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ALCOHOLISM CLINICAL & EXPERIMENTAL RESEARCH

ORIGINAL ARTICLE

Daily diary study of loneliness, alcohol, and drug use during the COVID-19 Pandemic

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Abstract

Background: Research conducted during the COVID-19 Pandemic has identified two co-occurring public health concerns: loneliness and substance use. Findings from research conducted prior to the pandemic are inconclusive as to the links between loneliness and substance use. This study aimed to measure associations of loneliness with three different types of substance use during COVID-19: daily number of alcoholic drinks, cannabis use, and non-cannabis drug use.

Method: Data were obtained between October 2020 and May 2021 from 2,648 US adults (M_{age} = 38.76, 65.4% women) diverse with respect to race and ethnicity using online recruitment. Participants completed baseline surveys and daily assessments for 30 days. A daily loneliness measure was recoded into separate within- and between-person predictor variables. Daily outcome measures included the number of alcoholic drinks consumed and dichotomous cannabis and non-cannabis drug use variables. Generalized linear multilevel models (GLMLM) were used to examine within- and between-person associations between loneliness and substance use.

Results: The unconditional means model indicated that 59.0% of the variance in the daily number of alcoholic drinks was due to within-person variability. GLMLM analyses revealed that, overall, people drank more on days when they felt a particularly high or particularly low degree of loneliness (positive quadratic effect). There was a negative and significant within-person association between daily loneliness and the likelihood of cannabis use. There was also a positive and significant within-person association between daily loneliness and the likelihood of non-cannabis drug use.

Conclusions: Associations between loneliness and substance use vary with substance type and whether within- or between-person differences are assessed. These findings are relevant to the persistence of substance use disorders and thus of potential clinical importance. Individuals who do not experience severe loneliness at intake but who show daily increases in loneliness above baseline levels are at heightened risk of alcohol and non-cannabis drug use. Future research could profitably examine just-in-time adaptive interventions that assess fluctuations in loneliness to prevent the development or exacerbation of substance use disorders.

KEYWORDS
alcohol and substance use, COVID-19, daily diary, ecological momentary assessment, loneliness

INTRODUCTION

Loneliness has been identified as a critical psychological health concern during the COVID-19 Pandemic due to social distancing, isolation, and community closures (Killgore et al., 2020). In a national survey from October 2020, 36% of respondents and 61% of young adults reported feeling frequent or constant loneliness (Weissbourd et al., 2021). Increased substance use (alcohol and other drug use) has also been identified as a public health concern during the COVID-19 Pandemic. Compared with the same period in 2019, adults consumed alcohol more frequently, and cannabis/other drug use increased by 3% to 8% between May and June 2020 (Pollard et al., 2020; Taylor et al., 2021). The relationship between loneliness and substance use is not well understood, with some studies conducted prior to the pandemic pointing to positive and others to negative associations (Åkerlind & Hörnquist, 1992; Barretta et al., 1995; Canham et al., 2016; Ingram et al., 2020; Rhew et al., 2021). Studies using intensive longitudinal methods, such as ecological momentary assessment (EMA) or daily diaries, have the potential to provide clarity on the daily-level temporal associations between loneliness and substance use, which may differ from previous studies that examine loneliness and substance use over longer periods of time (Kuerbis et al., 2018; Morgenstern et al., 2016; Simons et al., 2014). These daily methods are well suited to examine the proximal associations between loneliness and substance use during the COVID-19 Pandemic.

Loneliness and alcohol use

After alcohol sales rose 54% during initial pandemic stay-at-home orders, public health organizations warned that increased alcohol consumption as a result of social isolation, boredom, and stress could exacerbate negative health outcomes (Pollard et al., 2020). Nationally representative surveys conducted in June 2020 indicate 13.3% of participants reported starting or increasing their alcohol or substance use to cope with COVID-19-related stressors, and 40.9% of participants reported at least one adverse mental or behavioral health condition such as anxiety or depressive disorder (Czeisler et al., 2020). Loneliness has been a particularly salient stressor among low-income individuals, people with chronic physical and mental health conditions, and young women (Killgore et al., 2020; Luchetti et al., 2020). Prior research indicates lonelier people tend to engage in more excessive alcohol consumption, and in particular solitary drinking (Åkerlind & Hörnquist, 1992; Arpin et al., 2015; Barretta et al., 1995). However, other studies, including some EMA research, have found loneliness to be negatively or not at all associated with alcohol use (Canham et al., 2016; Kuerbis et al., 2018; Morgenstern et al., 2016; Rhew et al., 2021).

In the context of COVID-19, pandemic restrictions initially reduced the social consumption of alcohol and increased solitary alcohol consumption due to closures of bars and restaurants and guidelines limiting social gatherings (McPhee et al., 2020; Pakdaman & Clapp, 2021). An EMA study conducted with college students who had transitioned to online learning and had limited campus access during the beginning of the COVID-19 Pandemic found linear increases in alcohol use across 28 days (Papp & Kouros, 2021). A UK-based 30-day EMA study with a general population sample during the UK lockdowns, which restricted all social gatherings, found that people were drinking alcohol more frequently than prior to the pandemic (Naughton et al., 2021).

Prior research indicates that an individual's stable psychological and emotional traits are associated with alcohol use in different ways to their daily emotional states (Curran & Bauer, 2011). For example, Simons et al. (2014) found that both positive and negative state-level affect (within-person associations) were associated with higher alcohol use that day. However, at the trait (between-person) level, dispositional positive affect was associated with decreased alcohol use over the study period, whereas dispositional negative affect was associated with increased alcohol use. Loneliness is one component of negative affect. Therefore, the between-person differences in loneliness (i.e., *average level of loneliness* across a certain period) may have a different effect on their alcohol consumption than *feeling lonelier than usual* on a particular day (i.e., fluctuations in loneliness *within* a person over time). Studies that have used ecological momentary assessment (EMA) or daily diaries to examine the within-person effects of loneliness and alcohol use are not conclusive. In an EMA study of adults with alcohol use disorders (AUD), a significant within-person associations between loneliness and daily alcohol use did not exist (Kuerbis et al., 2018; Morgenstern et al., 2016). On the contrary, Arpin et al. (2015) found a positive within-person association between loneliness and solitary drinking and a negative within-person association between loneliness and social drinking. Daily diary research conducted during the pandemic has the potential to clarify these relationships.

