

Vicarious heterosexism-based stress induces alcohol, nicotine, and cannabis craving and negative affect among sexual minority young adults: An experimental study

Ethan H. Mereish^{a,b,*}, Robert Miranda Jr.^{c,d}

^a Lavender Lab, Department of Psychology, University of Maryland, College Park, MD, USA

^b Department of Health Studies, American University, Washington, DC, USA

^c Department of Psychiatry & Human Behavior, Brown University, Providence, RI, USA

^d E. P. Bradley Hospital, Providence, RI, USA

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ABSTRACT

Purpose: Sexual minority young adults are at increased risk for hazardous drinking and alcohol use disorder compared to heterosexual adults. Heterosexism-based stressors contribute and often explain inequities in alcohol outcomes. However, the extant research primarily relies on correlational designs, and often neglects the importance of alcohol craving, despite its foundational role in addiction. Leveraging a novel experimental mood induction paradigm, this study examined the effects of exposure to vicarious heterosexism-based stress on alcohol craving and negative affect among sexual minority young adults who drink heavily. We also examined its effects on cannabis and nicotine craving among participants who used cannabis and nicotine, respectively. Lastly, we examined moderating factors that could influence the impact of exposure to heterosexism-based stress on alcohol craving.

Methods: Participants were 101 heavy drinking sexual minority young adults, ages 20–35 ($M = 26.46$ years old; $SD = 3.49$), recruited from the community (51.5% female sex assigned at birth; 76.3% cisgender; 51.5% plurisexual; and 42.6% racial and ethnic minorities). They completed three mood induction trials counterbalanced over three visits on different days: heterosexism stress, general stress, and neutral. Structured interviews assessed criteria for DSM-5 alcohol use disorder (AUD) and substance use, and self-report measures assessed lifetime traumatic stressors.

Results: Most participants met criteria for past-year AUD (74.7%). Exposure to heterosexism stress produced more negative affect and substance craving than the neutral mood induction, even while controlling for demographic variables and lifetime exposure to traumatic and heterosexism stressors. Exposure to heterosexism-based stress had large effects on alcohol craving among participants who had greater drinking to cope motives and heterosexism-specific rejection sensitivity, whereas the effects were small for those who had lower drinking to cope motives and heterosexism-specific rejection sensitivity. Demographic, lifetime stress, prior alcohol use, and AUD symptom severity variables were not significant moderators. Greater substance craving induced by heterosexism-based stress in the laboratory was associated with greater recent and current substance use.

Conclusions: This study findings show that vicarious exposure to heterosexism elicits negative mood and alcohol, cannabis, and nicotine craving among sexual minority young adults who engaged in heavy drinking. The effects for alcohol craving were largest among those who endorse high levels of drinking to cope motives and heterosexism-based rejection sensitivity. These findings have implications for oppression-based stress and motivational models of addiction.

Sexual minority (e.g., lesbian, gay, bisexual, or queer) young adults are at greater risk for alcohol use, hazardous drinking, and alcohol use

disorder (AUD) than their heterosexual counterparts (Mereish, 2024). Sexual orientation inequities in hazardous drinking are widely

* Corresponding author. Lavender Lab, Department of Psychology, University of Maryland, College Park, 1121 Biology-Psychology Building, 4094 Campus Drive, College Park, MD, 20742, USA.

E-mail address: emereish@umd.edu (E.H. Mereish).

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understood within a context of stress related to oppression and stigma (Mereish, 2024). Oppression models posit that, beyond general stress, oppression inflicts unique stress (i.e., oppression-based stress; e.g., heterosexism, anti-bisexual prejudice) that drives health inequities, including hazardous drinking and AUD, among sexual minority adults (Brooks, 1981; Mereish, 2024; Meyer, 2003). Sexual minority adults are frequently exposed to and experience heterosexism stressors, directly and vicariously (Mereish et al., 2021; Mereish and Miranda, 2019). Mounting evidence from primarily correlational studies links heterosexism stress with greater alcohol use, and hazardous drinking among sexual minority young adults (Goldbach et al., 2014; Mereish, 2024).

Craving and negative affect are considered key mechanisms that drive the initiation, reinforcement, and maintenance of addiction, including AUD (Baker et al., 2004; Drummond, 2000; Monti et al., 2000; Sayette, 2016). Few studies, however, have tested whether exposure to oppression potentiate these mechanisms, leaving many unanswered questions regarding core tenets of oppression-based stress models (e.g., minority stress theory) as it applies to alcohol inequities. Among the limited literature using experiencing sampling methods (e.g., ecological momentary assessment; EMA), one study found that heterosexist parental rejection was associated with momentary alcohol and cannabis craving and negative affect among sexual minority youth (Parnes et al., 2023); the researchers also found that momentary oppression-based stressors were associated with same-day subsequent nicotine craving (Mereish et al., 2022). Although these studies leveraged rigorous methods, findings were correlational in nature.

Human laboratory paradigms can accelerate our understanding of alcohol inequities among sexual minority individuals. By bridging pre-clinical analog models of general stressors and field-based methods, like EMA, laboratory paradigms provide a mechanistic evaluation of how oppression stressors affect clinically relevant constructs or intermediate phenotypes — reliably measured dynamic processes underlying AUD risk — such as craving and negative affect. These approaches have several fundamental advantages, most notably the high level of experimental control, which maximizes scientific rigor and affords greater confidence that changes observed in the target variables, such as craving and affect, were caused by the experimental conditions (e.g., oppression stressors vs. a comparison condition). They also offer a high level of reproducibility, as the careful evaluation of procedures and measurements enables the replication of findings across studies and laboratories.

Over the past three decades, laboratory studies have examined alcohol craving among young adult drinkers (Plebani et al., 2012). These studies show that alcohol craving induced in the laboratory is related to craving and drinking outcomes in the natural environment (Plebani et al., 2012; Ramirez and Miranda, 2014). Additionally, stress-induced craving in the laboratory is a risk factor for relapse during AUD treatment (Higley et al., 2011). Despite their utility, little work has leveraged laboratory paradigms to advance our understanding of craving and negative affect as mechanisms of AUD among sexual minority young adults.

The only existing experimental study of oppression stress and craving among sexual minority individuals found that vicarious exposure to heterosexism stress elicited increased alcohol craving and negative affect and boosted craving induced by exposure to *in vivo* alcohol cues among sexual minority young adults who drank heavily (Mereish and Miranda, 2019). This study also found elevated psychophysiological stress reactivity, as assessed by the emotion-modulated startle response, to heterosexism-based stress compared to a neutral condition, which was positively associated with more past 30-day alcohol use (Mereish and Miranda, 2021). While this study was the first to manipulate heterosexism-based stress in a controlled laboratory setting and examine its effects on alcohol craving, the sample was small and predominately comprised of White cisgender participants, limiting its generalizability. More research is needed to validate this experimental paradigm in larger and more diverse samples.

