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Authors

Blair, Cheríe S
Javanbakht, Marjan
Comulada, W Scott
et al.

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Comparing factors associated with increased stimulant use in relation to HIV status using a machine learning and prediction modeling approach

Cheríe S. Blair[1], **Marjan Javanbakht**[2], **W. Scott Comulada**[3,4], **Robert Bolan**[5], **Steven Shoptaw**[6], **Pamina M. Gorbach**[1,2], **Jack Needleman**[3]

[1]Department of Medicine, Division of Infectious Diseases, David Geffen School of Medicine at UCLA, Los Angeles, CA

[2]Department of Epidemiology, UCLA Fielding School of Public Health, Los Angeles, CA

[3]Department of Health Policy and Management, UCLA Fielding School of Public Health, Los Angeles, CA

[4]Department of Psychiatry and Biobehavioral Sciences, David Geffen School of Medicine at UCLA, Los Angeles, CA

[5]Health and Mental Health Services, Los Angeles LGBT Center

[6]Department of Family Medicine, David Geffen School of Medicine at UCLA, Los Angeles, CA

Abstract

Stimulant use is an important driver of HIV/STI transmission among men who have sex with men (MSM). Evaluating factors associated with increased stimulant use is critical to inform HIV prevention programming efforts. This study seeks to use machine learning variable selection techniques to determine characteristics associated with increased stimulant use and whether these factors differ by HIV status. Data from a longitudinal cohort of predominantly Black/Latinx MSM in Los Angeles, California was used. Every 6 months from 8/2014–12/2020, participants underwent STI testing and completed surveys evaluating the following: demographics, substance use, sexual risk behaviors, and last partnership characteristics. Least absolute shrinkage and selection operator (lasso) was used to select variables and create predictive models for an interval increase in self-reported stimulant use across study visits. Mixed-effects logistic regression was then used to describe associations between selected variables and the same outcome. Models were also stratified based on HIV status to evaluate differences in predictors associated with increased stimulant use. Among 2,095 study visits from 467 MSM, increased stimulant use was

Corresponding Author: Cheríe S. Blair, Department of Medicine, Division of Infectious Diseases, 10833 LeConte Avenue, CHS 52-215, Los Angeles, CA 90095, Phone: 310-825-7225, Fax: 310-825-3632, cherieblair@mednet.ucla.edu.

Compliance with Ethical Standards:

Ethics approval: The study was reviewed and approved by the Office of Human Research Participant Protection (OHRPP) at the University of California, Los Angeles. The study was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki.

Consent to participate: Written informed consent was obtained from all participants prior to enrollment in the mSTUDY.

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reported at 20.9% (n=438) visits. Increased stimulant use was positively associated with unstable housing (adjusted [a]OR 1.81; 95% CI 1.27–2.57), STI diagnosis (1.59; 1.14–2.21), transactional sex (2.30; 1.60–3.30), and last partner stimulant use (2.21; 1.62–3.00). Among MSM living with HIV, increased stimulant use was associated with binge drinking, vaping/cigarette use (aOR 1.99; 95% CI 1.36–2.92), and regular use of poppers (2.28; 1.38–3.76). Among HIV-negative MSM, increased stimulant use was associated with participating in group sex while intoxicated (aOR 1.81; 95% CI 1.04–3.18), transactional sex (2.53; 1.40–2.55), and last partner injection drug use (1.96; 1.02–3.74). Our findings demonstrate that lasso can be a useful tool for variable selection and creation of predictive models. These results indicate that risk behaviors associated with increased stimulant use may differ based on HIV status and suggest that co-substance use and partnership contexts should be considered in the development of HIV prevention/treatment interventions.

Keywords

substance use; men who have sex with men; HIV; stimulants

INTRODUCTION

Stimulant use is substantially higher among men who have sex with men (MSM) compared to the U.S. general population (Centers for Disease Control and Prevention [CDC], 2019; Substance Abuse and Mental Health Services Administration [SAMHSA], 2019). Consumption of stimulants among MSM frequently occurs within social and sexual contexts, such as night clubs, bath houses, circuit parties, and sex clubs (Drumright et al., 2006; Giorgetti et al., 2017). Stimulant use, particularly methamphetamine, is a prominent driver of HIV transmission among MSM - thought to be driven by risky sexual behaviors with serodiscordant partners (Freeman et al., 2011; Ostrow et al., 2009). Despite significant advances in the field of biomedical HIV prevention, HIV transmission among MSM who use stimulants remains one of the predominant factors contributing to the ongoing HIV epidemic (Swartz & McCarty-Caplan, 2018). As such, understanding factors that are related to stimulant use and HIV risk is important to develop effective, targeted interventions for this key population.

