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Daily Stress Predicts Later Drinking Initiation via Craving in Heavier Social Drinkers: A Prospective In-Field Daily Diary Study

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Abstract

Stress has been linked to increased alcohol use but how stress may increase drinking in social drinkers is not well understood. Negative reinforcement processes may explain this link but the role of specific motivational processes, such as craving, and how these motivational processes are altered by drinking have not been studied. The current study assessed social drinkers ($n=81$) for recent quantity and frequency of alcohol intake (QFI) upon study enrollment, who then completed 30 days of electronic daily records of stress, craving and alcohol intake. Multilevel structural equation models tested if person-averaged (between-person) and daily (within-person) craving mediated the link between stress and later drinking each evening and if recent quantity-frequency of drinking (QFI) moderated these associations. At the between-person level, both greater subjective stress, $Est=0.38$, 95% CI: 0.19-0.57, and higher QFI predicted higher levels of craving, $Est=0.34$, 95% CI: 0.20-0.49. Higher craving predicted more frequent drinking throughout the study, $Est=0.34$, 95% CI: 0.01-0.29. At the within-person level, higher subjective stress predicted higher within-person craving; and the link between craving and later drinking was significant among those who had a higher QFI, $Est=0.84$, 95% CI: 0.58-1.12. The subjective stress-drinking relationship was mediated by a greater alcohol craving response in social drinkers, and higher the QFI, greater the alcohol craving response. These results indicate that both higher levels of stress and greater recent alcohol intake patterns sensitize the craving response that in turn facilitates later alcohol intake. The findings suggest that higher recent alcohol use predict greater stress-potentiated initiation of drinking via higher craving responses.

General Scientific Summary: The findings from this study provide ecological evidence that subjective stress is associated with a higher craving response, which in turn predicts a greater likelihood of later drinking. Both the craving response and its relationship to later drinking is greater in heavier social drinkers. This study supports the hypothesis that higher levels of alcohol intake is related to a sensitized shift towards greater alcohol motivation in response to stress in social drinkers.

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Keywords

social drinkers; stress; craving; alcohol; daily diary

High levels of alcohol intake above the recommended guidelines has increased significantly in the last decade, representing a public health problem (Grant et al., 2017). Several adverse health consequences are associated with risky alcohol use, even prior to the development of an Alcohol Use Disorder (AUD; Chen et al., 2013; Holstege et al., 2020; Ngo et al., 2018), including numerous social problems, such as academic or work difficulties (Howland et al., 2010; Webb et al., 1994), high-risk sexual behavior and increased risk for sexual assault (Yeater et al., 2020), and driving while intoxicated (Naimi et al., 2009), among others. Identifying contextual and individual-level characteristics that predict alcohol use in social drinkers could improve the efficacy of current prevention efforts, reducing the likelihood of adverse psychosocial and health consequences.

Stress has long been associated with drinking alcohol, and several theoretical frameworks have been proposed and tested to explain the link. The most common negative reinforcement models propose that drinking alcohol is a means to manage stress by dampening the stress response (Carver et al., 1989; Marlatt & George, 1984; Sher, 1987), or that drinking alcohol is a means of medicating against the emotional distress and providing stress relief (Blume et al., 2000; Khantzian, 1987). However, the specific processes by which stress may promote alcohol intake, especially in non-clinical samples, has not been clearly identified and tested.

More recently, the notion of a differential motivational response to stress that drives increased intake has been proposed (Sinha, 2001, 2008), building on the incentive sensitization theory of addiction (Berridge & Robinson, 2016; Robinson & Berridge, 1993, 2001). Stress-related feelings may drive individuals towards alcohol, not just for avoidance of these feelings or stress relief, but also for approach-related reasons via increased reward anticipation (Kumar et al., 2014; Pool et al., 2015). In this framework, regular high levels of alcohol intake may alter the psychobiological stress responses in ways that sensitize greater wanting of alcohol in a feed-forward manner (Sinha, 2011, 2013). While this model has been tested and supported in clinical AUD samples in laboratory, EMA, and clinical samples (Seo et al., 2013; Sinha et al., 2009, 2011; Wemm et al., 2019), no previous research has assessed whether it holds true in non-clinical samples of alcohol users.

Results from controlled experimental studies have found that acute stress provocations simultaneously increase subjective stress levels and stress-induced alcohol craving, and to a greater degree in heavier social drinkers (Blaine et al., 2019; Clay et al., 2018). When given the option to drink in an alcohol taste test paradigm, binge social drinkers consumed more alcohol (Blaine et al., 2019; Ramchandani et al., 2018) and reported higher craving (Blaine et al., 2019) when previously exposed to alcohol and stress imagery cues relative to a neutral cue. However, these studies did not directly assess the role of craving in the link between stress and alcohol intake in daily life. Thus, the goal of the current study is to examine whether craving mediates the link between stress and alcohol intake in the broad group of social drinkers and, if so, investigate if this relationship is influenced by higher recent levels of alcohol intake. We expected those with higher recent alcohol consumption, as measured

by an index of average typical quantity of alcoholic drinks and frequency of drinking days (QFI), to report greater craving and higher alcohol consumption, but not greater stress levels. We also hypothesized that craving would mediate the link between stress and alcohol intake, such that a higher craving response to stress will be associated with greater drinking later that evening. Furthermore, based on the previous laboratory studies, we hypothesized that heavier pre-study drinking levels will be associated with greater alcohol craving response to stress and such higher stress-induced craving may drive greater stress-related alcohol intake, in those who are consuming higher levels of alcohol. Elucidating this dynamic in a real-life setting (e.g., daily temporal associations) could help identify whether stressors and subjective stress predicts alcohol craving which in turn potentiates drinking and inform prevention strategies that may specifically target these dynamics.

Experience sampling studies, such as daily diaries and ecological momentary assessment, offer one method of testing the above outlined hypotheses in the real world. This is particularly important in the context of stress and craving. Both stress and craving are dynamic and constantly changing to meet the demands of the moment, thus examinations of these constructs should also be dynamic. Intensive longitudinal studies thus far have examined only one arm of the relationships among stress, craving, and drinking, usually stress as a predictor of drinking (Dvorak et al., 2014; Strahler et al., 2020) or stress as a predictor of craving (Mayhugh et al., 2018). Not accounting for the full dynamic between stress, craving, and drinking may underestimate the effect of stress-related craving on drinking. In previous work with two separate samples of individuals in early treatment for AUD, we reported that the relationship between stress and drinking was mediated by alcohol craving (Wemm et al., 2019). Higher stress was associated with higher levels of craving, which in turn led to greater next-day alcohol intake during early treatment. However, this previous work does not provide any insights on the well-known relationships between stress and alcohol intake in the broader sample of alcohol users. Thus, a non-clinical sample of social drinkers with variability in recent drinking history is necessary to examine how these relationships might play out in the real world.