Loneliness and drug use

Approximately 40% of US adults in 2019 reported illicit drug use, with 30% reporting cannabis use (Substance Abuse and Mental Health Services Administration, 2020). As predicted by researchers and public health officials at the start of the pandemic, data indicate individuals with substance use disorders (SUD) have faced heightened risk of adverse substance-related outcomes during the COVID-19 Pandemic. For example, the significant increase in drug overdose deaths between June 2019 and May 2020 compared with the previous 12 months has been attributed in part to the COVID-19 Pandemic (Kuehn, 2021).

A majority of individuals with substance use disorders report experiencing loneliness as a result of stigma and social isolation from others and may engage in substance/alcohol use as a way to cope with feelings of loneliness (Ingram et al., 2018, 2020). However, there has been limited research among populations without SUD diagnoses. Data collected shortly before the start of the COVID-19 Pandemic in January 2020 from a community

sample of young adults aged 18 to 23 indicated that frequent cannabis use over 30 days was associated with higher loneliness (Rhew et al., 2021). Research conducted during the COVID-19 Pandemic has also found positive associations between loneliness and drug use (Horigian et al., 2021). For emerging adults who had reported cannabis use prior to the pandemic in a previous study, self-isolation was associated with more frequent cannabis use during COVID-19 (Bartel et al., 2020). Further research is needed to study these relationships among middle to older-age adults and the inclusion of drugs other than cannabis.

Current Study

Preliminary studies indicate that loneliness and substance use have both increased during the COVID-19 Pandemic (Killgore et al., 2020; Pollard et al., 2020). However, the nature of the within- and between-person associations between these health concerns are unknown in the context of widespread social isolation. We conducted a pilot daily diary study from June to July 2020 to test initial hypotheses on the within- and between-person associations between loneliness and alcohol use during the pandemic while data collection for the larger study were underway (Bragard et al., 2021). Among a sample of 78 adults recruited from social media, people who felt "lonelier on average" (between-person association) drank more alcohol daily. However, people who felt "lonelier than usual" (within-person association) on a particular day drank less alcohol. Due to the low prevalence of drug use in the pilot sample, we were unable to analyze associations between loneliness, cannabis, and other drugs.

The purpose of this study was to examine the fluctuations of loneliness, number of alcoholic drinks consumed, and drug use over 30 days using a daily diary protocol to replicate and expand findings from our pilot study. Given the inconsistencies in the prior alcohol-use literature, we based our hypotheses regarding the number of alcoholic drinks on empirical findings from the pilot study.

H1a: Increases in daily loneliness beyond a person's average loneliness (within-person) would predict decreased number of alcoholic drinks consumed that day.

H1b: Average loneliness across 30 days (between-person) would be associated with increased number of alcoholic drinks consumed each day.

Given the greater consistency in prior studies regarding associations between loneliness and drug use, we based these hypotheses on previous literature (Ingram et al., 2020; Rhew et al., 2021).

H2a: Increases in daily loneliness beyond a person's average loneliness (within-person) would increase the likelihood of cannabis use that day.

H2b: Average loneliness across 30 days (between-person) would be associated a higher likelihood of cannabis use each day.

H3a: Increases in daily loneliness beyond a person's average loneliness (within-person) would increase the likelihood of non-cannabis drug use that day.

H3b: Average loneliness across 30 days (between-person) would be associated with a higher likelihood of noncannabis drug use each day.

An exploratory aim of this study was to examine the within- and between-person quadratic effects of loneliness on substance use, given the mixed findings in prior research. The array of positive, negative, and null associations in the loneliness and substance use literature suggests that a nonlinear effect may be masking the true nature of these associations.

METHOD

Participants and procedures

The analytic sample for this study consists of $N = 2648$ participants recruited by Qualtrics® Panel services between October 2020 and May 2021 weekly in waves. Details on the recruitment and sampling methods for this study are described in full in Devoto et al. (2022). Eligible participants were living in the United States and aged 18 years or older. Due to passive sensor data and social media language analyses in the broader study, eligible participants must have used a smartphone, written more than 500 words on Facebook, and posted at least five statuses outside of the past 180 days. To be considered "consented," participants had to provide access to their social media accounts. The baseline survey was hosted online on Qualtrics and included demographic, health, housing, employment, COVID-19 impact measures, and 25 psychological and behavioral assessment scales. Everyone who completed the baseline survey was invited to begin the 30-day daily diary surveys the following day. Each daily survey consisted of 19 items assessing mood, activities, health, social interactions, and substance use. Daily surveys were sent to participants' mobile devices in the evening. Participants were compensated in online payments by Qualtrics® Panel services. Participants received $30 for completion of the baseline survey and earned $1 for each daily survey entry for a total of $60 for these data collection components. This study was considered exempt by the University of Pennsylvania and Fordham University Institutional Review Boards.

Measures

Daily predictor and outcome measures

Loneliness

Loneliness was measured daily with a single item, "How lonely were you today?" adapted from the negative scale of the Positive Affect Negative Affect Schedule (PANAS) (Watson & Clark, 1994).

Response options ranged from 1 (*not at all*) to 5 (*all the time*). Single-item loneliness measures have been shown to have comparable validity to the UCLA Loneliness Scale, and EMA researchers recommend the use of single-item mood measures to reduce participant burden (Arpin et al., 2015; Kuerbis et al., 2018; Russell, 1996).