Factors contributing to HIV transmission among MSM differ by HIV status. For HIV-negative individuals, HIV acquisition is predominantly through condomless receptive anal intercourse with sexual partners living with HIV (Baggaley et al., 2010). For MSM living with HIV (MWH), risk for transmitting HIV to sexual partners is driven by condomless anal intercourse (particularly insertive) and HIV viral load, with higher levels of HIV viremia associated with increased risk of HIV transmission (LeMessurier et al., 2018). Given the differences that exist regarding mechanisms of HIV transmission, it is important to understand stimulant use and risk behavior within the context of HIV status, given the impact that these distinctions may have on HIV transmission dynamics.

While stimulant use is linked to sexual risk behaviors, evidence suggests that stimulant use prevalence and patterns of use may differ according to HIV status (Centers for Disease

Control and Prevention [CDC], 2019; Halkitis, Fischgrund, et al., 2005; Hood et al., 2018; Substance Abuse and Mental Health Services Administration [SAMHSA], 2019). MWH have a higher likelihood of using stimulants to avoid unpleasant emotions, social pressures, and conflict, compared to their HIV-negative counterparts (Halkitis, Green, et al., 2005). Among MWH, stimulants may be used as an avoidance coping strategy to deal with an HIV diagnosis (Halkitis et al., 2008). Stimulants may also be used to dispel potential anxieties or fears associated with sexual activity among MWH, resulting in MWH using stimulants for sexual reasons compared to HIV-negative MSM who tend to report using stimulants socially (Halkitis, Fischgrund, et al., 2005). These stimulant use patterns may influence sexual risk behaviors, as it has been suggested that stimulants may have a greater impact on frequency of condomless intercourse among MWH compared those who are HIV-negative (Halkitis et al., 2008). For example, longitudinal analysis of a cohort of MSM in the U.S. revealed that MSM who used stimulants and underwent HIV seroconversion had higher frequency of risky sexual behaviors and stimulant use than those who remained HIV-negative (Swartz & McCarty-Caplan, 2018).

These differences in stimulant use patterns highlight that the factors which are driving the ongoing stimulant and HIV epidemics among MSM are nuanced and complex. Determining whether the contexts that surround stimulant use patterns differ based on HIV status represents an important next step in understanding how stimulant use contributes to HIV transmission dynamics within the sexual networks of MSM and to the development of effective interventions. However, data explicitly evaluating differential factors contributing to ongoing stimulant use are limited, with most studies either including HIV status as a covariate or evaluating stimulant use within the context of a cohort comprised exclusively of MWH or HIV-negative MSM (Chartier et al., 2009; Colyer et al., 2020; Fletcher et al., 2020; Freeman et al., 2011). This study seeks to bridge this gap by evaluating differences in factors associated with increased stimulant use among a diverse cohort of MSM and examining how they differ according to HIV status. This analysis utilized machine learning techniques, specifically least absolute shrinkage and selection operator (lasso), to select variables and create predictive models to evaluate factors associated with increased stimulant use. Sub-analyses stratifying participants based on HIV status were conducted to evaluate differences in predictors associated with increased stimulant use. To the best of our knowledge, this will be one of the first studies to use machine learning techniques to select predictors associated with increased stimulant use and to compare differences according to HIV status. Findings from this analysis will provide important information on whether contexts surrounding increases in stimulant use patterns differ according to HIV status, which can be used to inform future HIV prevention programming efforts.