Current Study

To test the proposed hypotheses outlined above, the current study examined the prospective associations among subjective stress, craving, and subsequent later drinking each day for 30 days using an intensive longitudinal design in a group of social drinkers. Importantly, given our previous research assessing these associations in AUD, a key aspect of the current study was to determine if alcohol consumption directly predicted heightened stress, craving, and prospective drinking or altered the links among these constructs in social drinkers. Because of the repeated assessment inherent in such designs, we can control the prospective temporal associations between variables by focusing on occasions that meet specific criteria, such as examining pre-drinking craving to examine if stress predicted that drinking episode, thus modeling what would be examined in a lab, without sacrificing ecological validity (Morgenstern et al., 2014; Shiftman, 2009). We conducted multilevel structural equation models to parse an individual's subjective stress, craving and likelihood of drinking later that night across individuals (between-person) and from day-to-day fluctuations within an individual (within-person). Using this approach allowed us to examine if these relationships

played out differently depending on the level of analysis used to examine these relationships (Tennen et al., 2000). From a clinical perspective, teasing out the level that these dynamics play out could help inform *who* (between-person) and *when* (within-person) should be targets for prevention. We focused on subjective stress as a predictor of drinking and craving because subjective stress may more closely drive the negative reinforcement value of drinking or the motivation to drink. We hypothesized that individuals who experienced more subjective stress would have higher levels of craving and, as a result, have more frequent drinking (between-person). We also hypothesized that days with higher levels of stress would be marked by higher craving and would be more likely to result in a drinking day (within-person). We further hypothesized that a heavier recent drinking pattern, as measured by an index of quantity and frequency of past month alcohol use, would both heighten craving further. In turn, craving would be associated with greater drinking at both the between- and within-person levels.

Method

Participants

Socially drinking individuals were recruited from the Greater New Haven community through flyers, Craigslist and Facebook ads, and local newspaper advertisements. All participants provided written informed consent for the research protocol approved by the Yale University Human Investigation Committee. Individuals between the ages of 18 and 50 were included in the study if they could sign informed consent, read English, and complete the study evaluations. Participants were excluded if they: met current DSM-5 criteria for an Alcohol or other substance use disorder, excluding nicotine, using the Structured Clinical Interview for DSM-5 (First et al., 2015); had significant underlying medical conditions, or reported regular use of the following medications: anticonvulsants, sedatives/hypnotics, prescription analgesics, other antihypertensives, anti-arrhythmic, antiretroviral medications, tricyclic antidepressants, SSRIs, naltrexone, or Antabuse. A total of 101 individuals who reported consuming alcohol socially were enrolled in the study. Of those, nine individuals were excluded because they met DSM-V criteria for current AUD. Five individuals (6.7%) had a history of Alcohol Use Disorder but did not currently meet criteria and were included in the analyses. In addition, participants who were abstinent or non-drinking for the past month or during the study were excluded so that only social drinkers with drinking during the study were included in the study (11 total individuals). The final sample consisted of 81 mostly white ($n=46$, 56.79%, Table 1) individuals (female: $n=39$, 48.2%).

To assess whether we had adequate power to test the proposed hypotheses, we conducted a power analysis to test if we had sufficient power for the mediation models using data from our prior work in individuals with Alcohol Use Disorder (Wemm et al., 2019). Monte Carlo simulations were used to determine if we could assess the number of subjects needed to test the mediation model. We found that 65 participants with 24 daily observations would give us 85.6% of the 1000 simulations to assess the within-person mediation effects. This suggested there was sufficient power to test the proposed hypotheses in these analyses.

Self-report Measurements

Sociodemographic Information.—Demographic data, medical history, and family psychiatric history were assessed via interviews and self-reports in a pre-study baseline period over 2-3 intake sessions.

Recent Alcohol Use.—Participants were asked about the past month's frequency and average amount of alcohol consumed in a drinking episode using three different assessments at different points during the baseline intake period. First, average alcohol intake amounts and frequency of use were elicited at the first intake appointment using open-ended questions about the participants average amount of alcohol consumed during a typical drinking episode and the total number of days with drinking in the past 30 days. At a second intake appointment, we administered the Cahalan classification of hazardous alcohol consumption (Cahalan et al., 1969), which was used to supplement any missing previous drinking reports. Based on these responses, an average quantity and frequency index (QFI) of recent alcohol use was created for the pre-study recent alcohol intake measure by multiplying the number of drinking days in the thirty days prior to beginning the study by the average number of drinks per drinking day. In addition, the Alcohol Use Disorders Identification Test (AUDIT; Babor et al., 2001; Saunders et al., 1993) was used to determine levels of problematic drinking in the sample.

Daily Diary Monitoring

Participants completed a daily survey once a day over a 30-day period via a smartphone app (MetricWire, Inc). When completing training for the daily diaries, participants were instructed to complete the surveys as soon as they received them. Participants received a notification each day at 17:00:00 without reminders and were given 12 hours to complete the survey. Although they were given a wide window to complete the survey, the average time of day that the participants completed the survey was 18:09:44 ± 03:46:50, confirming that, on most days, participants completed the survey in the early evening shortly after being prompted.¹

The daily survey assessed participants' overall stress level by asking participants to, "Please rate your overall stress level since the last prompt" on a 100-point VAS scale with 1="Not at all" and 100="Extremely." Stress events were assessed by asking the following two questions, "TODAY: Which of the following events made you feel stress today?" to which they could check a box of twelve possible events (e.g., "Work/Education," "Home/Family," "Finances," among others) (Armeli et al., 2015; Wemm et al., 2019), which were dichotomized to indicate if any stressful events occurred that day ("1") or not ("0"). Participants' evening craving was assessed by asking, "How much do you want to drink alcohol right now?" with 1="Not at all" and 100="Very much." We also assessed drinking that occurred that day up to the point that they completed the assessment ("TODAY: How

¹We conducted two separate sets of analyses to ensure that the results were not influenced by completing the surveys earlier as compared to later in the evening. In the first set, we controlled for the hours that had elapsed since the survey was prompted. The second set of analyses was conducted after removing surveys that were completed after + 3 SDs of the average survey completion time. Six observations were removed from the second set of analyses. The pattern of results remained the same after controlling for time and excluding these outlying observations.

much did you drink?”). We also asked if they had drank alcohol after completing the previous evening’s survey (LAST NIGHT: Any drinks after your last survey? How much did you drink?”). Each drinking question included a description of standard drinks (i.e., 12 oz beer=1; 5 oz wine=1; 1.5 oz shot (liquor)=1). Because this was a socially drinking sample, the number of drinks were positively skewed; therefore, we dichotomized the reports of the previous night’s drinking into a drinking day (1) or not (0), and the dichotomized drinking day variable was used as our dependent variable.