Daily number of alcoholic drinks

Two single items were adapted from the AUDIT Alcohol Consumption Questions (AUDIT-C) (Bush et al., 1998), a widely used measure of hazardous alcohol use. Participants were first asked whether they drank alcohol yesterday (0 = No and 1 = Yes). Participants who responded positively to this question were then shown a graphic with examples of a standard drink of alcohol (beer, wine, and liquor) and asked to indicate the number of drinks they had had the previous day. Options ranged from 0 (*no drinks*), 1 (*less than 1*), 2 (*1 or 2*), 3 (*3 or 4*), 4 (*5 or 6*), 5 (*7 to 9*), and 6 (*10 or more*). This variable was recoded such that options 1 and 2 were combined: 0 (*no drinks*), 1 (*less than 1 to 2*), 2 (*3 or 4*), 3 (*5 or 6*), 4 (*7 to 9*), and 5 (*10 or more*). Daily alcohol use was shifted one day forward such that we could test it as an outcome variable the same day as reported loneliness.

Daily drug use

Participants were first asked, "Did you use cigarettes or any drugs yesterday? Check all that apply." The following substance options were given: 1 = cigarettes/nicotine/tobacco/vape juice; 2 = cannabis; 3 = cocaine; 4 = prescription stimulants; 5 = methamphetamine; 6 = inhalants; 7 = sedatives or sleeping pills; 8 = hallucinogens; 8 = street opioids; 9 = prescription opioids; 10 = other; and 11 = none. This variable was then collapsed into two separate binary variables (0 = Did not use and 1 = Used) as follows: (1) cannabis use; (2) any drug excluding cannabis. Cigarette/vape use was not included in the current analyses. Each drug use variable was shifted 1 day forward such that we could test them as outcome variables the same day as reported loneliness.

Daily survey time-varying covariates

Face-to-face conversations

Participants were asked to respond each day to the item, "About how many people did you have face-to-face (in-person) conversations with today?" Responses were measured on a discrete ordinal scale between *0* and *10 or more*.

Lockdown degree

Data from the Oxford COVID-19 Government Response Tracker were used to estimate the level of COVID restrictions in place in the state in which participants lived (Hale et al., 2021). A daily score was calculated based on the sum of the following indicators: closings of schools and universities, workplace closings, canceling of public events, limits on gatherings, closing of public transport, shelter-in-place orders, restrictions on internal movements between cities/regions, and restrictions on international travel. The maximum score was 20. A 30-day average was also calculated for each participant.

Weekend indicator

A new variable was computed based on the daily survey entry date to indicate whether it was a weekend day: 0 (Monday–Thursday) and 1 (Friday–Sunday).

Baseline measures

Demographic covariates

In the baseline survey, participants responded to questions about age, gender, race, ethnicity, political orientation, religious affiliation, education level, household income, number of children, and whether they had a romantic partner. As part of a longer COVID Impact Scale developed by the research team, participants indicated to what extent they had been socially distancing in the past week from 1 (*not at all*) to 4 (*completely*). Categorical variables with more than three levels were recoded into dichotomous indicators, so that they could be entered into analytic models. Religion was recoded as a binary variable (1 = identified with a religion and 2 = none/Atheist/Agnostic). Race and ethnicity were combined into a categorical variable with four levels (Black/African American, Hispanic/Latinx, Other races and ethnicities, and White). This variable was then transformed into dummy variables with White as the reference group due to it being the largest group (59.9%).

Baseline mental health assessments

Participants completed self-report screening tools for depression and anxiety. The 9-item Patient Health Questionnaire (PHQ-9) was used to measure depressive symptoms (Kroenke et al., 2001). The 7-item Generalized Anxiety Disorder (GAD-7) was used to measure symptoms of anxiety (Spitzer et al., 2006). Participants indicated whether they had been bothered in the last 2 weeks by a range of conditions. Example PHQ-9 items included "Feeling down, depressed, or hopeless" and "Trouble falling asleep, staying asleep, or sleeping too much." Example GAD-7 items included "Not being able to stop or control worrying" and "Feeling afraid as if something awful might happen." Response options for both scales ranged from 0 (*Not at all*) to 3 (*Nearly every day*).

UCLA loneliness scale

Participants completed the 3-item short version of the UCLA loneliness scale. This scale was used to provide evidence of the validity of the single-item loneliness daily survey measure. An example item of the scale is, "How often do you feel isolated from others?" Response options are categorized as 1 (*hardly ever*), 2 (*some of the time*), and 3 (*often*). The scale was found to have acceptable reliability in previous research ($\alpha = 0.72$) and has convergent validity with depressive symptoms, stress, and the longer version of the UCLA Loneliness scale (Russell, 1996). The daily loneliness item was significantly correlated with the baseline UCLA loneliness scale ($r = 0.46$, $p < 0.001$).

Alcohol Use Disorders Identification Test-Concise (AUDIT-C)

The 3-item AUDIT-C was used to provide evidence of the validity of the single-item alcohol use EMA measure (Bush et al., 1998). Item 1 assessed the frequency of having a drink containing alcohol with response options ranging from 0 (*never*) to 5 (*4 or more times a week*). Item 2 assessed how many drinks participants consumed in a typical day with response options ranging from 1 (*1 or 2*) to 5 (*10 or more*). Item 3 assessed how often participants had six or more drinks on one occasion with response options ranging from 1 (*never*) to 5 (*daily or almost daily*). Values from all three items are summed with higher scores indicating higher alcohol use. The daily number of drinks item was significantly correlated with the baseline AUDIT-C ($r = 0.43$, $p < 0.001$).

Analytic plan

Generalized linear multilevel models (GLMLM) with daily measures (Level 1; L1) nested within persons (Level 2; L1) were estimated in R (R Core Team, 2020) using the *lme4* package. To conduct GLMLM, the time-varying predictors were first separated into within-person (L1) and between-person (L2) components (Howard, 2015). L1 predictors (i.e., *daily* loneliness) were person-mean-centered by subtracting each person's mean score across 30 days of observations from their daily raw scores. These L1 measures contain only within-person variability. We also included person-level means of our key predictors (i.e., *average* loneliness) at L2 to model between-person variability in daily substance use. All L2 predictors were grand mean centered to facilitate the interpretation of partial coefficients.