1. Purpose of the present study

The present study examined a novel mood induction heterosexism-based stress paradigm that manipulated vicarious heterosexism-based stress in a controlled laboratory setting. We first examined the effects of vicarious exposure to heterosexism on negative affect and alcohol craving when compared to neutral and general stress conditions among a sample of sexual minority young adults who engaged in heavy drinking. We also examined the effects of vicarious heterosexism-based stress on nicotine or cannabis craving among participants who also use nicotine or cannabis, respectively. As further validation of the mood induction paradigm, we also examined a vicarious general stress condition and compared it to the neutral and heterosexism stress conditions. We hypothesized that heterosexism-based stress would elicit more negative affect and alcohol craving than the neutral mood induction, even while accounting for several key variables that are related to craving and alcohol use (i.e., sociodemographic characteristics, lifetime traumatic stress, lifetime oppression-based stress, recent alcohol use, and family history of alcohol addiction). Similarly, among sexual minority drinkers who also use nicotine or cannabis in our sample, we hypothesized that vicarious heterosexism-based stress would elicit more nicotine or cannabis craving, respectively. As an exploratory aim, we explored the associations between heterosexism-based stress-specific induced craving and alcohol, nicotine, and cannabis use in the natural environment.

As an additional exploratory aim of this study, we examined several moderating factors that could influence reactivity to heterosexism-based stress on alcohol craving. Given differences in experiences of oppression-based stress and alcohol use within subgroups of sexual minority adults, especially among sexual minority women, racial and ethnic minorities, as well as transgender and plurisexual individuals (Demant et al., 2018; Fish, 2019; Greene et al., 2020; Hughes et al., 2016; Mereish and Bradford, 2014; Schuler et al., 2020; Shokoohi et al., 2022), we first examined the moderating effects of gender identity, sexual orientation, race/ethnicity, and socioeconomic status. Compared to the neutral condition, we hypothesized that the heterosexism-based stress condition would have a stronger impact on alcohol craving for cisgender women, gender minority individuals, plurisexual individuals (e.g., bisexual), racial and ethnic minority participants, and individuals with lower socioeconomic resources compared to cisgender men, monosexual individuals (e.g., gay or lesbian), White participants, and individuals with greater socioeconomic resources.

Alcohol use and AUD are on a continuum of severity (Koob, 2013). AUD severity and lifetime exposure to stress are known to interact and impact the broader stress response as well as the associations between stress and alcohol craving and use (Koob, 2013; Koob and Volkow, 2010; Sinha, 2008). In fact, AUD severity influenced the associations between stress and drinking among sexual minority men who engaged in heavy drinking (Mereish et al., 2018) and sexual minority women and gender minority adults (Dyar et al., 2023). As such, we also tested the moderating effects of recent alcohol use and AUD severity as indicators of addiction severity. Given mixed findings in the literature regarding the role of addiction severity in moderating the associations between stress and alcohol use (Dyar et al., 2023; Mereish et al., 2018), we did not hypothesize a direction for its impact on the impact of the heterosexism-based stress condition on alcohol craving. Building on findings that individuals with greater lifetime and cumulative exposure to stress are more sensitive to the effects of stress on craving (Sinha, 2008) and that sexual minority adults vary in their sensitivity to heterosexism-based rejection based on their prior experiences of oppression-based stress (Feinstein et al., 2012; Pachankis et al., 2008), we also examined if lifetime cumulative stress exposure and heterosexism-specific rejection sensitivity influence sexual minority young adults' reactivity to heterosexism-based stress. We hypothesized that the heterosexism stress mood induction would elicit greater alcohol craving among sexual minority young adults with greater lifetime

exposure to traumatic and heterosexism stressors or who have higher levels of heterosexism-specific rejection sensitivity compared to sexual minority young adults with less lifetime exposure to stress or who have lower levels of heterosexism-specific rejection sensitivity.

Consistent with motivational and negative reinforcement models of addiction (Cooper et al., 2016; Cox and Klinger, 1988), sexual minority adults may be motivated to use alcohol to cope with heterosexism stress (i.e., coping motives; Mereish, 2024). As such, we also tested the moderating effects of general drinking to cope motives as well as motives specific to drinking to cope with heterosexism. We hypothesized that the heterosexism-based stress mood induction would elicit greater alcohol craving among participants with higher levels of drinking to cope motives more generally as well as drinking to cope specifically with heterosexism-based stress compared to participants with lower levels of coping motives. Additionally, for greater specificity, we expected that social drinking motives would not moderate the impact of heterosexism-based stress on alcohol craving.

2. Method

2.1. Research design

We leveraged a within-subjects design to test the effects of vicarious heterosexism-based stress, compared to general stress and a neutral condition, on negative affect and craving among sexual minority young adults who drink heavily. Participants underwent all three stress-induction conditions in counterbalanced order over three visits separated by at least 14 days to mitigate possible carryover effects. Variability in the duration between study visits permitted flexibility in scheduling sessions. Procedures were identical across experimental sessions, except for the type of stress induction administered. The first author's Institutional Review Board approved all study procedures.

Participants were enrolled in the study from 2019 to 2021. Due to COVID-19 pandemic, the study was paused from March to October of 2020, at which point it transitioned from being in-person and in the laboratory to entirely remote over the Zoom videoconferencing platform.

2.2. Study participants

Sexual minority young adults were recruited from a metropolitan area in the Mid-Atlantic region of the United States. Recruitment involved posting advertisements and flyers describing a study of lesbian, gay, bisexual, and queer people's health behaviors at public venues (e.g., coffee shops) and online (e.g., Craigslist, Facebook, Reddit) and outreach at community-based events (e.g., Pride).

Inclusion criteria were: a) self-identification as a sexual minority (e.g., lesbian, gay, bisexual, queer); b) aged 18–35 years; c) self-reported heavy drinking in the past 30 days defined as ≥ 2 drinking days per week, on average, with at least one heavy drinking occasion (≥ 4 standard drinks for females and ≥ 5 for males) (National Institute on Alcohol Abuse and Alcoholism, 2005; 2009); d) experienced ≥ 1 heterosexism stressor in the past 30 days, as assessed using the Daily Heterosexist Experiences Questionnaire (Balsam et al., 2013); and e) proficient in reading and communicating in English. Prospective participants were excluded if they were currently receiving AUD treatment or experiencing alcohol withdrawal, suicidal thoughts, or symptoms of psychosis. Due to a psychophysiological component of the larger project, individuals taking medications known to affect cortisol or hormonal contraceptives and those who were perimenopausal or postmenopausal were also excluded during the in-person portion of the study; these exclusionary criteria were dropped when the study transitioned to the virtual platform.

Enrolled participants ($N = 101$) were 20–35 years old ($M = 26.46$ years old; $SD = 3.49$). About half were assigned male sex at birth (48.5%); 51.5% were assigned female sex at birth. Considering both sex

assigned at birth and gender identity: 41.6% were cisgender men, 34.7% cisgender women, and 23.8% gender minorities (e.g., transgender, non-binary). Participants identified as gay (36.6%), queer (28.7%), bisexual (16.8%), lesbian (11.9%), pansexual (3%), and other plurisexual identities (3%). Participants' racial identification was: White (62.4%), Biracial/Multiracial (18.8%), Black/African American (7.9%), Asian American (6.9%), Middle Eastern (2%), American Indian or Alaskan Native (1%), and other (1%). Participants were 15.8% Latine. Considering race and ethnicity combined, 57.4% of the sample were non-Latine White and 42.6% were people of color. Most participant earned a gross annual income of \$30,00 or higher (69.3%).