Procedures

After an initial phone screen to determine preliminary eligibility, participants were invited to the center. Upon arrival, they were presented with a description of the study, provided their written informed consent, and completed an in-person screening followed by 1-2 intake appointments. During these appointments, participants completed assessments and provided urine samples to verify recent alcohol and drug use history. After completing the intake process, participants completed an orientation to the daily diary assessments and were enrolled in the surveys. A research assistant monitored compliance throughout the study. Participants were paid \$4 per day for responding to each daily prompt. They also received an additional \$10 bonus for completing all the surveys for that week (Figure 1 for procedure).

Data Analytic Plan

Descriptive statistics (*dplyr* and *psych* packages; Revelle, 2017; Wickham et al., 2015) and graphs (MplusAutomation, *ggplot2*, *viridis*, and *ggeffects* packages; Garnier et al., 2021; Hallquist & Wiley, 2018; Lüdtke, 2018; Wickham, 2016) were generated in R v3.6.0. Correlations and t-tests were used to determine if the QFI was correlated with demographic characteristics or baseline drinking measures (other than frequency and amount of past month drinking). Preliminary mixed models were conducted using the *lme4* package in R (Bates et al., 2014). We calculated the ICCs of subjective stress, craving, and drinking in Mplus to determine the percent of the variance in these variables that occurred just at the between level as compared to their total variance. We included gender, age, and weekend day as covariates in all models.

We used linear mixed models to investigate the association of daily stress events and QFI on subjective stress level. These models were primarily used to confirm that days with stress events did indeed have higher subjective stress level overall. The primary analyses were conducted using Multilevel Structural Equation Modeling (MSEM) with random coefficient prediction in Mplus v8.4, or “slopes-as-outcomes” (Raudenbush & Bryk, 2002). We used Bayesian MSEM with non-informative priors to test the *prospective* mediating effect of craving on the association between stress level and if drinking occurred later that evening. MSEM allows for the unbiased disaggregation of overall subjective stress and craving levels across individuals (between-person) from within-person daily fluctuations in subjective stress and craving (within-person; see Figure S1 for conceptual diagram) (Preacher et al., 2010). Furthermore, MSEM allows for the modeling different types of variables, such as binary or continuous in the present study, and deriving indirect effects from these latent variables. Categorical variables are modeled using a probit link. We converted the estimates to predicted probabilities for any relationship predicting drinking to ease interpretation.

QFI was log-transformed since it was significantly positively skewed. All continuous predictor variables (i.e., subjective stress, craving, age, log-transformed QFI) were standardized (z-scores) to ease interpretation of the moderation analyses and facilitate convergence. Drinking day was dichotomized as drinking having occurred that later that evening (1) or not (0). Since most reports occurred shortly after receiving the survey as instructed, we were able to lag the variables so that subjective stress and craving that evening predicted reports of initiating drinking that occurred after they completed that assessment based on the next day's survey. Analyses were limited to days on which no drinking had occurred prior to completing the daily prompt assessment to ensure that we were measuring pre-drinking craving only and only predicting if drinking occurred later that night. We chose this analytic strategy for the following reasons. First, we were primarily interested in what motivated a drinking episode, while also preserving the analyses' prospective prediction of drinking while still examining the within-day processes of these variables. Second, we opted for methodological control rather than statistically controlling for drinking that had already occurred that day as there are well-documented issues with using statistical control as means of imposing incremental validity where methodological control would suffice (Breugh, 2008; Christenfeld et al., 2004; Westfall & Yarkoni, 2016). Third, evening or night drinking has been associated with adverse consequences, particularly in social drinkers, whereas day drinking is associated with more adverse consequences in older, heavier drinkers (Dawson, 1996; Greenlund et al., 2021). Finally, social drinkers typically drink in the evening (Room et al., 2012), thus we captured the majority of drinking episodes in our non-clinical sample.

At the between-person level (Level 2), we estimated the associations of between-person latent variables stress, craving, and drinking days.² We also included an observed variable, QFI, that existed solely at the between-person level and upon which we regressed craving and drinking. At the between-person level, we estimated the following mediation paths: stress and craving (a_{between} path), craving and drinking (b_{between} path), stress and drinking (c'_{between} path), and the indirect association of stress on drinking via craving ($\text{indirect}_{\text{between}}$ path). At the within-person level, we obtained the estimated a random slope for the associations between the latent within-person variables: stress and craving (a_{within} path), craving and drinking (b_{within} path), stress and drinking (c_{within} path), and the indirect association of stress on drinking via craving ($\text{indirect}_{\text{within}}$ path).

We then tested if QFI moderated the associations among stress, craving, and drinking (Figure S1) by assessing if each person's slope (i.e., the within-person random slope) in the mediation model differed based on their QFI score (Zyphur et al., 2018). Since the QFI variable exists only at the between-person level, we could not estimate QFI's main effect directly on the within-person level variables, e.g., determine if craving that day was influenced by QFI. We instead focused on how QFI altered the relationships among stress, craving, and drinking by using each individual's random slope as a latent variable. At the between level, two latent product terms were estimated, Stress X QFI and Craving X QFI, and then regressed on craving and drinks later that day. We retained any significant interactions in the final moderated mediation model, reported below.

²A latent variable was placed "behind" the between-person components of stress, craving, and drinking variables to facilitate latent variable interaction in our moderated mediation models, as described in Zyphur and colleagues (2018).

We also ran these models using stress events in the place of subjective stress. We chose to focus on subjective stress here because of our hypothesis that stress-related feelings would be associated with the negative reinforcement value or desire for alcohol. The stress event results are summarized in the Supplemental Materials.

As recent findings report an effect of race on the links between stress and craving (Pedersen et al., 2021), we conducted an exploratory analysis that examined the effect of racial identity on the links between mean subjective stress, craving, and frequency of drinking days using a general linear model (*lm* package) included in the supplemental materials.