METHODS

Data Source and Study Procedures

Data for this analysis came from the Men Who Have Sex with Man and Substance Use Cohort at UCLA Linking Infections, Noting Effects (mSTUDY; U01 DA036267), an ongoing longitudinal cohort designed to evaluate the impact of substance use on HIV transmission. The cohort consists of a group of racially/ethnically diverse MSM who are

living with or are at high-risk for HIV. Methods have been previously described (Aralis et al., 2018). Briefly, the cohort consists of predominantly Black and Latinx MSM, half with active substance use at enrollment. Participants were recruited to include half MWH and half HIV-negative MSM by design. HIV-negative MSM were recruited from a community-based university research clinic, and MWH were recruited from a community-based organization that provides clinical and community resources for the lesbian, gay, and transgender community in Los Angeles. Inclusion criteria for the cohort were: 1) 18–45 years old at the time of study enrollment, 2) born male, 3) condomless anal intercourse with a man in past 6 months (if HIV-negative). Study enrollment began in August 2014, and recruitment is ongoing to replace loss to follow-up. To date, 577 MSM have been enrolled. This analysis consists of visits that occurred from August 2014 (study inception) to December 2020 where participants provided self-reported data on stimulant use in last 6 months.

Study visits occurred every 6 months. At each visit, participants underwent STI testing, clinician interview, and completed a computer-assisted self-interview survey that collected information on the following: demographics, substance use, mental health, and sexual behaviors. Rectal and pharyngeal swabs as well as urine samples were collected at each visit and tested for gonorrhea/chlamydia (GC/CT) with nucleic acid amplification testing (Aptima Combo 2, GenProbe, San Diego, CA). Blood samples were collected for syphilis testing using rapid plasma reagin (RPR) with confirmatory testing via the *Treponema pallidum* particle agglutination test (TPPA). Infectious syphilis (i.e., primary, secondary, or early latent) was defined following positive test results through confirmation from the local health department and using the Centers for Disease Control and Prevention determination (Workowski & Bolan, 2015). Study personnel assisted with notifying participants of their STI testing results and facilitated linkages to care for positive results. The study was reviewed and approved by the Office of Human Research Participant Protection (OHRPP) at the University of California, Los Angeles.

Statistical Analysis

Measures—The purpose of this analysis was to utilize machine learning for variable selection and prediction to determine factors associated with increased stimulant use. We also sought to evaluate if predictors associated with increased stimulant use differed by HIV status. Our increased stimulant use outcome variable was constructed from the question “In the last 6 months, how often did you use [drug]?”. Possible stimulants included methamphetamine, cocaine powder, and crack cocaine. Response options included: “Daily”, “Weekly”, “Monthly”, “Less often than monthly”, “Once”, and “Never”. Methamphetamine, cocaine powder, and crack cocaine were combined into one composite “stimulants” variable. We chose to create a composite stimulants variable given the well-established link of stimulant use with sexual risk behavior and HIV transmission (Gamarel et al., 2015; Hojilla et al., 2018; Swartz & McCarty-Caplan, 2018). A lag variable was created, indicating whether there was an increase in reported stimulant use compared to the prior visit (e.g., reporting using stimulants “once” at T_n followed by “weekly” use at T_{n+1}), which was binary (no increased stimulant use or yes increased stimulant use).

Predictors for inclusion in lasso models were selected based on whether the variable had a conceptually relevant relationship with stimulant use based on the literature (Supplemental Tables 1 and 2). Variables included participant demographics as well as the following constructs: housing instability (Glick et al., 2018), history of incarceration (Anderson-Carpenter et al., 2017), intimate partner violence (Wu et al., 2014), depression (Javanbakht et al., 2020), substance use (Patterson et al., 2005), sexual behaviors (Semple et al., 2010), and last sexual partner characteristics (Wray & Monti, 2019).

For substance use variables, participants were asked the question “In the last 6 months, how often did you use [drug]?”. Potential drug options included: fentanyl, heroin, prescription opiates, marijuana, and poppers. Response options included: “Daily”, “Weekly”, “Monthly”, “Less often than monthly”, “Once”, and “Never”. Given relatively low prevalence of reported opiate use and overlap between types of opiates used in this sample, fentanyl, heroin, and prescription opiates were combined into one composite opiates variable. Regular drug use was a binary variable defined as reporting daily or weekly use in the past 6 months (e.g., for regular opiate use, yes = reporting “weekly” or “daily” opiate use in past 6 months; no = reporting “monthly”, “less often than monthly”, “once”, or “never” in past 6 months). Transactional sex was defined as the participant giving or receiving money, drugs, and/or a place to stay in exchange for anal sex in the past 3 months.