3. Procedures

Prospective participants first completed a brief online screening questionnaire, and, if tentatively eligible, a telephone screening to further determine provisional eligibility. Those who seemed eligible were invited to a final interview, completed in person before COVID-19-related restrictions and remotely using Zoom thereafter.

As illustrated in Fig. 1, participants completed three experimental test sessions in counterbalanced order. At the start of each in-person session, participants' breath alcohol content (BAC) was assessed using a breathalyzer (BACtrack S80 Breathalyzers/KHN Solutions Inc., San Francisco, CA). A BAC of .00 was required to continue with the session. BAC was not assessed for remote participants. During each session, participants completed structured clinical interviews, self-report questionnaires, and experimental procedures. Participants received monetary compensation for their participation, and transportation was provided when needed.

Stress Induction Procedures. This study used an established vicarious heterosexism-based stress induction paradigm (Mereish and Miranda, 2019). At the start of each session, participants watched a 10-min relaxation video and then completed craving and mood assessments. In each session, participants then viewed 28 color photographs selected to represent each respective experimental condition (i.e., vicarious heterosexism-based stress, general stress, neutral condition). Examples of heterosexism-based stress images include hate crime scenes (e.g., vandalized property with heterosexist graffiti) or victims (e.g., a screenshot of TV news reports describing "gay couple attacked" with an image of the victims) as well as individuals holding heterosexist signs. Across all three conditions, images were balanced to ensure equal numbers of faces, news reports, signs, scenes, and human interactions. Fig. 2 has an example of news report for each condition. Some images were selected from the International Affective Picture System (Lang et al., 1999), but most were obtained online, typically from news or social media outlets. In an earlier study (Mereish and Miranda, 2019), the 28 images per condition were parsed into two 14-image blocks; however, for this study, we displayed all 28 images in a single block for each condition.

The same experimental procedures were conducted in-person in the laboratory and remotely in participants' private settings via Zoom. Remote participants were required to be on a computer instead of a smartphone or tablet. They received training in Zoom (e.g., screen sharing and hiding video panels to view images clearly and without viewing the researcher). Participants were also required to have their video on during the entire session. They were observed live to ensure they watched the stress induction images and were not distracted. We also conducted a practice round with two practice images to ensure participants could see the full-screen pictures on their computers. If there were any concerns, they were resolved before the study's mood induction was conducted. These procedures were repeated for participants for each of the three remote visits to ensure rigor and standardization of the mood induction procedures.

At the beginning of each trial, participants were instructed to sit quietly and view each picture the entire time it was displayed on the screen. They were also instructed to imagine that they were victims of

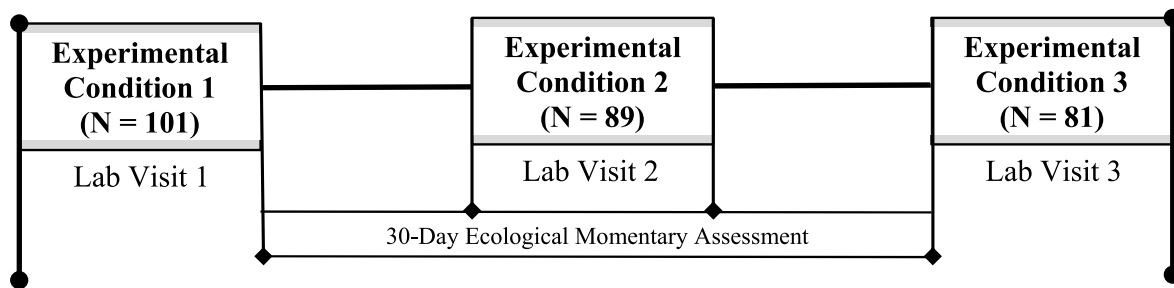


Fig. 1. Timeline of study activities.

Note. A total of 101 participants completed the first visit, 89 of them completed the second visit, and 81 of them completed the third visit. Participants underwent all three stress-induction conditions in counterbalanced order over three visits separated by at least 14 days to mitigate possible carryover effects. Specifically, 94 participants completed the heterosexism-based stress condition, 88 completed the general stress condition, and 88 completed the neutral condition.

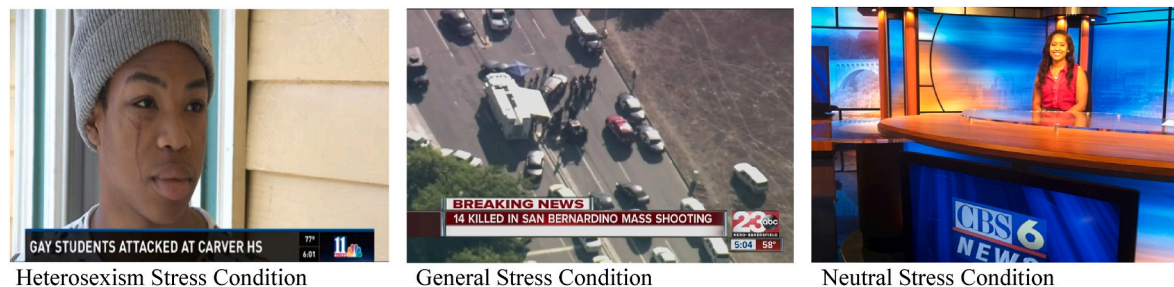


Fig. 2. Example image stimuli for each experimental condition.

the violent acts depicted in the two unpleasant conditions. Participants did not receive this instruction for the neutral stimuli because it did not apply to this condition. At the start of each condition, participants viewed a slide providing context to clearly delineate its content (i.e., heterosexism stress: “The following pictures show real-life situations that involved negative events, harassment, or violence against people that is because of their sexual orientation.”; general stress: “The following pictures show real-life situations that involved negative events, harassment, or violence against people that is NOT because of their sexual orientation.”; neutral: “The following pictures show real-life situations that involve everyday people.”). Participants sat in a darkened room, and each image was displayed on a computer for 10 s. Upon watching an image block, participants rated their cravings and mood.

At the end of each session, participants’ psychological distress and craving for substances was assessed. If they endorsed any residual distress or craving, they were debriefed and assisted in identifying coping skills to help regulate emotions and manage cravings.

3.1. Measures

Demographics. Participants’ age, sex assigned at birth, gender identity, race, ethnicity, sexual orientation, and gross annual income were assessed at screening/baseline.

Lifetime Overall Traumatic Stress Exposure. A range of lifetime adverse and traumatic stressors (e.g., life-threatening illness or accident, sexual assault, childhood and adulthood abuse) were assessed with 13-items from the Stressful Life Events Screening Questionnaire – Revised (0 = No and 1 = Yes; Cronbach’s $\alpha = .73$; Goodman et al., 1998).

Lifetime Heterosexism-Based Stress Exposure. A range of lifetime heterosexism-based stressors (e.g., rejection, discrimination, verbal/physical assault) were assessed with 44 items from the Daily Heterosexist Experiences Questionnaire (0 = Did not happen/not applicable to me to 5 = it happened and it bothered me extremely; Balsam et al., 2013). The parenting subscale was not included given the sample was comprised of young adults (Cronbach’s $\alpha = .84$).

