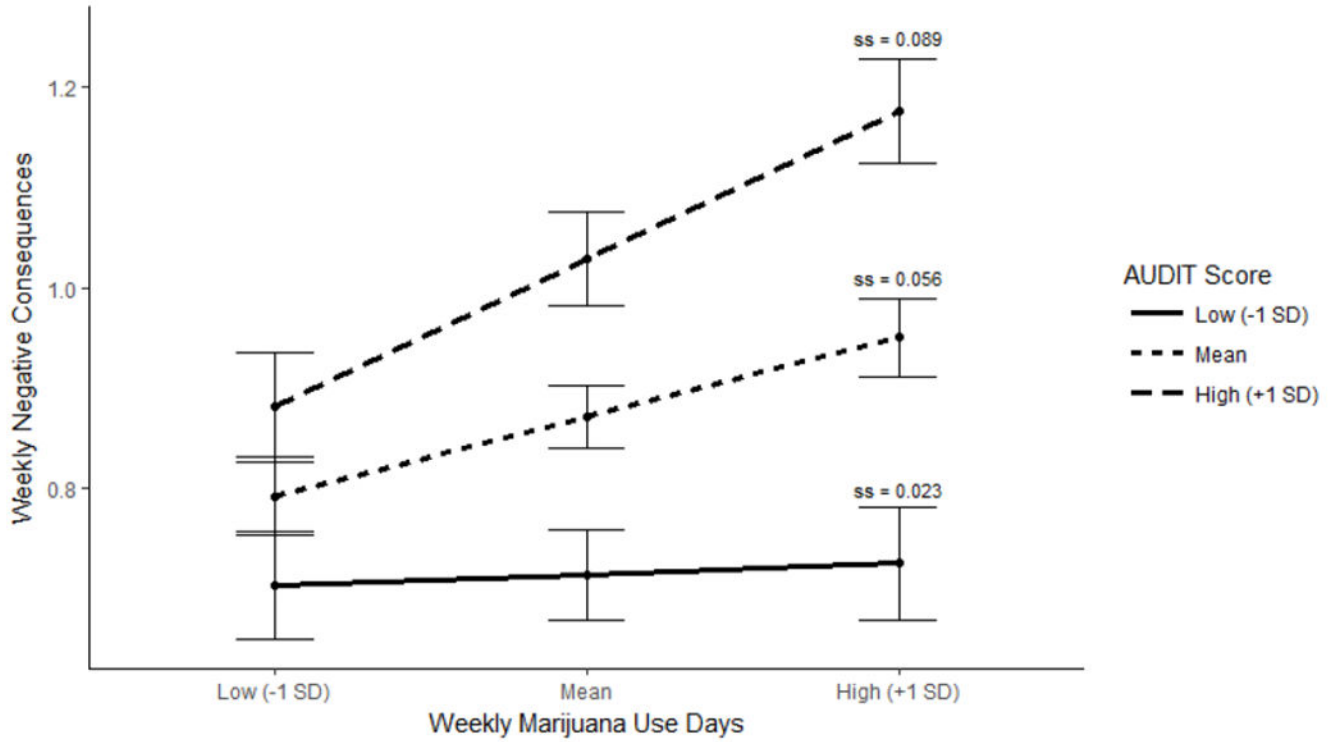


Figure 2.

Relationship between weekly marijuana use days and weekly negative alcohol use consequences for levels of AUDIT

Note. Error bars represent standard errors around fitted estimates. SS = simple slope.

Table 1.

Descriptive statistics (N = 488)

Variable	Mean	SD	Median	Min.	Max.
AUDIT	5.42	4.51	5	0	22
Number of Drinks on Drinking Days	4.79	2.06	4.41	1	15
Percent Marijuana Use Days	16	25	4	0	100
Weekly Number of Negative Consequences	0.89	0.85	0.68	0	6
Weekly Number of Positive Consequences	3.85	2.02	3.68	0	10.89
Percent Co-Use Days	6	10	02	0	76

Note. AUDIT was assessed once (baseline); all other measures were measured in bi-weekly assessments. SD = Standard Deviation; Min. = Minimum; Max. = Maximum

Table 2. Parameter estimates of GLMMs predicting daily number of alcoholic drinks (Model 1a) and eBAC (Model 1b)

Variable	Model 1a			Model 1b		
	Estimate	SE	t-value	Estimate	SE	t-value
Intercept	-0.13	-	-	.04	-	-
Age	.04	.08	.44	-0.002	.002	-0.97
Sex (ref: male)	-0.40	.07	-5.77	-	-	-
Race (ref: White)	-0.04	.07	-0.58	.0009	.002	.59
Weekend (ref: weekday) ^a	1.30	.01	90.26	0.03	.0003	87.17
Study day ^a	-0.00009	.00004	-2.33	-3.7×10⁻⁶	8.0×10⁻⁷	-4.57
% Marijuana use days	-0.80	.14	-5.61	-0.01	.003	-4.65
Daily cigarette use (ref: no) ^a	1.40	.03	40.51	0.03	.0007	40.45
AUDIT	.07	.008	9.37	.002	.0002	9.48
Any marijuana use (ref: no) ^a	.81	.04	18.42	.01	.0009	16.36
Any marijuana use ^a × AUDIT	0.03	.006	4.45	.0005	.0001	4.21
Any marijuana use ^a × Study day ^a	.0004	.0001	3.85	7.1×10⁻⁶	2.2×10⁻⁶	3.24

Note: Coefficients are unstandardized. Sex was excluded as a covariate from Model 1b as sex informed the computation of the outcome variable, eBAC. Bolded effects are significant at $p < .05$.

^aDenotes time-varying.

Parameter estimates of GLMMs predicting weekly positive (Model 2a) and negative (Model 2b) alcohol use consequences

Table 3.

Variable	Model 2a			Model 2b		
	Estimate	SE	t-value	Estimate	SE	t-value
Intercept	6.61	-	-	1.29	-	-
Age	-0.19	.22	-0.88	-0.06	.08	-0.81
Sex (ref: Male)	0.51	.18	2.75	0.34	.07	5.07
Race (ref: White)	-0.13	.19	-0.66	0.18	.07	2.61
Weekly drinks per drinking day ^a	0.28	.009	31.08	0.15	.005	30.43
Weekly Cigarettes per day ^a	0.02	.02	1.05	0.02	.01	1.57
Biweekly period ^a	-0.04	.002	-26.87	-0.01	.0009	-12.05
% Marijuana use days	-0.10	.39	-0.25	-0.13	.15	-0.87
Past-week marijuana use days ^a	0.12	.03	4.34	0.06	.02	3.65
AUDIT	0.03	.02	1.63	0.04	.007	4.73
Past-week marijuana use days ^a × AUDIT	-0.0002	.004	-0.05	0.007	.002	3.87
Past-week marijuana use days ^a × Biweekly Period ^a	-0.002	.0008	-1.98	-0.0008	.0005	-1.86

Note: Coefficients are unstandardized. Bolded effects are significant at $p < .05$.

^aDenotes time-varying.