We tested a series of models growing in complexity for each substance use outcome (see Table S1 for reduced-form model equations): number of drinks (Models 1a–1h), binary cannabis (Models 2a–2f), binary drug use excl. Cannabis (Models 3a–3f).

We first tested the unconditional means models for each outcome. For the continuous alcohol use outcome, the intraclass correlation (ICC) was estimated to assess the proportion of variance in alcohol use due to between-person differences and thus calculate the proportion of within-person variability (Bolger & Laurenceau, 2013). Linear growth models were tested for all three outcome variables to assess whether daily substance use had any linear time-related trends.

Simple models using one predictor at a time were run with potential covariates to test for significance. All significant covariates were then entered into a model to test for independent significant effects on daily substance use. We tested models with random intercepts and with random slopes. A random intercepts model allows individual variation in participants' baseline levels of substance use. A random intercepts and random slopes model also allows for individual variation in the strength and direction of the relationship between loneliness and substance use. For this analysis, we only allowed the time-varying covariate loneliness to have random slopes as our focal predictor. The Akaike Information Criterion (AIC) was used to compare the model fit of the more complex random intercepts/random slopes models by assessing the precision of the estimated effects versus parsimony of the model (Bolger & Laurenceau, 2013). A lower value implies a better fit. We then tested a model with loneliness plus all significant covariates. Finally, as exploratory analyses, we tested for nonlinear effects of loneliness by adding the fixed and random quadratic terms for L1 and L2 loneliness. The AIC of the full model was also examined.

Sensitivity analyses

Although MLM is robust to missing data, a sensitivity analysis was conducted to assess whether including participants with high numbers of missing daily survey entries was influencing the model. All models were run with a more conservative sample of participants with at least 20 days of daily survey entries, and significant effects were compared to the full sample (with at least one daily survey). The significant effects were similar across both samples. Therefore, the full sample was used in all reported analyses.

Given the rolling recruitment of participants from October 2020 to May 2021, we examined the data descriptively to detect any seasonal effects that might have influenced our results. We noticed slight increases for participants who completed the 30-day daily diary protocol during December and February, and this may have been explained by heightened drinking during holidays or common drinking events (e.g., Christmas, New Year's Eve, Valentine's Day, and the Super Bowl). However, these increases were not dramatically different from other months (typically only an increase of about one serving). We also examined a subsample of individual trajectories and did not observe clear patterns around known holiday dates. For these reasons, we decided not to control for any seasonal or holiday effects in the alcohol use models. The individual trajectories did suggest that an alcohol use day typically followed by a nonalcohol use day. This is consistent with the findings that this sample is, on average, a low-alcohol use sample (with low rates of AUD according to the AUDIT screening tool given in the baseline survey).

RESULTS

Sample descriptive statistics, missing data estimates, and grand means of time-varying covariates can be found in Table 1. Due to the small percentage (1.7%) of individuals self-describing their gender identity or choosing not to respond, these individuals were excluded from subsequent analyses. Most participants were women (65.4%), and the average age of the sample was 38.76 years old (SD = 12.53). Due to the small proportion of participants who chose to self-describe their gender or preferred not to say (1.7%), we excluded these participants from the analytical models so as not to overestimate the effects of this subgroup. Approximately 40% of the sample were Black, Indigenous, or People of Color (BIPOC) individuals: 15.9% Black or African American, 9.8% Hispanic/Latinx, and 11.7% other racial/ethnic groups. There was

TABLE 1 Participant characteristics

N = 2648	n	%
Gender		
Male	798	30.1
Female	1735	65.5
Prefer not to say	2	0.1
Self-describe	43	1.6
Race/Ethnicity		
Black or African American	422	15.9
Hispanic/Latinx	260	9.8
White	1585	59.9
Asian, Asian American, Hawaiian Native or Pacific Islander, American Indian or Alaska Native, Middle Eastern, or Multiracial	309	11.7
Political orientation		
Very conservative	87	3.3
Conservative	193	7.3
Moderately conservative	234	8.8
Moderate	478	18.1
Moderately liberal	371	14.0
Liberal	594	22.4
Very liberal	499	18.8
Apolitical	53	2.0
Other	67	2.5
Religion		
Protestant/Other Christian	793	29.9
Catholic	418	15.8
Mormon	39	1.5
Jewish	143	5.4
Muslim	24	0.9
Hindu	30	1.1
Other non-Christian religion	32	1.2
None/Atheist/Agnostic	79	3.0
Other	837	31.6
Education		
Less than a high school diploma	13	0.5
High school degree or diploma	183	6.9
Technical/Vocational school	73	2.8
Some college—college, university, or community college—but no degree	448	16.9
Two-year associate degree from a college, university, or community college	233	8.8
Four-year bachelor's degree from a college or university	990	37.4
Postgraduate or professional degree, including masters, doctorate, medical, or law degree	636	24.0
Household income		
<10,000	158	6.0
10,000 to 19,999	173	6.5
20,000 to 29,999	226	8.5
30,000 to 39,999	246	9.3
40,000 to 49,999	219	8.3
50,000 to 59,999	261	9.9
60,000 to 69,999	186	7.0
70,000 to 79,999	211	8.0
80,000 to 89,999	133	5.0
90,000 to 99,999	138	5.2
100,000 to 149,999	363	13.7
150,000 or more	244	9.2
Frequency of social distancing behaviors		
Never	24	0.9
Rarely, in about 10% of the chances when I could have	31	1.2
Occasionally, in about 30% of the chances when I could have	48	1.8
Sometimes, in about 50% of the chances when I could have	108	4.1
Frequently, in about 70% of the chances when I could have	390	14.7
Usually, in about 90% of the chances I could have	1110	41.9
Every time	834	31.5
Participants with a romantic partner	1754	66.2
At least one drinking day during daily diary protocol	1608	60.7
At least one cannabis use day during daily diary protocol	516	19.5
At least one noncannabis drug use day during daily diary protocol	408	15.4
Participants with at least 20 daily surveys	1999	75.5