This study was not preregistered. Data and syntax are available upon request from the authors.

Results

Demographics and Survey Response Rate Preliminary Analyses

Baseline drinking behavior and participants' demographic characteristics are included in Table 1 (see Supplemental Figure 1 for a distribution of the pre-study frequency and average amount of alcohol use). Individuals with higher QFI were male, younger, and had a higher AUDIT score. QFI was uncorrelated with both the number of total completed surveys and the number of surveys with no drinking at the time of prompt. QFI was positively correlated with the average level of craving, the number of drinks overall, the average drinks on a drinking day, and the percent number of any drinking and heavy drinking days in the smartphone prompts. Individuals with a past history of a psychiatric diagnoses did not drink more than those without a diagnosis history (Table 1).

Daily Diary Completion

The average daily diary completion rate was 82.0% for all 30 days in the study ($n=2060$ days). When we limited the data to only days with no drinking before completing the evening survey for that day, we retained most of the recorded days (81.9% or 1688 days), 265 of which were drinking days.

A substantial portion of the variance in subjective stress (50.4%) and craving (49.3%) occurred at the between-person level (Subjective stress $ICC=0.504$, 95% CI: 0.423 – 0.592; Craving $ICC=0.493$, 95% CI: 0.413-0.583). 13.0% of the variance in drinking days was accounted for at the between-person level ($ICC=0.130$, 95% CI: 0.082-0.199).

Stress Events Association with Subjective Stress

We used multilevel models to assess the effect of stress events and QFI on subjective stress. Stress events that day were associated with higher subjective stress that night relative to non-stress days, $F(1, 1597.41)=526.34$, $p<0.001$ (Figure 2a), and there was no significant QFI effect on daily subjective stress ($p=0.893$, Figure 2d) or on stress events ($p=0.687$, Figure 2e).

Mediation Model

We conducted mediational analysis using Bayes MSEM predicting if drinking occurred later that night using subjective stress and craving, after controlling for age, gender, and weekend day (Figure S1). The results are reported here, and the coefficients can be found in Table S1.

Between-person Level Associations.—Higher subjective stress was associated with higher craving, $b=0.380$, 95% CI: 0.191 – 0.573 (Figure 3a-3b, Table S1), and those with higher QFI had higher craving responses, $b=0.337$, 95% CI: 0.187-0.486 (Figure 2b), and were more likely to drink that evening, $b=0.119$, 95% CI: 0.018-0.297 (Figure 2c, Table S1). Those with higher levels of craving drank more alcohol, $b=0.328$, 95% CI: 0.054-0.676 (Figure 3c), with 36.8% of the variance in craving, $R^2=0.368$, 95% CI: 0.204-0.520, and 72.2% of the variance in drinking at the between-person level being explained by the model, $R^2=0.722$, 95% CI: 0.373-0.995. Subjective stress was related to a higher probability of drinking indirectly via its effect on craving, *Stress Indirect*: $b=0.119$, 95% CI: 0.018-0.297. The direct effect of subjective stress on drinking was not significant, $b=-0.200$, 95% CI: $-0.522 -0.100$ (Figure 3a).

Within-person Level Associations.—Like the between-person level results, subjective stress had an indirect effect on later drinking via its effect on craving (Table S1). Individuals who reported higher subjective stress on a particular day experienced more craving that evening, $b=0.130$, 95% CI: 0.028-0.230 (Figure 3d-e), with 38.9% of the variance in craving at the within-person level accounted for by this model, $R^2=0.389$, 95% CI: 0.358-0.419. Days with higher craving also resulted in heavier drinking that night $b=0.540$, 95% CI: 0.371-0.714 (Figure 3d). The model accounted for 5.9% of the variance in drinking at the within-person level, $R^2=0.059$, 95% CI: 0.027-0.103. Like the between-person level patterns, daily subjective stress was associated a greater likelihood of drinking by way of its effects on craving, $b=0.069$, 95% CI: 0.014-0.135, and the direct effect of subjective stress on drinking was not significant, $b=-0.003$, 95% CI: $-0.137-0.143$.

Moderated Mediation Model

For brevity, we report only the final model here (Table 2). Estimates for the full moderation model for subjective stress can be found in the Table S1.

QFI continued to have a main effect on craving and drinking but did not moderate the stress → craving and craving → drinking links at the between-person level (Figure 3a). At the within-person level, the link between craving that day and drinking later that night differed as a function of QFI, $b=0.249$, 95% CI: 0.036 – 0.48 (Figure 3f). The moderated effect became significant for individuals -0.5 SD below mean QFI and remained significant at every 0.5 SD increment above. For interpretation, we focused on -1 SD below and $+1$ SD above the mean. Those with higher QFI scores ($+1$ SD) were 19.3% more likely to drink later that evening if they were experiencing higher craving that evening, $b=0.668$, 95% CI: 0.471-0.883; whereas craving was not associated with drinking later that evening in lighter drinkers (-1 SD), predicted probability = 0.087, $b=0.175$, 95% CI: $-0.216-0.516$. When examining the overall mediation effect, the findings supported moderated mediation. The indirect effect of daily subjective stress on nightly drinking via its effect on craving

was significant for heavier social drinkers (+1 SD), $b=0.086$, 95% CI: 0.020-0.169, but not lighter drinkers (-1 SD), $b=0.019$, 95% CI: -0.030-0.082.

Stress Event Effects

We explored the effect that stress events had on drinking via craving using similar analyses. These results have been detailed in the Supplemental Results section, and are summarized here (Tables S2-S3, Supplemental Figure 3). At the between-person level, individuals who experienced more frequent stress events throughout the study reported higher craving on those days regardless of QFI, $b=0.664$, 95% CI: 0.474-.890, $p=0.013$ (Supplemental Table 3). At the within-subject level, having a stress event that day was not directly associated with craving, $b=0.033$, 95% CI: -0.096-0.162, $p=0.066$. The craving-drinking relationship at both the within and between-person levels remained the same in the final stress events model.