Alcohol and Other Substance Use. During the first visit, participants

completed a structured interview assessing their past 60-day alcohol and other substance use using a timeline follow-back (TLFB) interview (Sobell and Sobell, 1992). During the second and third visits, TLFB assessed participants’ substance use over their past 14 days. We calculated the number of drinking days, nicotine use days, and cannabis use days for past 60 days at baseline and for each 14-day period for the second and third visits.

AUD. Participants completed a baseline Structured Clinical Interview for the DSM-5 (SCID-5; First, 2014) to assess their symptoms for lifetime and past year AUD.

Family History of Alcohol-Related Issues. Participants completed the family history scale (Carey and DeMartini, 2010) to describe if any of their family members (i.e., parents, siblings, grandparents, and aunts/uncles) had difficulties with alcohol use over their lifetime (0 = no; 1 = yes). Consistent with prior work (Carey and DeMartini, 2010), a dichotomous score was computed if a participant reported having any family member with alcohol issues.

Coping and Social Drinking Motives. Participants’ drinking to cope motivations for drinking over the past three months were assessed with drinking to deal with negative feelings (4-items; e.g., “feel less shame”; $\alpha = .62$) and relief tension (4-items; e.g., “to forget about problems”; $\alpha = .71$) subscales of the Desired Effects of Drinking (DEOD) scale (Doyle et al., 2011). The two subscales were highly correlated ($r = .62$) and combined into one subscale to assess drinking to cope motives ($\alpha = .79$). Social motives were assessed with the 4-item social facilitation subscale (e.g., “feel more comfortable in social situations”; $\alpha = .75$) of the DEOD scale (Doyle et al., 2011). Additionally, based on the items of these subscales, two additional subscales were developed for this study to assess LGBT-specific drinking motives. Specifically, we developed a 9-item Drinking to Cope with Heterosexism motives subscale (e.g., “to feel less shame related to my sexual orientation” and “to forget about negative experiences related to my sexual orientation”; $\alpha = .92$) and a 5-item LGBTQ-Based Social motives (e.g., “To fit in with other LGBTQ people”; $\alpha = .90$) subscale. Response ranges (0 = never to 3 = always).

Heterosexism-Specific Rejection Sensitivity. The 12-item Gay-Related Rejection Sensitivity (Feinstein et al., 2012; Pachankis et al.,

2008) assessed heterosexism-specific rejection sensitivity ($\alpha = .83$). Participants read 12 scenarios and rated each one for concern/anxiety (1 = *very uncomfortable* to 6 = *very concerned*) and the likelihood they would experience sexual orientation-specific rejection (1 = *very unlikely* to 6 = *very likely*). The scores for each item were multiplied and a mean of the items was computed.

Craving. We captured alcohol craving at baseline and immediately before and after each stress induction using a well-established visual analog slider scale ("How strong is your urge to drink alcohol right now?"; Fox et al., 2007). We relied on the single-item measure (0 = *no urge* to 10 = *strongest ever*) to mitigate the effects of introspection on subsequent trials.

Negative Affect. We assessed negative affect immediately before and after each stress induction with four items (*distressed, upset, afraid, hostile*). These were the top four item loadings on the Negative Affect subscale of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988), as previously used in sexual minority research (Mereish and Miranda, 2019). Participants were asked "Indicate how you feel right now; that is at the present moment" (0 = *very slightly or not at all* to 4 = *extremely*). A mean score was computed.

3.2. Data analytic plan

Due to the non-independence of the data for examining within person effects, we tested our main hypotheses with generalized estimating equation (GEE) models, which control for autocorrelation without biasing results. All models used an autoregressive covariance matrix structure and assumed a normal link function. Given our primary interest in within-person effects across the three conditions (i.e., heterosexism stress, general stress, neutral), we initially entered each condition as a nominal predictor in each model with the heterosexism-based stress condition as the reference. This approach tests whether the neutral or general stress conditions' means significantly differ from the reference heterosexism-based stress condition's mean. To test for differences between the general stress and neutral conditions, the neutral condition served as the reference category in follow-up analyses. Consistent with prior work (Mereish and Miranda, 2019) and to estimate effect sizes, continuous variables were standardized ($M = 0$, $SD = 1$); model coefficients represent differences in standard deviation units associated with the predictors. Beta (β) can be interpreted as the expected mean-level change in standard deviation units when comparing within-person self-rated negative affect or craving in the reference condition to the comparison condition.

To test whether heterosexism-based stress elicited greater negative affect and craving than the neutral or general stress induction conditions, we examined participants' affect and craving captured immediately following the stress induction procedure on each day. All models were tested with and without person-level covariates (i.e., counterbalance order, mood induction administration method [i.e., in-person vs. remote], age, gender, race/ethnicity, sexual orientation, income, lifetime traumatic stress exposure, lifetime heterosexism stress exposure, past 60-day substance use, and family history of alcohol problems) and all models controlled for baseline negative affect or craving. Specifically, we controlled for baseline negative affect and past 60 day drinking at baseline for the negative affect model, and we controlled for baseline craving and past 60-day substance use (i.e., alcohol, nicotine, and cannabis, respectively) for the respective craving models (i.e., alcohol, nicotine, and cannabis, respectively). Analyses were performed using SPSS, version 29 (IBM, Armonk, NY).

We examined the moderating effects of social identities (i.e., age, gender identity, sexual orientation, race/ethnicity, and socioeconomic status), addiction severity (i.e., AUD symptoms and past 60 day drinking at baseline), lifetime stress exposure (i.e., overall traumatic stress and heterosexism-based stress) and stress sensitivity (i.e., heterosexism-specific rejection sensitivity), and drinking motives on the impact of the heterosexism-based stress induction on alcohol craving. Given the

focus of the present study is heterosexism-based stress and alcohol craving, the moderators were only tested for the heterosexism-based stress mood induction compared to the neutral mood induction with alcohol craving as the dependent variable. We did not test these moderators for nicotine or cannabis craving due to concerns with sample sizes and power as well as lack of conceptual fit for some moderators (e.g., AUD, drinking motives). As a specificity test, the moderators were tested for the general stress mood induction compared to the neutral mood induction with alcohol craving as the dependent variable.

Lastly, correlations examined associations between heterosexism-based stress-induced craving and substance use in the natural environment. Correlations were conducted for past 60-day substance use reported at baseline and past two-week substance use reported at the second and third laboratory visits in the TLFB.

4. Results

Participants ($N = 101$) completed 270 experimental sessions, with a retention rate of 89.1%. Specifically, 101 participants completed the first visit, 89 completed the second visit, and 81 completed the third visit. While all participants ($N = 101$) completed the first visit, one participant's first session data were not recorded due to a device malfunction. Ninety-four completed the heterosexism-based stress condition, 88 completed the general stress condition, and 88 completed the neutral condition. Most missed sessions resulted from the COVID-19 lockdowns, which halted research activities and interrupted participation for those enrolled just before the lockdown ($n = 10$). Fifty-three participants completed the study in person, 48 participated remotely.