Creation of Lasso Models—Lasso models were created for variable selection and development of predictive models. Lasso regression selects predictors by fitting models using all possible predictors and shrinking the regression coefficients of predictors that do not sufficiently contribute to error minimization to zero, thus eliminating them from the model (Tibshirani, 2011). Lasso was selected over traditional statistical models because the regularization methods used in lasso promote sparse models that minimize standard errors and improve interpretability of models (Tibshirani, 1996). In comparison to lasso, traditional statistical models are prone to overfitting, resulting in models with low bias but high variance, which may result in inaccurate predictions (Hastie et al., 2015). The dataset was randomly split 50/50 into a testing and training dataset (Stata Corp LLC., 2019). All potential variables (Supplemental Table 1) were included in initial lasso models. All models controlled for age, race/ethnicity, and HIV status. Models were fit on the training dataset using ten-fold cross-validation and ordered based on the magnitude of the tuning parameter (λ), i.e., a parameter to control the degree to which regression coefficients are shrunk towards zero to obtain suitable model fit (Hastie et al., 2009). The model with the value of λ that minimized the out-of-sample prediction error was identified and cross-validation plots were created to ensure that λ was minimized. Goodness of fit (GOF) and model performance were evaluated over a grid of λ values within one standard error (SE) of the minimal value of λ. Models were evaluated using the testing and training datasets by 1) deviance and deviance ratios, 2) area under the receiver operating curve (AUC) using mixed-effects logistic regression models, and 3) Matthews Correlation Coefficient (MCC). The lasso model within 1 SE of the minimal value of λ with the lowest deviance and deviance ratio (Hastie et al., 2015), highest AUC (Lasko et al., 2005), MCC closest to an absolute value of 1 (Chicco & Jurman, 2020), and had the most consistent indices between the training and testing datasets was selected as the final lasso model. To evaluate whether

predictors associated with increased stimulant use differed by HIV status, the dataset was also stratified by HIV status and lasso models were created as above.

For the final models selected, descriptive statistics (frequency, percentage, median, interquartile range [IQR]) of the predictors selected by lasso models were calculated. Chi-square and Kruskal-Wallis tests were used to evaluate whether the distribution of predictors differed based on increased stimulant use. Mixed-effects logistic regression analyses were used to calculate unadjusted and adjusted odds ratios using variables selected from the final lasso model, using increased stimulant use as the outcome variable. Complete case analysis was used (n=2,095/2,676 visits), and all analyses were conducted using Stata 16.1 (StataCorp, College Town, TX).

RESULTS

Entire Cohort

The sample consisted of 2,095 visits across 467 participants. Increased stimulant use was reported at 20.9% (n=438) of visits (Table 1). Median age was 33 years (IQR 28–40; range 18–50) and 53.8% (n=1,126) of visits were completed by MWH. Almost half of study visits were completed by Latinx participants (50.1% of study visits; n=1,049), followed by Black (38.9%; n=814), White (6.5%; n=136), and other racial/ethnic groups (4.6%; n=96). Participants who reported increased stimulant use reported a higher prevalence of unstable housing, unemployment, cannabis use and binge drinking, regular opiate use, and last partner substance use (specifically, stimulants and ecstasy), compared to those without increased stimulant use. Positive STI testing occurred more frequently during visits with increased stimulant use (23.7%; n=104/334) compared to visits without increased stimulant use (13.8%; n=228/1,429).

Lasso models selected predictors associated with constructs surrounding financial insecurity, substance use, sexual risk behaviors, and last partnership characteristics (AUC=0.75). In adjusted analysis (Table 2), transactional sex associated the most highly with increased stimulant use, with MSM who reported transactional sex having over twice the odds of reporting increased stimulant use (aOR 2.30; 95% CI 1.60–3.30) compared to those who did not report transactional sex. Having a last partner who used stimulants had higher odds of increased stimulant use (aOR 2.21; 95% CI 1.62–3.00) compared to participants whose last partner did not use stimulants. Positive STI testing was associated with 1.59 times higher odds (95% CI 1.14–2.21) of increased stimulant use, compared to negative STI testing. Increased stimulant use was also positively associated with unstable housing, vaping/cigarette use, cannabis use, regular opiate use, anal intercourse while intoxicated, and having a last partner who was anonymous, compared to participants who did not report those behaviors.