Discussion

The current study demonstrated the associations between daily stress and later evening drinking in nonclinical social drinkers. Although prior studies reported that using alcohol to cope with subjective stress and negative moods has been linked to hazardous alcohol consumption patterns (Dvorak et al., 2014; White et al., 2016), it has been unclear how subjective stress triggers alcohol-seeking behaviors in drinkers' daily lives. This study is the first to prospectively test that craving mediates the association between subjective stress and later alcohol use in community social drinkers in their natural settings. We found that craving mediates the effects of subjective stress on later initiation of alcohol intake, particularly in heavier social drinkers. This suggests subjective stress might affect alcohol consumption by via its effect on craving, rather than directly triggering the alcohol use. Further, the craving response to stress and its association with later alcohol use is stronger in heavier social drinkers. These results are notable when considering that the QFI was unrelated to higher feelings of subjective stress, as one would expect if the motivation for drinking was stress relief. Thus, stress and QFI independently predicted craving, suggesting a potential '*sensitization*' of motivated drinking progressively in those consuming higher alcohol intake even prior to the development of an Alcohol Use Disorder. Overall, there was an additive effect of subjective stress and QFI. If an individual was both highly stressed and drinking more prior to study initiation, their craving levels were higher than that of their peers, which then translated into more drinking on average (between-person). While subjective stress was associated with higher alcohol approach motivation (i.e., high craving) across all individuals, whether they began drinking that day in response to this enhanced motivation depended upon their already established drinking patterns (within-person). Notably, the indirect effect of stress on drinking via craving at the within-person level was significant only among individuals with average to heavier alcohol consumption, a finding consistent with our prior findings in treatment-seeking individuals with AUD (Wemm et al., 2019). Collectively, these results suggest that the stress-motivated drinking is associated with higher levels of alcohol intake and occurs even in individuals who do not have AUD. This finding may have significant implications for prevention as higher stress-related craving may play a role in hazardous drinking and its adverse social and health consequences.

These results are consistent with both the incentive-salience model (Robinson & Berridge, 1993) and stress sensitization of craving models (Sinha, 2001, 2008, 2013; Uhart & Wand, 2009). There is increasing evidence that stress increases approach motivation for a variety of rewarding behaviors (e.g., interpersonal touch, money, food; Kumar et al., 2014; Massaccesi et al., 2021; Pool et al., 2015). This drive towards rewarding behaviors under stress may occur for all social drinkers, but with higher levels alcohol consumption, there is a greater craving response, with a higher likelihood that higher craving leading to drinking. Specifically, with increasing alcohol intake, there is a higher craving response that compounds upon stress-potentiated drinking, that in turn predicted a greater likelihood of subsequent drinking (Sinha, 2011, 2013). We found that drinking was more likely to occur on evenings where heavier social drinkers experienced higher levels of stress-related craving, as evidenced by the significant indirect effect of the moderated mediation model, but this was not the case in lighter social drinkers. Notably, although lighter drinkers also showed associations between stress and craving at the within-person level; their overall levels of craving were lower and did not translate into a drinking episode. Although these models have been supported by laboratory findings, they have not yet been translated to daily human behaviors in real-world settings. Research on the biobehavioral effects of alcohol and stress suggests high levels of alcohol intake progressively alters executive self-control processes that regulate stress, emotion, and reward, thereby weakening and disrupting adaptive coping and promoting incentive-driven motivation processes (Sinha, 2013; Sinha et al., 2016). Our findings add to the literature by showing that stress-driven motivation prospectively predicts alcohol consumption not only at the between-person level (*who*) but also at the daily within-person level (*when*) in heavier drinkers. Our findings, along with other studies, suggest that psychological and neurobiological adaptations may be occurring long before social drinkers reach the threshold of even mild AUD (Blaine & Sinha, 2017; Wemm & Sinha, 2019), emphasizing the need for early identification and prevention of cravings in response to stress in those at higher levels of alcohol consumption.

A strength of the current study, and other studies that use intensive repeated measure designs, is that they enable systematic examinations of within-person day-by-day influences on drinking separately from between-person differences. This approach allowed us to uncover two nuanced findings: first, the indirect effect of subjective stress at the within-level was significant in heavier social drinkers, however, it was significant for all drinkers at the between-person level; and second, the effect of stress events was different at the between-person level as compared to the within-person (as described in the supplemental material). Our results suggest that inherently within-person drinking dynamics, such as stress effects on drinking, should not be tested solely with between-person data as these associations can differ from within-person associations not only in magnitude but also in direction. Although between-person level characteristics can inform *who* is more at-risk for initiating drinking and might provide evidence of psychobiological shifts that have occurred as a function of more exposure to alcohol, the within-person level relationships can inform *when* individuals are most at risk and provide critical context-driven information suggesting key processes proximal to drinking behavior. These findings suggest that targeted prevention efforts that help heavier social drinkers manage their specific stress-related craving could reduce the likelihood that these individuals would consume more alcohol.

An additional advantage of the current study is that we could assess the temporal relationships among subjective stress, craving and later drinking. By examining only days with no drinking before the evening prompt, we could be sure that fluctuations in stress and craving were predicting initiating later drinking. In once-daily diary studies, researchers are often limited to predicting behavior that is either measured simultaneously with subjective feelings and thereby cannot control for the sequence of how these processes might unfold or are limited to predicting behavior that occurs the following day. Our analytic strategy allowed for predicting initiation of drinking that occurred *after* but still temporally proximal to craving and stress assessments. However, by doing so, we limited our analyses to days that did not include drinking prior to the evening and may not reflect this dynamic in all drinking-related scenarios. Nonetheless, it is worthwhile to study drinking that occurs in the late evening, as social drinkers primarily consume alcohol in the evening (Groefsema & Kuntsche, 2019) and night drinking may disrupt autonomic functioning (Greenlund et al., 2021). In addition, day drinking in social drinkers tends to be associated more with event-specific days (e.g., birthdays, holidays) and social events (e.g., tailgating) and thus may have a different set of antecedents as compared to night drinking (Calhoun & Maggs, 2021).

Our findings suggest that individual differences drove a large part of the relationships among subjective stress, craving, and drinking in the real-world. Nearly half of variance in subjective stress level (50.4%) and craving (49.3%) could be accounted for by between-person level differences. In contrast, a smaller proportion of drinking day variation was at the between-person level (13.0%). Thus, stress and craving varied almost equally across people and occasions, whereas initiating drinking tends to change more across occasions in social drinkers. Although individuals experience the highs and lows of stress regularly, not all fluctuations in subjective stress manifest in behavioral responses, such as drinking. Finally, although stress and craving were assessed at the same time, the questions inquiring about subjective stress and stress events encompassed the entire day, whereas craving was assessed at that moment. The framing of the questions lends support for the temporal order of the stress → craving relationship, but more research should use random prompts and within-day lagged assessments to verify the temporal order of the stress craving relationship. Nevertheless, our data identified stress-related vulnerability factors leading to alcohol consumption, which can be used as a target for interventions to control risky drinking behaviors. Targeted prevention efforts that identify heavier social drinkers based on their propensity to experience stress-related motivation might reduce the likelihood that they initiate drinking.