4.1. Substance use, AUD, lifetime stress exposure, and family history of alcohol issues

In the 60 days before the study, participants ($N = 101$) had an average of 31.35 drinking days ($SD = 11.54$, range: 11–60 days), 5.03 nicotine use days ($SD = 13.79$, range: 0–60 days), and 12.47 cannabis use days ($SD = 18.16$, range: 0–60 days). Participants reported on average of 7.34 drinking days ($SD = 3.33$, range: 0–14 days) during the 14-day TLFB administered at the second laboratory visit. Participants reported on average of 6.82 drinking days ($SD = 3.24$, range: 1–14 days) during the 14-day TLFB administered at the third laboratory visit. Thirty-eight (37.6%) participants reported any nicotine use and 66 (65.3%) reported any cannabis use. Participants who used nicotine ($n = 38$) reported on average of 13.37 nicotine use days ($SD = 19.99$ range: 1–60 days), 31.55 alcohol use days ($SD = 10.76$, range: 17–60 days), and 11.37 cannabis use days ($SD = 17.25$, range: 0–58 days). Participants who used cannabis ($n = 66$) reported on average of 19.08 cannabis use days ($SD = 19.47$ range: 1–60 days), 32.82 alcohol use days ($SD = 11.41$, range: 17–60 days), and 5.55 nicotine use days ($SD = 14.44$ range: 0–60 days).

Most (74.7%) met criteria for past-year AUD: 35.8% met criteria for mild AUD (2–3 symptoms); 16.8% met criteria for moderate AUD (4–5 symptoms); 22.1% met criteria for severe AUD (6 or more symptoms). Six were not assessed for AUD due to early withdrawal from the study. Most of the sample (80.6%) had at least one family member with a history of alcohol-related issues.

All participants experienced at least one heterosexism-based stressor in their lifetime, with an average of 26.59 heterosexism-based stressors reported ($SD = 6.24$, Range: 11 to 44). Most participants (82%) reported experiencing at least one adverse traumatic stressor in their lifetime, with an average of 2.51 lifetime traumatic stressors ($SD = 2.34$, Range: 0 to 11). The most prevalent traumatic stressors reported were lifetime sexual victimization (43.2%), verbal abuse (38.2%), death of a close loved one due to an accident, homicide, or suicide (33.7%), other life-threatening situations (29.2%), rape (22.7%), adulthood physical abuse (18%), and childhood physical abuse (15.9%).

4.2. Effects of mood condition on negative affect and substance craving

Table 1 presents descriptive statistics across stress conditions and Table 2 and Table 3 report GEE model results with heterosexism-based stress as the reference category. Supplementary Fig. 1 includes spaghetti plots for all dependent variables.

Negative affect. As reported in Table 2, the heterosexism-based stress condition produced more negative affect than the general stress and neutral conditions ($ps < .001$). While accounting for covariates, the effect sizes for these differences were medium for general stress ($\beta = -.646$) and large for neutral ($\beta = -1.583$). In addition, general stress produced more negative affect than the neutral condition ($\beta = .937$; $SE = .084$; 95% CI = .772, 1.101; $p < .001$). Results were consistent when covariates were included in the model, including similar effect sizes. No covariate was statistically significant.

Alcohol craving. As reported in Table 2, heterosexism-based stress elicited greater alcohol craving than general stress ($p = .007$) and the neutral conditions ($p < .001$). While accounting for covariates, the effect sizes were small for general stress ($\beta = -.188$) and small-to-medium for the neutral condition ($\beta = -.493$). General stress produced more alcohol craving than the neutral condition ($\beta = .305$; $SE = .0634$; 95% CI = .181, .429; $p < .001$). Results and effect sizes were consistent with and without covariates included in the model.

Nicotine craving. As reported in Table 3, among participants who used nicotine, heterosexism-based stress elicited more nicotine craving than the neutral condition ($p < .001$); the effect size was small-to-medium without covariates ($\beta = -.483$) and medium with covariates ($\beta = -.508$). Heterosexism-based stress did not elicit more nicotine craving than general stress ($p = .077$). General stress produced more nicotine craving than the neutral condition ($\beta = .305$; $SE = .102$; 95% CI = .106, .505; $p = .003$). Results were consistent with covariates, including similar effect sizes.

Cannabis craving. As reported in Table 3, among participants who used cannabis, heterosexism-based stress produced more cannabis craving than the neutral condition ($p = .015$); the effect size was small without covariates ($\beta = -.293$) and similar with covariates. Heterosexism-based stress did not elicit more cannabis craving than general stress ($p = .648$). General stress elicited more cannabis craving than the neutral condition ($\beta = .272$; $SE = .119$; 95% CI = .038, .506; $p = .023$). Results and effect sizes were consistent when covariates were included in the model.

4.3. Moderator effects of social identities, drinking and AUD, stress, and drinking motives

Drinking to cope motives ($\beta = .268$; $SE = .077$; 95% CI = .118, .419; $p < .001$), drinking to cope with heterosexism motives ($\beta = .385$; $SE = .083$; 95% CI = .222, .547; $p < .001$), and heterosexism-based rejection sensitivity ($\beta = .233$; $SE = .089$; 95% CI = .058, .408; $p = .009$) were all significant moderators of reactivity to heterosexism-based stress effects on alcohol craving compared to the neutral mood induction. Figs. 3 and 4 illustrate these effects.

The moderating effects for age ($p = .320$), gender identity (cisgender

women, $p = .975$; gender minority, $p = .884$), race/ethnicity ($p = .324$), sexual orientation ($p = .220$), income ($p = .203$), AUD symptoms ($p = .425$), number of drinking days over past 60 days at baseline ($p = .589$), family history of alcohol problems ($p = .769$), lifetime exposure to heterosexism-based stress ($p = .236$), lifetime traumatic stress exposure ($p = .431$), general social drinking motives ($p = .940$), and LGBTQ-specific social drinking motives ($p = .448$) all were not significant. As a specificity analysis, all the moderators were also tested for the reactivity to the general stress mood induction compared to the neutral mood induction; results indicated that all moderators were not significant.

To aid in the interpretation of the significant moderating effects, we computed simple slope regressions (Aiken and West, 1991). We tested simple main effects for the stress induction condition (heterosexism-based stress versus neutral) based on low or high drinking to cope motives, drinking to cope with heterosexism motives, and heterosexism-specific rejection sensitivity. The low and high cutoffs were based on one half of a standard deviation below or above the mean. Figs. 3 and 4 illustrate significant moderation effects.

As highlighted in Fig. 3A and B, among participants with low drinking to cope motives and drinking to cope with heterosexism motives, heterosexism-based stress elicited more alcohol craving than the neutral condition ($\beta = .319$; $SE = .096$; 95% CI = .130, .508; $p < .001$; and $\beta = .282$; $SE = .082$; 95% CI = .122, .442; $p < .001$, respectively); however, the effect sizes were small. Among participants with high drinking to cope motives and drinking to cope with heterosexism motives, heterosexism-based stress elicited more alcohol craving than the neutral condition ($\beta = .751$; $SE = .225$; 95% CI = .310, 1.192; $p < .001$; and $\beta = .930$; $SE = .235$; 95% CI = .471, 1.390; $p < .001$, respectively); these effect sizes were large. As highlighted in Fig. 4, among participants with low heterosexism-specific rejection sensitivity, heterosexism-based stress elicited more alcohol craving than the neutral condition ($\beta = .372$; $SE = .126$; 95% CI = .125, .620; $p = .003$); however, the effect size was small. Among participants with high heterosexism-specific rejection sensitivity, heterosexism-based stress elicited more alcohol craving than the neutral condition ($\beta = .812$; $SE = .193$; 95% CI = .433, 1.190; $p < .001$) and the effect size was large.