Stratified by HIV Status

Among MWH, the sample consisted of 1,199 study visits across 242 participants. Increased stimulant use was reported at 22.9% (n=274) of visits, and median age was 36 years (IQR 31–41) (Supplemental Table 3). Compared to lasso models containing the entire cohort and

those restricted to HIV-negative participants, lasso tended to select constructs surrounding polysubstance use among models restricted to MWH (AUC=0.71). In adjusted analyses (Table 3), increased stimulant use was positively associated with unstable housing (aOR 2.25; 95% CI 1.45–3.51), vaping/cigarette use (1.99; 1.36–2.92), using poppers regularly (2.28 1.38–3.76), and transactional sex (2.33; 1.48–3.65) and was negatively associated with reporting that one's last partner was a regular/main partner (0.70; 0.49–0.99), compared to MWH who did not report those characteristics/behaviors.

Among HIV-negative participants, the sample consisted of 912 study visits across 228 participants. Increased stimulant use was reported at 18.2% (n=166) of study visits and median age was 30 years (IQR 26–36). HIV-negative participants with increased stimulant use reported lower income and education levels as well as higher frequency of unemployment, unstable housing, cannabis use, sexual risk behaviors, and last partner substance use (e.g., alcohol, poppers, and injection drug use) compared to those who did not report increased stimulant use (Supplemental Table 4). Compared to lasso models containing the entire cohort as well as those restricted to MWH, lasso models including HIV-negative participants tended to include more sexual risk behaviors and last partner substance use (AUC=0.76). In adjusted analysis (Table 4), increased stimulant use was positively associated with unstable housing (aOR 1.94; 95% CI 1.09–3.45), cannabis use, transactional sex (2.53; 1.40–4.55), group sex while intoxicated (1.81; 1.04–3.18), and having a last sexual partner who injected drugs (1.96; 1.02–3.74) and was negatively associated with higher levels of education, compared to HIV-negative participants who did not endorse those characteristics/behaviors.

DISCUSSION

In this analysis of a diverse cohort of MSM in Los Angeles, California, increased stimulant use was positively associated with unstable housing, transactional sex, polysubstance use, STIs, and sexual risk behavior. However, constructs correlated with increased stimulant use in lasso models differed when the sample was stratified by HIV status. Among MWH, polysubstance use was highly correlated with increased stimulant use. However, among HIV-negative participants, last partnership characteristics and sexual risk behaviors were correlated with increased stimulant use. This analysis is among the first to utilize lasso for variable selection and creation of predictive models to evaluate factors that are associated with increased stimulant use. Our approach demonstrates that machine learning techniques can be a useful and efficient tool to assist with selecting relevant predictors from datasets with large amounts of potential variables to create conceptually relevant models. Using lasso for variable selection allowed us to evaluate differences in predictors that were associated with increased stimulant use according to HIV status. These findings provide an important next step in understanding the disproportionate effect that the complicated stimulant use epidemic has on certain MSM subpopulations and could be used to inform future HIV prevention interventions.

Unstable housing and transactional sex were consistently selected across all models, suggesting that these variables were highly correlated with increased stimulant use regardless of HIV status. Compared to non-sexual minorities, sexual minorities

disproportionately experience unstable housing, often due to homophobia, rejection, and abuse that forces them from their homes (Baams et al., 2019; Romero et al., 2020). Furthermore, stimulants are often used as form of coping with stressful feelings associated with being unstably housed as well as a means of survival (Johnson & Chamberlain, 2008). For example, stimulants may be utilized to stay awake to protect belongings, facilitate social interaction with others, or as an alternative to psychiatric medications (Bungay et al., 2006). Unstably housed MSM may also use stimulants to obtain a sense of belonging, to bond with others, or due to perceived social norms (Barman-Adhikari et al., 2016; Johnson & Chamberlain, 2008). Additionally, transactional sex has a strong association with unstable housing and can be used as a mechanism to obtain financial support or shelter among unstably housed individuals (Mimiaga et al., 2009). Transactional sex may also occur for the purpose of obtaining drugs (Javanbakht et al., 2019). These findings underscore the importance of addressing the underlying factors that often drive the interdependent relationship between unstable housing, stimulant use, and transactional sex. Specifically, these results suggest the potential utility of interventions, such as contingency management, designed to reduce these barriers through linkages to financial or community resources in exchange for not using substances (Tracy et al., 2007).