	M	SD
Age	38.76	12.53
Number of children	0.81	1.13
Lockdown degree (range: 0 to 20)	14.61	2.22
Loneliness (range: 1 to 5)	1.83	1.12
Face-to-face conversations (continuous)	4.52	2.86
Number of drinks each day (range: 0 to 5)	0.31	0.72
Number of alcohol-use days (range: 0 to 30)	4.50	6.25
Number of cannabis-use days (range: 0 to 30)	2.14	6.09
Number of noncannabis-use days (range: 0 to 30)	1.19	4.46

a greater frequency of politically liberal individuals, and approximately 70% of the sample had either an associate's or bachelor's degree. There was a somewhat uniform distribution of household income with a median of $50 to 59,999. Most participants had a romantic partner (66.2%), and 55.5% did not have any children. Most participants (74.4%) reported social distancing at least 90% of the time. During the 30-day daily diary period, nearly two-thirds

of the sample drank alcohol on at least 1 day (M_{days} = 4.5 days, SD = 6.25), while 19.5% used cannabis (M_{days} = 2.14, SD = 6.25) and 15.4% used a noncannabis drug on at least 1 day (M_{days} = 1.19, SD = 4.46). The mean daily loneliness score was 1.83 (SD = 1.12) and the ICC (between-person variance) for loneliness was 60.8%, meaning that 39.2% of the variance in daily loneliness was due to within-person variability. Bivariate correlations among covariates are presented in the Supplementary Materials (Table S2). Daily survey response rates were high, with three-quarters of the sample completing at least 20 daily surveys.

Multilevel models and generalized linear mixed models

For clarity and succinctness, only the final, complex models for each outcome variable (Models 1h, 2f, and 3f) are reported in Table 2. However, the series of mixed models for each substance use outcome is described below and reported in more detail in the Supplementary Materials (Tables S3–S5).

Daily number of alcoholic drinks

The unconditional means model indicated that the ICC (between-person variance) was 41.0%, meaning that 59.0% of the variance in daily number of alcoholic drinks is due to within-person variability (Bolger & Laurenceau, 2013). Models 1b and 1c indicated that there were no linear time dependencies but that the autoregressive (AR1) effect was significant (Table S3). This means that alcohol use did not increase linearly from day 1 to 30 but that alcohol use on day *t* is more closely related to alcohol use the following day (day *t* + *1*) than later days in the time series. Simple models with single covariates as predictors indicated that all L1 covariates were significantly associated with daily number of alcoholic drinks. People tended to drink more on the weekends, when their state lockdown restrictions increased, and when they had more face-to-face conversations than usual. All L2 covariates were significantly associated with alcohol use except for age, having a romantic partner, depression, and anxiety which were excluded from subsequent models. The following groups consumed more alcohol daily: men, people with fewer children, those with higher income and education levels, nonreligious people, more liberal people, people who socially distanced less frequently, and white people (Table S3, Model 1d).

Models 1e and 1f indicated significant L1 (within-person) effects of loneliness on daily number of alcoholic drinks, not accounting for any covariates, were significant and negative. Comparison of the AICs indicated that the more complex random intercept/random slopes model (1f) was an improvement in fit compared with the random intercept/fixed slopes model (1e); therefore, the random slopes term was retained in subsequent models. In Model 1g (Table S3), all significant covariates were added to the model. The L1 (within-person) effect of loneliness (γ_{10}) on daily number of alcoholic drinks remained significant and negative. The between-person effect (L2) of loneliness (γ_{01}) on daily alcohol use was not statistically significant. To examine this finding further, we tested the quadratic effects of L1 and L2 loneliness on daily alcohol use (Table 2, Model 1). The quadratic L1 loneliness term was positive and significant (a U-shaped curve, see Figure 1), indicating participants who were "much lonelier than usual" and "much less lonely than usual" consumed more alcohol. The quadratic L2 loneliness term was negative and not significant ($p = 0.053$).

Daily cannabis use

There was no linear effect of time (DAY_{ti}) on the probability of using cannabis, so we did not include time as a fixed covariate in subsequent models. Simple models with single covariates as predictors indicated that individuals were more likely to use cannabis from Friday to Saturday (Table S4, Single Covariate Models). Younger, more liberal, nonreligious adults with lower income and education levels were more likely to use cannabis. Higher levels of depression and anxiety were also associated with a greater likelihood of using cannabis. After entering the racial/ethnic group dummy variables into the model, the three other race/ethnicity groups were significantly less likely to use cannabis than the white reference group. Gender, number of children, having a partner, frequency of social distancing, number of face-to-face conversations, and lockdown degree were not associated with a higher likelihood of daily cannabis use. After entering all significant covariates, the following remained significant: age, education, being nonreligious, weekend, and all three race/ethnicity dummy variables (Table S4, Model 2c).

The random intercepts model with L1 and L2 loneliness as the sole predictors indicated a significant positive between-person effect (Table S4, Model 2e). Individuals who were "lonelier on average" (L2) were more likely to use cannabis. The random slopes model with L1 and L2 loneliness as the sole predictors (Table S4, Model 2e) suggested there were significant within-person effect in the opposite direction. When individuals felt "lonelier than usual" (L1), they were less likely to use cannabis. This slope was allowed to vary between persons. Comparison of the AICs indicated that the difference between the more complex random slopes model and the simpler fixed slopes model was $\Delta = 1.0$. Based on existing guidelines (Burnham & Anderson, 2004), there is still substantial support for the more complex random slopes model because $\Delta < 2$. Furthermore, given the significance of the within-person association in the random-slopes model, the random-slopes term was retained in the final model. After entering all significant covariates into the model (Table 2, Model 2), L1 loneliness remained significant but L2 loneliness was no longer significant. See Figure 1 for spaghetti plots of predicted log-odds and probability with the sample average. As a sensitivity analysis, we also ran the same models with the subsample of participants ($n = 516$) who reported at least 1 day of cannabis use, and the results were comparable, and therefore, were not reported in this paper.