The current study is subject to certain limitations. First, the subjective stress, stress events, and drinking reports were retrospective in nature, albeit within a 12-24-hour span. Social drinkers had to reflect on their overall stress level and occurrence of stress events that day or recall how many drinks they had the previous day. Although the time is still relatively short, there is the potential to introduce some retrospection error and possible bias. Also, we focused on daily reports of subjective stress and craving. Craving is highly variable across the day and can occur in settings where stress might be absent, such as in the context of alcohol cues or around people with whom they usually drink. Because we only had daily surveys and wanted to maintain the prospective nature of the analyses, we may have

lost information about days where drinking had occurred earlier than the evening. Future research using random prompts and event-contingent surveys would allow us to examine day drinking events and enable investigators to fully explore sequences of stress, craving, and drinking in the real-world. In addition, the sample size is modest for assessing moderated mediation and may have the potential to overestimate small effects. The sample size was determined by previous work and future research should seek to replicate our findings in a larger sample of social drinkers. Future studies should evaluate the effect independent and synergistic associations of stress events and subjective stress levels with alcohol cues on craving in a large group of social drinkers in various social contexts. Finally, we did not find an association between previous non-substance DSM diagnoses and drinking levels, which is counter to previous findings that higher levels of drinking in social drinkers were associated with more depression and anxiety (El-Guebaly, 2007; Kenney et al., 2018). We specifically recruited individuals who were in good mental and physical health making the findings relevant to the broad sample of social drinkers but limiting its applicability to those with mood and anxiety symptoms. We also did not find any effects of racial identity on the relationship between subjective stress and craving – a finding that diverges from Pedersen and colleagues (2021); however, we were likely underpowered to detect any moderating effect of race. Future research studies should examine the moderating effect of psychiatric diagnoses and racial identity with a larger sample of social drinkers with a more diverse psychiatric history.

Despite these limitations, the current study provides ecological evidence for the influence of subjective stress on craving and drinking particularly in heavier social drinkers, suggesting that higher levels of alcohol intake contribute to a sensitized shift toward stress-related alcohol motivational processes which in turn predicts higher alcohol intake. Heavier social drinkers who feel more stressed may be at higher risk for drinking via the experience of high levels of craving that day. Most prevention programs for at-risk drinkers focus on the use of alcohol in the context of social settings or modifying expectancies around drinking (Bridges & Sharma, 2015), with less focus on stress-motivated alcohol use. If these alterations are occurring before the onset of AUD, there is a missed opportunity for stress-related craving and associated drinking as a potential target for prevention efforts at reducing hazardous alcohol intake.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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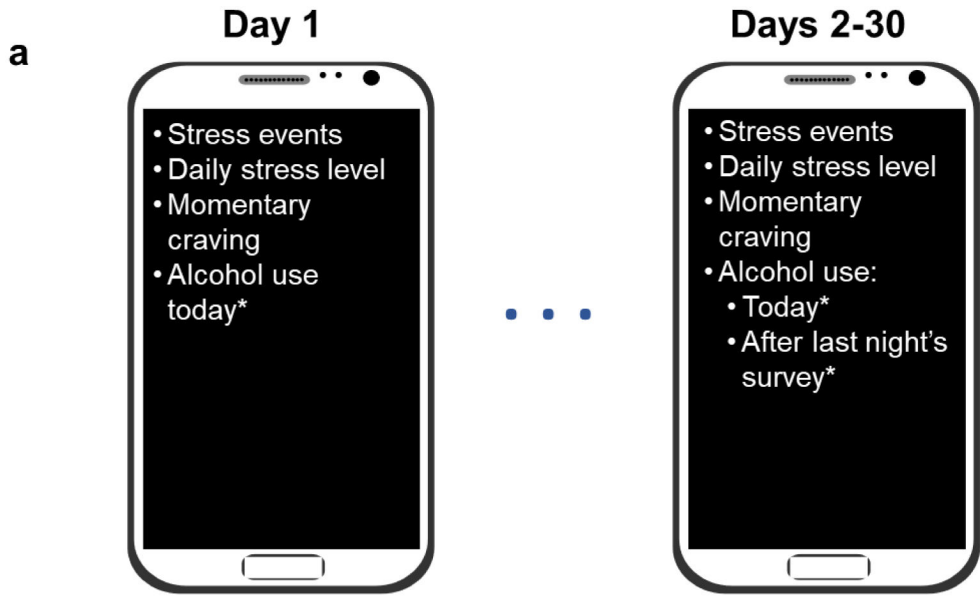
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*Only days with no drinking at the time of evening prompt were included in the models.

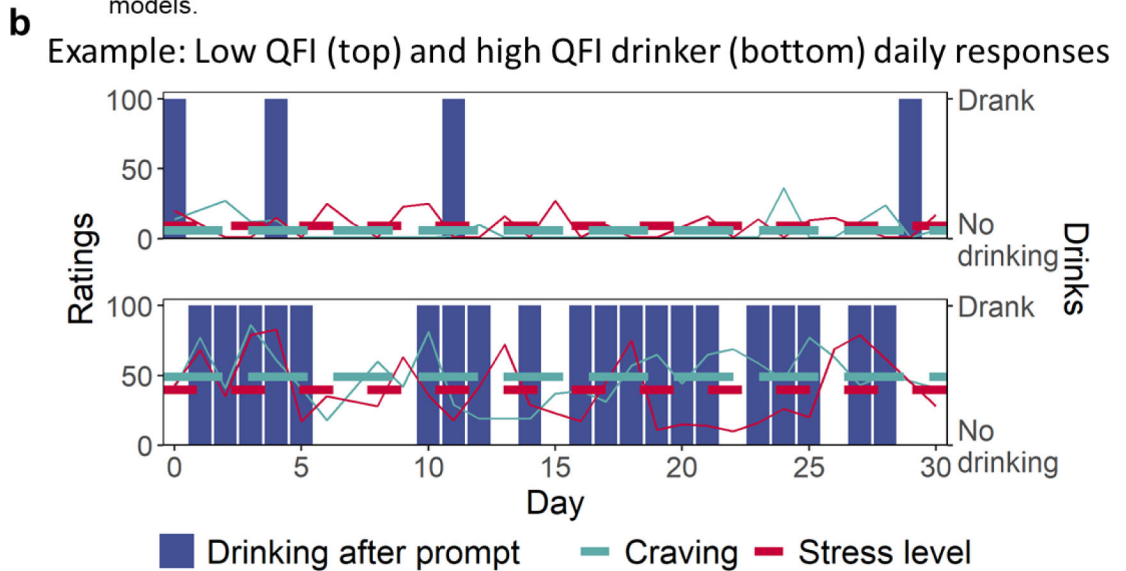


Figure 1. Procedure diagram for the daily diaries.