4.4. Associations among craving and substance use

Results of correlations indicated that greater alcohol craving induced by heterosexism-based stress was significantly associated with greater alcohol use days over the past 60 days at baseline ($r = .25$, $p = .015$), over the first 14 days of the study ($r = .28$, $p = .007$), and over the last second 14 days of the study ($r = .30$, $p = .006$). Among participants who used nicotine, greater nicotine craving induced by heterosexism-based stress was significantly associated with greater nicotine use days over the past 60 days at baseline ($r = .41$, $p = .013$), over the first 14 days of the study ($r = .59$, $p < .001$), and over the last two 14 days of the study ($r = .66$, $p < .001$). Among participants who used cannabis, greater cannabis craving induced by heterosexism-based stress was significantly associated with greater cannabis use days over the past 60 days at baseline ($r = .65$, $p < .001$), over the first 14 days of the study ($r = .36$, p

Table 1 Means for negative affect and craving by mood induction condition.

Condition	Affect and Craving Outcomes							
	Negative Affect (N = 101)		Alcohol Craving (N = 101)		Nicotine Craving (n = 38)		Cannabis Craving (n = 66)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Heterosexism Stress	1.14 (.31)	2.33 (.74)	1.45 (1.93)	2.49 (2.60)	1.43 (2.37)	2.34 (3.11)	1.69 (2.34)	2.25 (2.95)
General Stress	1.16 (.36)	1.86 (.67)	1.16 (1.89)	1.74 (2.25)	1.56 (2.27)	2.03 (2.63)	1.78 (2.52)	2.21 (3.00)
Neutral	1.11 (.29)	1.10 (.29)	1.14 (1.72)	1.07 (1.86)	1.35 (2.44)	1.24 (2.54)	1.75 (2.23)	1.59 (2.09)

Note. M = unstandardized mean; SD = standard deviation.

Table 2
Summary of GEE models predicting negative affect and alcohol craving as a function of mood condition.

Predictor	Negative Affect					Alcohol Craving				
	β	SE	95% CI		p	β	SE	95% CI		p
			LL	UL				LL	UL	
Model without Covariates										
Pre-Mood Induction Affect/Craving	.237	.0441	.151	.324	<.001	.757	.0563	.647	.867	<.001
Mood Condition										
General Stress	-.627	.0937	-.811	-.444	<.001	-.190	.0708	-.328	-.051	.007
Neutral	-1.548	.0987	-1.742	-1.355	<.001	-.478	.0769	-.629	-.327	<.001
Heterosexism Stress*	-	-	-	-	-	-	-	-	-	-
Model with Covariates										
Pre-Mood Induction Affect/Craving	.228	.0474	.135	.321	<.001	.765	.0490	.669	.861	<.001
Mood Condition										
General Stress	-.646	.0966	-.836	-.457	<.001	-.188	.0731	-.331	-.045	.010
Neutral	-1.583	.1022	-1.783	-1.383	<.001	-.493	.0798	-.649	-.336	<.001
Heterosexism Stress*	-	-	-	-	-	-	-	-	-	-
Person-Level Covariates										
Counterbalance	.002	.0314	-.059	.064	.943	.014	.0208	-.027	.054	.516
Administration Method	.151	.1138	-.072	.374	.183	.157	.0913	-.022	.336	.086
Age (years)	6.32	.0139	-.027	.027	.996	.003	.0143	-.025	.031	.812
Cisgender Women	-.102	.1368	-.371	.166	.454	-.053	.1094	-.267	.162	.629
Transgender/Gender Diverse	-.302	.1686	-.633	.028	.073	-.267	.1236	-.510	-.025	.031
Race (BIPOC)	-.059	.0977	-.250	.133	.548	-.098	.0674	-.230	.034	.146
Sexual Orientation (Plurisexual)	.062	.1300	-.193	.317	.632	.236	.1128	.015	.457	.037
Income	.213	.1158	-.014	.440	.065	.212	.0798	.055	.368	.008
Lifetime adverse experiences	.074	.0581	-.040	.187	.205	-.010	.0531	-.114	.094	.852
Lifetime heterosexism stress	-.047	.0526	-.150	.056	.375	.166	.0538	.060	.272	.002
Past 60 Day Drinking	-.043	.0534	-.147	.062	.422	.035	.0371	-.038	.108	.343
Family Hx of Alcohol Problems	.028	.1294	-.226	.282	.828	-.082	.1324	-.342	.178	.536

Note. Continuous measures are standardized; the reported coefficients for these variables represent standardized effects (effect size d). *Reference category. Cisgender men, White, monosexual, and earning greater than \$29,999 were the reference categories for gender, race, sexual orientation, and income, respectively. Administration method was either in-person in the laboratory or live observation remotely over Zoom, with in-person as the reference group. GEE = generalized estimating equation; SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit.

Table 3
Summary of GEE models predicting nicotine and cannabis craving as a function of mood condition among participants who used nicotine and cannabis.

Predictor	Nicotine Craving					Cannabis Craving				
	β	SE	95% CI		p	β	SE	95% CI		p
			LL	UL				LL	UL	
Model without Covariates										
Pre-Mood Induction Craving	.829	.0598	.712	.946	<.001	.817	.0534	.712	.921	<.001
Mood Condition										
General Stress	-.205	.1161	-.433	.022	.077	-.051	.1109	-.268	.167	.648
Neutral	-.483	.1134	-.705	-.260	<.001	-.293	.1212	-.531	-.056	.015
Heterosexism Stress*	-	-	-	-	-	-	-	-	-	-
Model with Covariates										
Pre-Mood Induction Craving	.871	.0504	.772	.969	<.001	.687	.0764	.537	.836	<.001
Mood Condition										
General Stress	-.202	.1228	-.443	.039	.100	.002	.1109	-.215	.219	.985
Neutral	-.508	.1164	-.736	-.279	<.001	-.270	.1216	-.508	-.031	.027
Heterosexism Stress*	-	-	-	-	-	-	-	-	-	-
Person-Level Covariates										
Counterbalance	-.008	.0241	-.055	.040	.750	-.026	.0188	-.063	.011	.165
Administration Method	.132	.1537	-.169	.434	.389	-.058	.0752	-.205	.089	.440
Age	.061	.0275	.007	.115	.026	.005	.0135	-.021	.031	.713
Cisgender Women	.051	.1159	-.176	.278	.661	.168	.1118	-.051	.387	.134
Transgender/Gender Diverse	.469	.1759	.124	.814	.008	.060	.1216	-.178	.298	.621
Race (BIPOC)	-.382	.1204	-.618	-.146	.001	.105	.0719	-.036	.246	.146
Sexual Orientation (Plurisexual)	-.195	.1129	-.416	.026	.084	-.028	.0785	-.182	.126	.721
Income	-.058	.0730	-.201	.085	.428	.039	.0702	-.099	.176	.582
Lifetime adverse experiences	.258	.1012	.060	.456	.011	.114	.0480	.019	.208	.018
Lifetime heterosexism stress	-.090	.0635	-.215	.034	.156	.021	.0686	-.113	.156	.755
Past 60 Day Nic/Can Use	-.103	.0601	-.221	.015	.087	.247	.0655	.118	.375	<.001
Family Hx of Alcohol Problems	-.027	.1730	-.366	.312	.878	-.001	.1408	-.277	.275	.992

Note. Continuous measures are standardized; the reported coefficients for these variables represent standardized effects (effect size d). *Reference category. Cisgender men, White, monosexual, and earning greater than \$29,999 were the reference categories for gender, race, sexual orientation, and income, respectively. Administration method was either in-person in the laboratory or live observation remotely over Zoom, with in-person as the reference group. GEE = generalized estimating equation; SE = standard error; CI = confidence interval; LL = lower limit; UL = upper limit.