TABLE 2 Multilevel models for the within- and between-person effects of loneliness on daily number of alcoholic drinks, cannabis, and noncannabis drug use

	Model 1 $DAILY\ ALCOHOL_{ti}$		Model 2 $DAILY\ CANNABIS_{ti}$		Model 3 $DAILY\ DRUG_{ti}$	
	Est	95% CI	OR	95% CI	OR	95% CI
Fixed effects						
INTERCEPT (γ_{00})	0.20	[0.02, 0.34]	0.02	[0.00, 0.14]	0.00	[0.00, 0.00]
DAY(t)	0.00	[0.00, 0.00]	–	–	–	–
Baseline measures						
AGE (γ_{03})	–	–	0.97	[0.95, 1.00]	–	–
$GENDER_i$ (γ_{05})	−0.07	[−0.11, −0.03]	–	–	–	–
$BLACK_i$ (γ_{06})	−0.02	[−0.10, 0.06]	0.29	[0.08, 1.06]	–	–
$HISPANIC\text{- }LATINX_i$ (γ_{07})	−0.13	[−0.20, −0.05]	0.26	[0.08, 0.92]	–	–
$OTHER\ RACE\text{-}ETHN_i$ (γ_{08})	−0.01	[−0.04, 0.07]	0.40	[0.17, 0.96]	–	–
$INCOME_i$ (γ_{09})	0.02	[0.01, 0.02]	0.95	[0.86, 1.06]	0.95	[0.88, 1.02]
$EDUCATION_i$ ($\gamma_{0,10}$)	0.01	[−0.01, 0.02]	0.73	[0.58, 0.93]	–	–
$CHILDREN_i$ ($\gamma_{0,11}$)	−0.01	[−0.03, 0.01]	–	–	–	–
$NONRELIGIOUS_i$ ($\gamma_{0,12}$)	0.11	[0.07, 0.15]	3.50	[1.72, 7.10]	–	–
$POLITICAL_i$ ($\gamma_{0,13}$)	0.02	[0.01, 0.03]	1.12	[0.91, 1.39]	–	–
$SOCIAL\ DISTANCE_i$ ($\gamma_{0,14}$)	−0.04	[−0.06, −0.02]	–	–	–	–
$DEPRESSION_i$ ($\gamma_{0,15}$)	–	–	1.01	[0.92, 1.10]	1.08	[1.004, 1.14]
$ANXIETY_i$ ($\gamma_{0,16}$)	–	–	1.06	[0.97, 1.15]	1.04	[0.97, 1.11]
Daily measures						
WEEKEND (γ_{40})	0.12	[0.11, 0.13]	1.29	[1.12, 1.47]	0.98	[0.86, 1.12]
$LOCKDOWN_{ti}^{(PMC)}$ (γ_{20})	0.01	[0.004, 0.02]	–	–	–	–
$MLOCKDOWN_i$ (γ_{02})	0.00	[−0.01, 0.01]	–	–	–	–
$FACE_{ti}^{(PMC)}$ (γ_{30})	0.01	[0.01, 0.02]	–	–	–	–
$MFACE_i$ (γ_{03})	0.00	[−0.01, 0.01]	–	–	–	–
$LONELY_{ti}^{(PMC)}$ (γ_{10})	−0.03	[−0.04, −0.02]	0.89	[0.80, 0.98]	1.35	[1.35, 1.62]
$MLONELY_i$ (γ_{01})	0.02	[−0.01, 0.05]	1.01	[0.67, 1.53]	1.20	[0.91, 1.63]
$LONELY_{ti}^{(PMC)} \times LONELY_{ti}^{(PMC)}$ (γ_{11})	0.02	[0.01, 0.03]	–	–	–	–
$MLONELY_i \times MLONELY_i$ (γ_{12})	−0.02	[−0.03, 0.00]	–	–	–	–
Random effects						
τ_{00}	0.18	[0.17, 0.20]	34.37		17.77	
τ_{10}	0.01	[0.004, 0.008]	–	–	0.14	
τ_{11}	0.001	[0.0001, 0.003]				
σ^2	0.28	[0.28, 0.28]	–	–	–	–
AR1 (ρ)	0.13	[0.12, 0.14]	–	–	–	–
AIC	79,534.35		8569.9		8445.1	
ICC	41.03%					

Note. τ_{00} = Variance of the intercept. τ_{11} = Variance of the slope. σ^2 = Variance of the residual. *BLACK*, *HISPANIC-LATINX*, *and OTHER RACE-ETHNICITY* are dummy variables with White as the reference group.

Abbreviations: AIC, Akaike Information Criterion; ICC, intra-class correlation.

Daily noncannabis drug use

There was no linear effect of time (DAY_{ti}) on the probability of noncannabis drug use (Table S5, Model 3b), so we did not include time as a fixed covariate in subsequent models. Simple models with single covariates as predictors indicated participants were less likely to use drugs from Friday to Sunday. Participants with higher levels of depression and anxiety and with lower household income were more likely to engage in noncannabis drug use. Age, gender, race/ethnicity, political ideology, number of children, education level, religion,