Note. Participants could complete daily diaries at 5 pm each day. Participants were asked about any stress events that might have occurred that day, their overall stress level for the day, their craving at this moment, and if they had drunk alcohol after completing the survey last night or during the day today. Only days where the participants had not yet consumed alcohol that day were included in the models. At the bottom, sample data is shown from two representative participants. The solid red line is subjective stress level on each day, the solid green line is craving, and the bars indicate if the participants had initiated drinking after completing that day’s prompt, as reported in the following day’s daily diary. The dashed lines indicate each person’s between-subject craving and drinking.

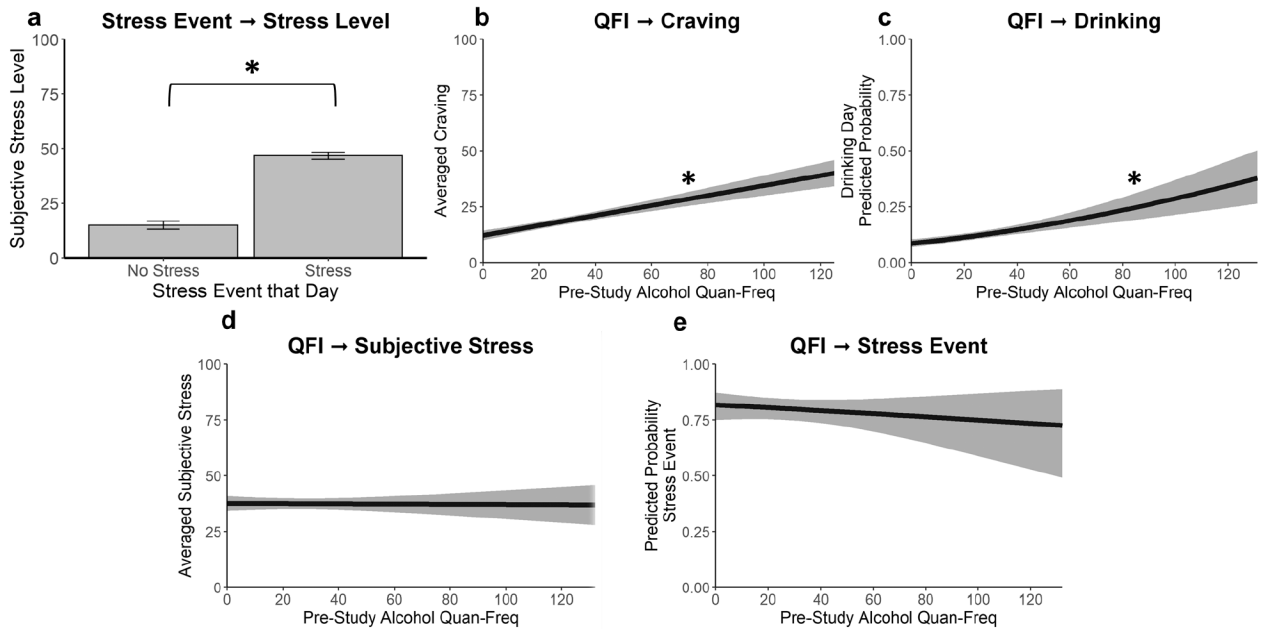


Figure 2. Relationship between Subjective Stress Ratings, Stress Events, Craving, Pre-Study Recent Quantity and Frequency of Alcohol Use (QFI) and During Study Percent Days with Stress on Non-drinking Days.

Note. Relationship between (2a) stress event and subjective stress, (2b) QFI and person-averaged (between) craving, and (2c) QFI and person-averaged (between) drinking frequency, (2d) QFI and person-averaged (between) subjective stress level, and (2e) QFI and overall probability of a stress event (between). * indicates significant effects (95% CI that do not cross 0).

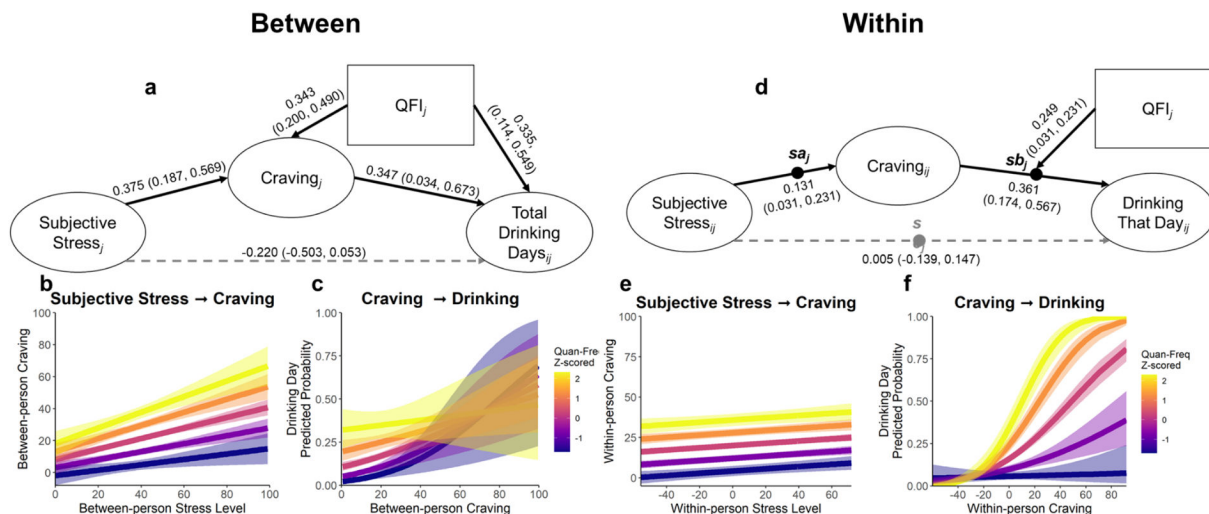


Figure 3. Relationships of Subjective Stress, Craving, and Daily Drinking Probability at the Between and Within-person Levels.
Note. The final moderated mediation model for subjective stress at the between- (3a) and within-person level (3d). Significant paths are shown in solid black lines, non-significant paths are depicted with gray dashed lines. Graphs depicting the relationships of subjective stress on craving (3b, 3e) and craving on initiating drinking (3c, 3f) by z-scored log-transformed QFI. Between-subject effects were converted to the original metric, while within-subject effects were kept at the centered values. Individuals with higher levels of subjective stress experienced more craving (3b) and higher QFI predicted higher levels of craving. Increased craving was associated with more drinking throughout the study (3c). Days with increased stress were associated with heightened craving that day (3e). QFI moderated the relationship between craving and drinking at the within-person level such that individuals with higher QFI were more likely to drink if their craving was also high (3f).