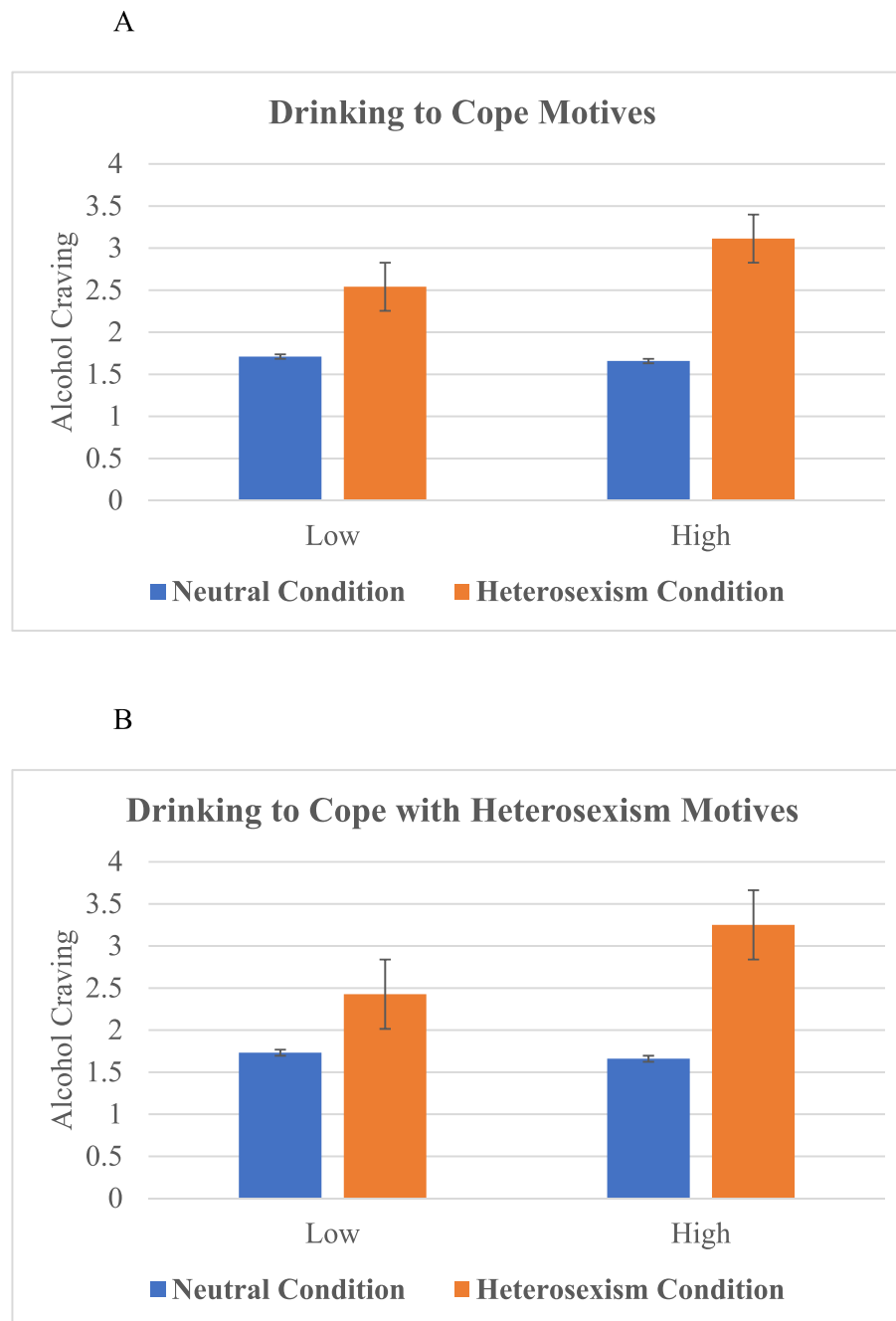


Fig. 3. Moderating effects of participants' levels of drinking to cope motives on the impact of the mood induction experimental conditions (heterosexism-based stress vs. neutral) in eliciting alcohol craving.

= .006), and over the last two 14 days of the study ($r = .65, p < .001$).

5. Discussion

This study provided support for a heterosexism-based stress experimental paradigm among sexual minority young adults who engaged in heavy drinking. The results indicated that vicarious exposure to heterosexism-based stress elicited greater negative affect and alcohol craving compared to the general stress and neutral conditions. We also found that heterosexism-based stress produced greater nicotine and cannabis cravings than the neutral mood induction among participants who used nicotine and cannabis, respectively. These effects were consistent even when controlling for several key relevant factors, such as sociodemographic variables, prior substance use, lifetime exposure to

traumatic and heterosexism stressors, and family history of alcohol-related issues. Moreover, we found that general and heterosexism-specific drinking to cope motives and heterosexism-specific rejection sensitivity accentuated the impact of the heterosexism-based induced stress on alcohol craving; these effects were specific to heterosexism-based stress as these moderators were not significant when examined for their effects on reactivity to the general stress condition. While not an original aim of this study, our results also provide further support for the use of this heterosexism-based stress experimental paradigm in both in-person laboratory or remote contexts, as we did not find differences between these two administration methods in our focal outcomes.

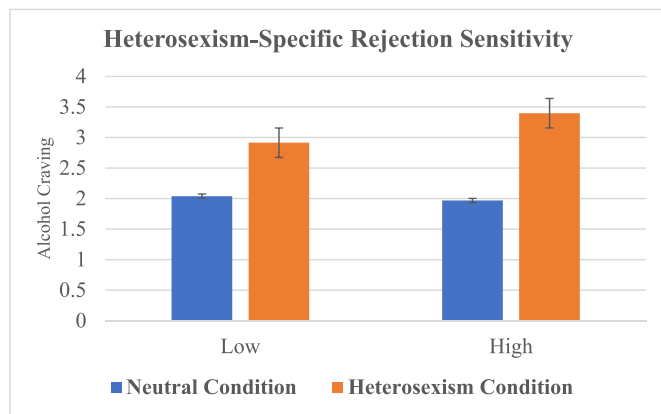


Fig. 4. Moderating effects of participants' levels of heterosexism-specific rejection sensitivity on the impact of the mood induction conditions (heterosexism-based stress vs. neutral) in eliciting alcohol craving.

Note. Fig. 4 illustrate significant moderation effects of heterosexism-specific rejection sensitivity.