In addition to socioeconomic disadvantage, having a partner who used stimulants and engaging in anal intercourse while intoxicated were positively associated with increased stimulant use. These findings highlight the unique social and sexual contexts where stimulants are frequently consumed by MSM, such as sex clubs, circuit parties, and bath houses (Drumright et al., 2006; Giorgetti et al., 2017; Reback et al., 2004). Stimulants are often used by MSM in sexual settings to obtain sexual partners, increase libido, augment sexual stamina, and for disinhibition (A Bourne et al., 2015; Weatherburn et al., 2017). However, sexualized stimulant use can impair decision making and lead to risk behaviors, such as increased number of casual partners and impaired condom negotiation (Berry et al., 2020; Hoenigl et al., 2016). Due to these contexts, sexualized stimulant use is independently associated with HIV/STIs and is an important driver of HIV/STI transmission within the sexual networks of MSM who use stimulants (Lai et al., 2020; Reback & Fletcher, 2018). As increased stimulant use was also associated with having an STI, a known risk factor for HIV transmission, these findings underscore the importance of coordinated public health efforts that incorporate treatment of comorbid stimulant use into HIV/STI treatment and prevention interventions.

Among MWH, polysubstance use (e.g., binge drinking, smoking, regular opiate use, and regular popper use) correlated highly with increased stimulant use. Polysubstance use among MWH may be used as a coping mechanism related to an HIV diagnosis, HIV-related stigma, or depressive symptoms (Earnshaw et al., 2020; Glynn et al., 2019). Substance use may also be used as an avoidant coping strategy to mitigate stress associated with being a sexual minority (Mereish et al., 2017). This minority stress may be exacerbated by the stigma of living with HIV, potentially resulting in increased substance use. This consideration is highlighted in a study by Jerome et. al., where MWH who used substances reported higher levels of distressing emotions related to an undesirable self-image and daily stressors than their HIV-negative counterparts (Jerome et al., 2009). The need for external validation due to a negative self-image may cause MWH to engage in substance use to feel more desirable

and to form connections with others in both social and sexual contexts (Edelman et al., 2016). MWH may use substances for social inclusion among groups where substance use is socially accepted and due to fear that they may be excluded from these groups if they do not engage in substance use (W. Hawkins et al., 2019). Furthermore, the normalization of substance use within social circles may perpetuate continued substance use and serve as a potential barrier to reductions in consumption, particularly if the individual perceives that their social network would not be supportive of their desire to stop using substances (Edelman et al., 2016). Understanding these contexts and drivers of substance use among MWH is particularly important from a public health standpoint given the well-established connection between substance use and sexual risk behavior (Hegazi et al., 2017), which was further supported by our findings demonstrating that increased stimulant use was associated with transactional sex and having a last partner that was a non-primary partner. In addition to increased sexual risk behavior, substance use is also associated with antiretroviral therapy nonadherence, further reinforcing the contribution of substance use to ongoing HIV transmission within certain MSM subpopulations (Socias & Milloy, 2018). Collectively, these findings highlight the importance of interventions designed to improve peer support, reduce HIV-related stigma, and the value of integrating substance use treatment into the HIV care continuum.

In contrast to MWH, increased stimulant use correlated highly with socioeconomic status, sexual risk behaviors (e.g., having group sex or anal intercourse while intoxicated), and last partner substance use among HIV-negative participants. These findings are consistent with data demonstrating that stimulant use is highly prevalent within sexual contexts and associated with increased individual-level sexual risk behaviors among MSM who use stimulants (Loza et al., 2020; Shoptaw & Reback, 2007). However, our results suggest that partnership dynamics may influence stimulant use patterns or vice versa. It is possible that MSM who use stimulants may seek out partners with similar patterns of substance use or that their partners' substance use may influence their own behaviors (Derrick et al., 2019; Shariati et al., 2017). Alternatively, HIV-negative MSM may tend to use stimulants within sexualized contexts where substance use is more common and where they are more likely to encounter partners who also engage in sexualized substance use, such as circuit parties, bath houses or sex clubs (Adam Bourne et al., 2015; Fulcher et al., 2019). Beyond individual-level risk behavior, substance use within sexual partnerships has been associated with sexual risk behaviors, such as condomless anal intercourse with serodiscordant partners (Brown et al., 2017). Furthermore, within stable partnerships, partnership-level substance use may influence couples' sexual behavior and decision-making surrounding risk mitigation strategies, such as sexual agreements and whether those agreements are broken (Mitchell et al., 2014). These findings highlight the sexual contexts in which substances are used among HIV-negative MSM and further support the extant literature indicating that stimulant use likely plays a substantial role in HIV seroconversion and STI transmission within such subpopulations that use stimulants (Halkitis et al., 2006; Hoenigl et al., 2016). As partnership dynamics likely influence sexualized substance use and subsequent sexual risk behaviors, these results suggest the potential utility of sexual partnership-based interventions that combine substance use treatment with HIV prevention.