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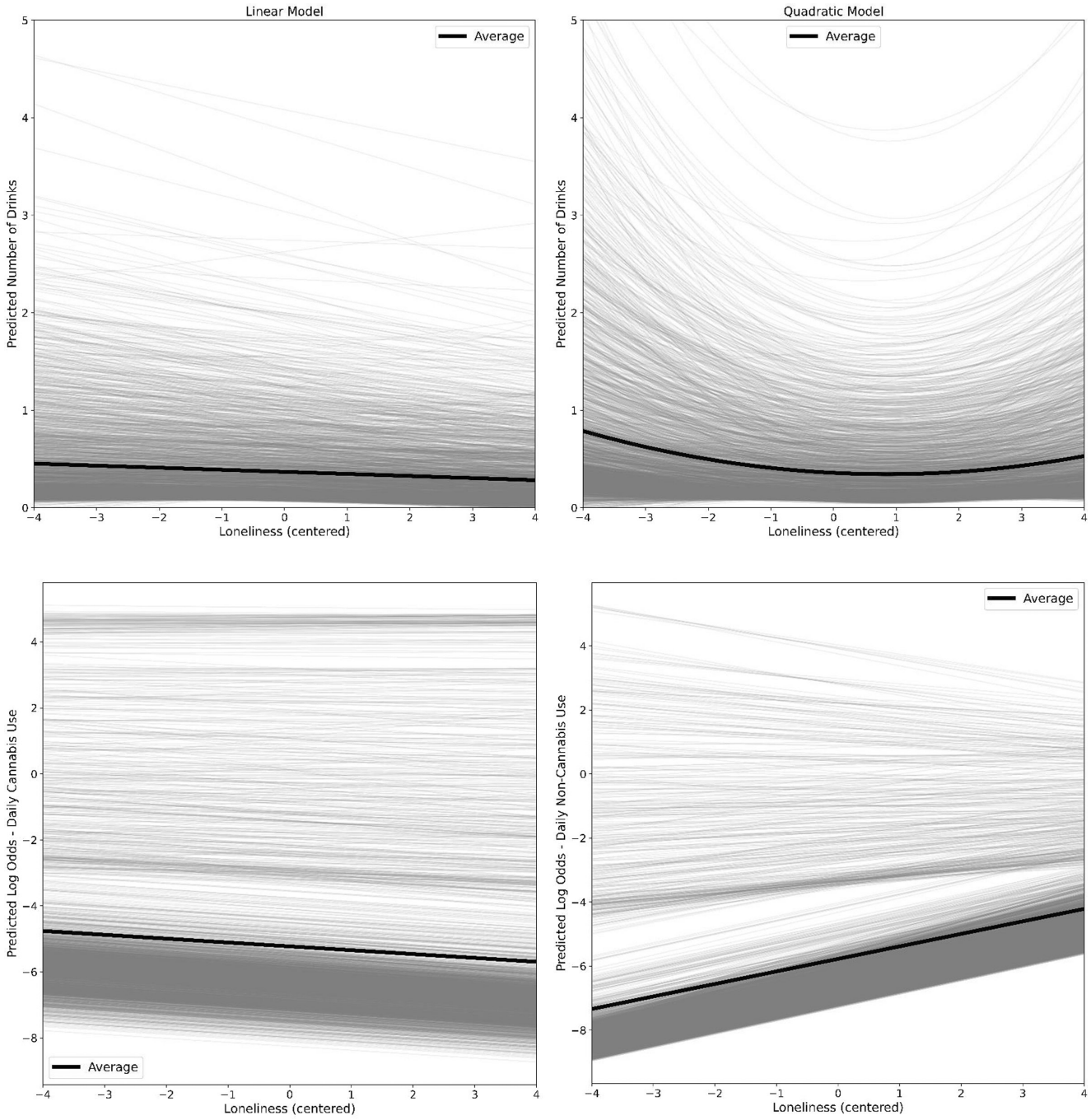

FIGURE 1 Models of daily loneliness and predicted daily number of alcoholic drinks (linear and quadratic) and predicted log-odds of cannabis and noncannabis drug use

having a partner, number of face-to-face conversations, degree of lockdown restrictions, and frequency of social distancing were not significantly associated with noncannabis drug use. After entering all significant covariates, only weekend, depression, household income remained significant (Table S5, Model 3c).

Both the random intercepts and the random slopes models with L1 and L2 loneliness as the sole predictors revealed significant positive within- and between-person effects. Comparison of the AICs indicated that the more complex random slopes model was an improvement in fit. Individuals who were feeling "lonelier than usual" and "lonelier on average" were more likely to engage in noncannabis drug use each day. After entering all significant covariates into the random slopes model (Table 2, Model 3), only L1 loneliness and depression remained significant. See Figure 1 for spaghetti plots of predicted log-odds and probability with the sample average. As a sensitivity analysis, we also ran the same models with the subsample of participants ($n = 408$) who reported at least 1 day of noncannabis drug use. We did this to ensure that the effects found were not influenced by the large proportion of participants who reported no drug use at all. The results were comparable and therefore were not reported in this paper.

DISCUSSION

There has been concern about increased substance use during the COVID-19 Pandemic due to social isolation and loneliness (Pollard et al., 2020). Given mixed findings in the prior literature, the current project aimed to elucidate associations between loneliness and daily substance use with intensive longitudinal data collected through a large daily diary study. Furthermore, given the ways individuals use a variety of substances, we sought to distinguish how self-reported loneliness is differentially related to the number of alcoholic drinks, cannabis use, and noncannabis drug use that day. The significant results from the current study suggest that during the COVID-19 Pandemic, when social distancing guidelines were in place across the United States, adults drank more on days when they felt a particularly high or particularly low degree of loneliness beyond their individual average. Furthermore, feeling lonelier than usual was also a significant risk factor for noncannabis drug use but was not a risk factor for increased cannabis use.

Although the linear effect of within-person loneliness and daily number of alcoholic drinks replicated findings from our pilot study and some prior research (Arpin et al., 2015; Bragard et al., 2021), our ability with the larger sample to study the quadratic effect complicates the interpretability of the linear effect. Exploratory analyses revealed a positive quadratic effect, suggesting that daily alcohol use increased when individuals felt either "much lonelier than usual" or "much less lonely than usual." This finding could suggest that only severe loneliness is a risk factor for increased alcohol use. It is also relevant to note that the current sample reported zero to low loneliness on average (M = 1.83, range: 1 to 5). Therefore, a small daily increase in loneliness above a person's average may not be salient enough to increase the number of alcoholic drinks consumed. It may require a much larger increase in loneliness. The significant nonlinear association could explain the conflicting findings in prior research that demonstrated both positive and negative associations between loneliness (Barretta et al., 1995; Canham et al., 2016). In any case, the exploratory nature of this analysis and the skewed distribution of loneliness in the current sample highlights the need for replication in future studies.