5.1. Vicarious heterosexism-based stress elicited alcohol, nicotine, and cannabis craving

To our knowledge, our study is the first to show that vicarious exposure to heterosexism-based stress elicited alcohol, nicotine, and cannabis craving among sexual minority young adults in a controlled experimental paradigm. This finding corroborates a prior experimental study that showed heterosexism-based stress elicited alcohol craving and enhanced in vivo alcohol cue-elicited craving among sexual minority young adults who drank heavily (Mereish and Miranda, 2019), and it extends this work to show similar effects for nicotine and cannabis craving. These findings are consistent with prior correlational work that found that oppression-based stress was associated with substance craving among sexual minority youth (Mereish et al., 2022; Parnes et al., 2023).

Supporting oppression-based stress models and integrating them with addiction models that highlight alcohol craving as a foundational mechanism of addiction (Drummond, 2000; Monti et al., 2000; Sayette, 2016), our findings provide robust experimental evidence of the unique effects of heterosexism-based stress in producing alcohol and other substance craving among sexual minority young adults. This is especially the case as these effects were consistent while controlling for important and relevant sociodemographic and addiction-related factors. Additionally, we found that heterosexism-induced craving in a controlled experimental setting was associated with substance use in the natural environment. These findings underscore the utility of this experimental paradigm and the importance of craving as a key mechanism in AUD and alcohol and other substance use among sexual minority young adults.

5.2. Heterosexism-based stress and negative affect

The results of this study also show that exposure to vicarious heterosexism-based stress produced significant and large increases in negative affect compared to the neutral and general stress conditions. These findings are consistent with a prior experimental study and provide further support for this novel experimental heterosexism-based paradigm (Mereish and Miranda, 2019). Consistent with negative reinforcement models of addiction (Koob, 2013; Koob and Volkow, 2010) and oppression models (Brooks, 1981; Mereish, 2024; Meyer, 2003), negative affect is another key mechanism that drives the development, progression, and maintenance of AUD and other health inequities among sexual minority young adults.

5.3. Drinking to cope motives

This study provides novel findings regarding the role of drinking to cope motives in understanding the impact of heterosexism-based stress on alcohol craving among sexual minorities. Specifically, heterosexism-based stress elicited large alcohol craving effects among participants who endorsed greater general and heterosexism-specific drinking to cope motives compared to participants who had lower levels of drinking to cope motives. Providing further specificity, social motives were not significant moderators. This finding highlights for whom does exposure to heterosexism stress may elicit the largest effects in alcohol craving, which has implications for addiction models and future research. These results provide support for motivational and negative reinforcement models of addiction (Cooper et al., 2016; Cox and Klinger, 1988), indicating that sexual minority young adults may drink to cope with negative emotions and distress, and extends coping motives to a specific and culturally relevant domain for sexual minority adults (i.e., coping with heterosexism-based stress). While both general and heterosexism-specific drinking to cope motives significantly moderated the impact of heterosexism-based stress condition on craving, the effect size was larger for drinking to cope with heterosexism versus general drinking coping motives. This finding provides a deeper understanding of drinking motives among sexual minority young adults and support the need for future research to assess motives that are specifically related to heterosexism-based stress, which general drinking to cope measures do not fully capture. Future longitudinal research is needed to better delineate how heterosexism-based stress and other factors, such as LGBT-specific social and drinking norms, impact the development of these drinking motives among sexual minority young adults.

5.4. Heterosexism-Specific Rejection Sensitivity

Another novel finding of this study is the significant moderating effects of heterosexism-specific rejection sensitivity on the impact of heterosexism-based stress on alcohol craving. Exposure to vicarious heterosexism-based stress elicited alcohol craving with large effect sizes for participants with high levels of heterosexism-specific rejection sensitivity, whereas it elicited alcohol craving but with small effect sizes for participants with low levels of heterosexism-specific rejection sensitivity. Our results underscore another between-person variable that helps inform our understanding for whom does exposure to heterosexism stress may elicit the largest effects in alcohol craving. While heterosexism-specific rejection sensitivity may be developed as a way for sexual minority adults to anticipate and protect themselves from future heterosexism-based stress, it also serves as a risk factor as it compromises their interpersonal relationships and psychological well-being (Meyer, 2003; Pachankis et al., 2008).

5.5. Addiction severity and lifetime exposure to traumatic and heterosexism stress

The lack of significant moderation results in terms of addiction severity and lifetime stress exposure can be understood in several ways. As heavy drinking and prior exposure to heterosexism-based stress were inclusion criteria in our study, most of the participants in our sample met criteria for AUD, drank frequently, and were frequently exposed to traumatic and heterosexism stressors in their lifetime. Additionally, most participants reported having at least one family member with a history alcohol-related issues. Therefore, it is likely that sample was limited in its variability and range of addiction severity and exposure to stress. In other words, our results were limited to sexual minority young adults who engaged in heavy drinking, met criteria for AUD, and were exposed to trauma over their lifetime. Future research could build on this study by examining these effects among sexual minority young adults along a wider range of the addiction continuum and lifetime exposure to stress. This could help better inform whether heterosexism-

based stress and trauma exposure have stronger effects on alcohol craving among sexual minority young adults who engage in heavy drinking but have not progressed further into the addiction severity continuum, and how heterosexism-based stress and trauma exposure can play role in understanding the development and progression of AUD.

6. Limitations and additional future directions

The study has several strengths, including its utilization of experimental and within-subjects study design, inclusion of a diverse sample of sexual minority young adults who drink heavily, consideration of lifetime traumatic and stress exposure, family history of alcohol-related issues, and addiction severity, and the examination of moderating individual difference factors. However, these strengths should be considered within the context of their limitations. While the experimental paradigm manipulated heterosexism-based stress more broadly is a strength, more research is needed to discern the unique impact of oppression-based stress among specific groups of sexual minority individuals who experience unique forms of oppression-based stress (e.g., anti-bisexual oppression toward plurisexual people). Similarly, given that intersectional oppressional-based stress is also associated with alcohol and other substance use among sexual and gender minority youth of color (Mereish et al., 2023), future work is needed to adapt and advance this paradigm for sexual minority young adults of color and consider intersecting forms of oppression (e.g., racism). Moreover, while the rigorous within-person design is a strength of this study, it did not allow for a comparison between sexual minority and heterosexual individuals. Lastly, as with any experimental study, our results may have been influenced by demand characteristics or experimenter bias. As experimental studies have limited external validity, future research is needed to examine the impact of heterosexism-based stress on alcohol craving and other alcohol-related outcomes in the natural environment.

Given our noteworthy findings related to craving, interventions for reducing alcohol and other substance use must integrate the context of heterosexism when addressing substance cravings. Furthermore, our findings related to drinking motives and rejection sensitivity indicate that they are important modifiable mechanisms that should be targets of intervention. With the recent alarming and significant increase of heterosexist and cissexist legislation targeting sexual and gender minority people in the U.S. (Human Rights Campaign, 2023), sexual minority people are both frequently vicariously exposed to oppression-based stress and are direct targets of it across all contexts in their daily lives (e.g., in-person and online and in the media). As such, multi-level interventions are urgently needed to reduce and eliminate heterosexism and other forms of oppression in all contexts of sexual minority peoples' lives.

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CRedit authorship contribution statement

Ethan H. Mereish: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Robert Miranda:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.yinstr.2024.100668>.

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