Table 1

Descriptive Statistics on Basic Background and Demographic Information.

	Mean or Freq <i>n</i> =81	SD or %	<i>r</i> , <i>t</i> , or <i>F</i> with QFI
Demographic and Clinical History			
Gender – Female (%)	39	48.15%	-2.46 ^{<i>b</i>}
Age (in years)	27.18	7.93	0.01
Race			
White, Non-Hispanic	46	56.79%	0.25 ^{<i>c</i>}
Black, Non-Hispanic	17	20.99%	
Other or Hispanic	18	22.22%	
Years of Education	15.68	2.16	-0.10
Lifetime Non-SUD DSM diagnosis	14	17.2%	0.43 ^{<i>b</i>}
Anxiety-related disorder	2	2.47%	0.02 ^{<i>b</i>}
Bipolar-related disorder	1	1.23%	0.32 ^{<i>b</i>}
Depression-related disorder	13	16.05%	0.71 ^{<i>b</i>}
OCD-related disorder	2	2.47%	0.47 ^{<i>b</i>}
Eating-related disorder	3	3.70%	0.88 ^{<i>b</i>}
Sleeping-related disorder	2	2.47%	0.67 ^{<i>b</i>}
Trauma-related disorder	1	1.23%	0.99 ^{<i>b</i>}
Alcohol Involvement			
Years of alcohol use	10.08	8.48	0.11
Age of first alcohol use	17.10	2.56	-0.34
Baseline drinking days (past 30 days)	9.74	5.48	--
Baseline amount per drinking episode (past 30 days)	4.80	2.01	--
Quantity-frequency index (QFI)	27.25	28.25	--
AUDIT total score	5.51	3.69	0.57
Lifetime Past Alcohol Use Disorder	5	6.17%	-1.24 ^{<i>b</i>}
Lifetime Past Non-AUD Substance Use Disorder	3	3.70%	-0.51 ^{<i>b</i>}
Daily diaries – Average per person			
N of total completed surveys/30 days	24.75	5.72	0.07
N of completed surveys with no drinking at time of prompt	20.84	6.92	-0.21
N of Stress Days ^{<i>a</i>}	14.16	8.63	-0.11
Average Stress Level ^{<i>a</i>}	37.65	20.98	-0.01
Average Craving ^{<i>a</i>}	19.02	17.19	0.35
Average Drinks on Drinking Day ^{<i>a</i>}	2.93	1.71	0.58

	Mean or Freq <i>n</i> =81	SD or %	<i>r</i> , <i>t</i> , or <i>F</i> with QFI
Average % Drinking Days ^{<i>a</i>}	21.26	22.62	0.30
Average % Heavy Drinking Days ^{<i>a</i>}	6.12	12.67	0.52

Note. Self-report daily surveys obtained daily over a 30-day assessment period. AUDIT = Alcohol Use Disorder Identification Test, SUD = Substance Use Disorder, AUD = Alcohol Use Disorder. Results in bold typeface indicate a significant result ($p < .05$).

^{*a*} indicates that the percentage and averages are calculated based on days with no drinking prior to completing the evening prompt; all reported drinking data is gathered from the next day's report of the drinking that occurred after the prompt.

^{*b*} indicates that the grouping demographic variable was used in a t-test to predict the QFI.

^{*c*} indicates that the grouping demographic variable was used in an ANOVA to predict the QFI.

Table 2

Final moderated mediation investigating subjective stress level on daily drinking, directly and indirectly via craving, using MSEM.

Parameter	Est.	Posterior SD	<i>p</i>	95% C.I.	
				Lower	Upper
Between					
a_{mx} : Stress Level → Craving	0.375	0.098	<.001	0.187	0.569
b_{ym} : Craving → Drinks	0.347	0.164	0.014	0.034	0.673
c_{yx} : Stress Level → Drinks	-0.076	0.142	0.296	-0.355	0.207
c'_{yx} : Stress Level → Drinks	-0.206	0.154	0.090	-0.514	0.090
a_{mw} : QFI → Craving	0.343	0.074	<.001	0.200	0.490
b_{yw} : QFI → Drinks	0.335	0.111	0.001	0.114	0.549
Indirect _{between}	0.124	0.073	0.014	0.010	0.292
Within					
a_{mx} : Stress Level → Craving	0.131	0.051	0.004	0.031	0.231
b_{ymw} : QFI x Craving → Drinks at mean QFI	0.249	0.115	0.008	0.036	0.488
-1 SD QFI: Craving → Drinks	0.175	0.187	0.183	-0.216	0.516
+1 SD QFI: Craving → Drinks	0.668	0.106	0.000	0.471	0.883
c_{yx} : Stress Level → Drinks at mean QFI	0.059	0.075	0.211	-0.088	0.210
-1 SD QFI: c_{yx} : Stress Level → Drinks	0.026	0.076	0.363	-0.120	0.178
+1 SD QFI: c_{yx} : Stress Level → Drinks	0.093	0.081	0.127	-0.067	0.253
c'_{yx} : Stress Level → Drinks	0.005	0.072	0.474	-0.139	0.147
indirect _{within} at mean QFI	0.052	0.025	0.004	0.011	0.111
-1 SD QFI: indirect _{within}	0.019	0.028	0.185	-0.030	0.082
+1 SD QFI: indirect _{within}	0.086	0.037	0.004	0.020	0.169

Note. Est. = estimate, SD = standard deviation, C.I.= credibility interval, *p* = Bayesian one-tailed p-value, or the proportion of the posterior distribution that overlaps zero (for positive estimates=proportion below zero, for negative estimates=proportion above zero), *c'* = the direct effect of stress on drinking after accounting for craving, *c* = the total effect of stress on drinking. Significant associations are in bold typeface. Analyses controlled for gender, age, and weekend day. The Bayesian credibility interval encompasses the lower 2.5% and 97.5% in the posterior distribution.