In contrast to our pilot study and contrary to our hypothesis (H1b), there was no significant relationship between people's average loneliness levels across the 30 days and their daily alcohol use, an unexpected finding given the significant positive association we found in our pilot study and correlational analyses of baseline loneliness and alcohol measures. However, this nonsignificant association is consistent with existing cross-sectional and daily diary research that found no link (Kuerbis et al., 2018; Rhew et al., 2021). One possible explanation for the different within- and between-person effects of loneliness is that the context of individuals' alcohol use is a key factor. Previous research indicates that loneliness significantly predicts increased solitary alcohol consumption but decreased social alcohol consumption in community-dwelling adults with a mean age of 36 (Arpin et al., 2015). In other words, feeling lonely is a risk factor for drinking alcohol alone, but people who report feeling lonely may be less likely to drink in social settings. Canham et al. (2016) studied a sample of middle-aged and older adults (50+) and found that loneliness was associated with less frequent alcohol consumption. Similarly, they hypothesized that alcohol use could be a social facilitator, suggesting that people experience an increased sense of community within the contexts they drink (e.g., pubs or social clubs). The daily surveys in the current research did not contain questions about social or solitary alcohol consumption, a limitation of the study. However, there was a positive within-person association between heightened lockdown restrictions and alcohol use. During COVID-19, many social settings such as schools, churches, and community organizations had to limit in-person gatherings, but bars and restaurants were largely open for people to gather with friends and family (Guy et al., 2021) This finding, combined with the positive within-person association between face-to-face conversations and alcohol use and the existence of a positive quadratic effect, lends support to Arpin et al. (2015) findings and provides a fruitful avenue for future intensive longitudinal research designs in this area.

The results for cannabis use did not support Hypotheses 2a and 2b. Feeling "lonelier than usual" was associated with a lower likelihood of cannabis use that day when the strength of this association is allowed to vary between people (based on the lack of significance for this within-person effect when the random-slopes term was removed). After adding the random-slopes term and all significant covariates into the final model, feeling "lonelier on average" compared with others was not associated with greater cannabis use. Exploratory analyses indicated that the key covariates that explained away the between-person association between loneliness and cannabis use were age, education, political spectrum, religion, household income, depression, and anxiety. These findings diverge from limited prior research indicating that higher loneliness or self-isolation was associated with frequent cannabis use in young adults both before and during the pandemic (Bartel et al., 2020; Rhew et al., 2021). The conflicting findings may be partly due to the age range of the current sample, which included more middle and older-age adults. Prior research suggests that whereas younger people use cannabis to relieve boredom, middle-aged and older adults are more likely to use cannabis to help with sleeping or to treat medical conditions (Haug et al., 2017).

The associations between loneliness and noncannabis drug use were distinct from number of alcoholic drinks and cannabis use, and findings revealed a clearer pattern that is consistent with prior literature. Participants who are "lonelier on average" were more likely to use noncannabis drugs daily. After controlling for baseline levels of depression, this between-person association between loneliness and noncannabis drug use became nonsignificant, so Hypotheses 3b was not supported. Loneliness and depression are highly related, so these results indicate that the association between average loneliness and the likelihood of noncannabis drug use is largely due to individuals' depressive symptoms. Consistent with Hypothesis 3a, the within-person association between loneliness and noncannabis drug use, however, remained significant after controlling for baseline depression. These results indicate that feeling "lonelier than usual"

is a significant risk factor for noncannabis drug use. The finding that more severe lockdown restrictions were positively associated with noncannabis drug use also highlights how social restrictions have heightened risk of individuals with SUDs. Our daily diary study expands on cross-sectional research conducted during the pandemic that found a positive association between loneliness and drug use among young adults (Horigian et al., 2021). Furthermore, the results have important implications for the prevention and clinical treatment of drug use, given that what a patient reports on an intake survey might not be as predictive of their likelihood to use drugs as their fluctuating emotions on a daily basis.

Limitations

The external generalizability of the current sample is limited due to our inclusion criteria (must have used a smartphone, written more than 500 words on Facebook, and posted at least five statuses outside of the past 180 days), a majority of white and female participants, and purposive sampling methods. Requiring participants to be active social media users may have been a factor in participants' self-reported loneliness. Prior research is mixed on the effects of social media on loneliness and studies conducted during COVID-19 have demonstrated both positive and negative associations between social media use and loneliness depending on age group and type of social media use (Bonsaksen et al., 2021; Pennington, 2021). Recruiting online via Qualtrics does not allow for a truly representative sample of the US population as participants must already have signed up for research panels. A key strength of our study is the large sample of daily diary participants with high retention rates, which is unique in comparison with most EMA or daily diary studies.

CONCLUSION

To our knowledge, this current paper is the first large-scale daily diary study conducted during the COVID-19 Pandemic to examine within-person associations between loneliness and different types of substance use. In summary, our findings indicate that loneliness was a risk factor for noncannabis drug use during the COVID-19 Pandemic. A novel exploratory finding regarding the positive quadratic association between loneliness and alcohol use suggests that severe loneliness is a risk factor for alcohol use. Loneliness was not significantly associated with increased cannabis use after accounting for depressive symptoms and socio-demographic factors.

Our findings are particularly relevant for clinical and applied settings. Individuals who do not meet clinical cutoffs for severe loneliness at intake but who experience daily increases above and beyond baseline levels are at heightened risk of alcohol and noncannabis drug use. Our research supports the study of just-in-time adaptive interventions (JITAI) via text messaging, smartphone apps, or wearable devices (Coughlin et al., 2021; Nahum-Shani et al., 2018) to assess in the moment whether patients are experiencing heightened feelings of loneliness and if they could benefit from immediate support to prevent alcohol and noncannabis drug use.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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