Limitations

Our findings must be considered within the context of limitations. As a machine learning variable selection technique, lasso aids interpretation by selecting a distinct subset of predictors but tends to exclude correlated variables from models, potentially leading to misspecification and omitted variables bias, relative to ridge regression and other techniques. However, we accounted for this by conducting sensitivity analyses to ensure that correlated variables were not spuriously deleted (results not shown). It is also important to note that, while lasso selected variables that were highly correlated with our outcome, we are unable to make causal inferences from our models. As this was a secondary data analysis, our study was constrained to measures that were contained in the dataset, resulting in potential omitted variables bias and measurement bias. This consideration is particularly relevant as certain constructs regarding sexual risk behaviors and substance use were not captured within the dataset, such as partnership dyadic characteristics and contexts/settings in which substance use and sexual activities took place, which should be considered in the interpretation of our results and represent an important area of future research. We presented confidence intervals to aid interpretation of the regression coefficients but suggest caution making statistical inferences in the context of variable selection (Lockhart et al., 2014). As increased stimulant use was reported in 20.9% of visits, AUC may be overestimated due to imbalances in our data. However, we sought to overcome this potential limitation by utilizing multiple metrics to assess model performance when selecting our models, such as the MCC which is robust to class imbalance and asymmetry (Chicco & Jurman, 2020). Finally, as this cohort comprises a diverse sample of MSM with high rates of substance use, this limits the generalizability of our findings to other subpopulations of MSM.

Conclusions

This study is among the first to utilize lasso for variable selection to evaluate factors associated with increased stimulant use among a diverse cohort of MSM. Our analysis adds to the literature by demonstrating that variables commonly collected in HIV and substance use research can be used to build models which predict stimulant use with a reasonable degree of accuracy. Furthermore, this study is among the first to explicitly evaluate differences in factors that may contribute to increased stimulant use based on HIV status. As engagement in healthcare may differ according to HIV status (Babel et al., 2021; Powers & Miller, 2015), characterizing differences in predictors of stimulant use based on HIV status is crucial toward the development of efficacious HIV/STI interventions that can be incorporated into HIV treatment and prevention efforts. Our findings demonstrate that increased stimulant use was positively associated with unstable housing and transactional sex regardless of HIV status. These results underscore the importance of designing HIV prevention interventions that address the underlying factors that often drive the interdependent relationship between unstable housing, stimulant use, and transactional sex which contribute to ongoing HIV/STI transmission among vulnerable MSM subpopulations. Specifically, strategies such as contingency management may prove beneficial in these populations (Tracy et al., 2007).

Our analysis revealed that polysubstance use was associated with increased stimulant use among MWH, whereas sexual risk behaviors, sexualized substance use, and last

partner substance use were correlated with increased stimulant use among HIV-negative participants. These findings indicate that the underlying motivations and factors which contribute to stimulant use patterns among MSM likely differ based on HIV status and suggest that these distinctions should be considered in the design of HIV prevention and treatment interventions. Specifically, our results demonstrate the potential role of interventions that integrate substance use treatment into the HIV care continuum and reduce HIV-related stigma among MWH who use stimulants, such as educational programming, counseling, and linkages to support groups (Heijnders & Van Der Meij, 2006). Conversely, HIV-negative MSM who use stimulants may benefit from HIV prevention interventions that address sexualized substance use as well as sexual partnership-based interventions.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1:

Participant characteristics, substance use, sexual risk behavior, and last partner characteristics, stratified by whether increased stimulant use was reported at mSTUDY visits 8/2014–12/2020 (N=2,095 visits)

	No Increased Stimulant Use (n=1,657)	Increased Stimulant Use (n=438)	p-value
	n (%)	n (%)	
Age (median, IQR)	33 (28–40)	33 (28–39)	0.76
Race/Ethnicity			
White	104 (6.3%)	32 (7.3%)	0.13
Black	665 (40.1%)	149 (34.0%)	
Latinx	812 (49.0%)	237 (54.1%)	
Other	76 (4.6%)	20 (4.6%)	
HIV			
Negative	791 (47.7%)	178 (40.6%)	**0.008**
Living with HIV	866 (52.3%)	260 (59.4%)	
Employment status [a]			
Employed	1,327 (80.1%)	311 (71.0%)	**<0.001**
Unemployed	330 (19.9%)	127 (29.0%)	
Unstable housing [a]			
No	1,454 (87.7%)	326 (74.4%)	**<0.001**
Yes	203 (12.3%)	112 (25.6%)	
Substance Use			
Binge drinking [a]			
Never	965 (58.2%)	207 (47.3%)	**<0.001**
Monthly or less	540 (32.6%)	166 (37.9%)	
Weekly/daily	152 (9.2%)	65 (14.8%)	
Vaping/Cigarette use [a]			
No	1,226 (74.0%)	247 (56.4%)	**<0.001**
Yes	431 (26.0%)	191 (43.6%)	
Cannabis use [a]			
No	890 (53.7%)	157 (35.8%)	**<0.001**
Weekly or less frequent	434 (26.2%)	144 (32.9%)	
Daily	333 (20.1%)	137 (31.3%)	
Regular opiate use [a]			
No	1,606 (96.9%)	416 (95.0%)	**0.048**
Yes	51 (3.1%)	22 (5.0%)	
Sexual Risk Behavior			
Sexually transmitted infection			
No	1,429 (86.2%)	334 (76.3%)	**<0.001**
Yes	228 (13.8%)	104 (23.7%)	
Anal intercourse while intoxicated [a]			

	No Increased Stimulant Use (n=1,657)	Increased Stimulant Use (n=438)	p-value
	n (%)	n (%)	
No	915 (55.2%)	132 (30.1%)	**<0.001**
Yes	742 (44.8%)	306 (69.9%)	
Transactional sex [a]			
No	1,484 (89.6%)	311 (71.0%)	**<0.001**
Yes	173 (10.4%)	127 (29.0%)	
Last Partner Characteristics			
Last partner was an unknown person			
No	1,502 (90.6%)	376 (85.8%)	**0.003**
Yes	155 (9.4%)	62 (14.2%)	
Last partner used stimulants			
No	1,292 (78.0%)	225 (51.4%)	**<0.001**
Yes	365 (22.0%)	213 (48.6%)	
Last partner used ecstasy			
No	1,591 (96.0%)	398 (90.9%)	**<0.001**
Yes	66 (4.0%)	40 (9.1%)	

[a] Last 6 months; IQR = Interquartile range

Table 2:

Unadjusted and adjusted odds ratios of factors associated with increased reported stimulant use at mSTUDY visits (N=2,095)

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Age	1.00 (0.98–1.02)	0.97	1.01 (0.98–1.03)	0.68
Race/Ethnicity				
White	Ref	--	Ref	--
Black	0.77 (0.40–1.50)	0.44	1.08 (0.57–2.06)	0.80
Latinx	1.11 (0.58–2.12)	0.76	1.55 (0.82–2.91)	0.17
Other	0.87 (0.35–2.11)	0.75	1.30 (0.55–3.05)	0.55
HIV				
Negative	Ref	--	Ref	--
Living with HIV	1.44 (1.03–2.02)	**0.035**	1.30 (0.93–1.81)	0.12
Employment status [a]				
Employed	Ref	--	Ref	--
Unemployed	1.49 (1.09–2.02)	**0.011**	1.13 (0.82–1.55)	0.45
Unstable housing [a]				
No	Ref	--	Ref	--
Yes	2.74 (1.94–3.86)	**<0.001**	1.81 (1.27–2.57)	**0.001**
Substance Use				
Binge drinking [a]				
Never	Ref	--	Ref	--
Monthly or less	1.55 (1.15–2.08)	**0.004**	1.59 (1.17–2.15)	**0.003**
Weekly/daily	2.04 (1.30–3.22)	**0.002**	1.76 (1.13–2.75)	**0.013**
Vaping/Cigarette use [a]				
No	Ref	--	Ref	--
Yes	2.29 (1.69–3.10)	**<0.001**	1.69 (1.24–2.31)	**0.001**
Cannabis use [a]				
No	Ref	--	Ref	--
Weekly or less frequent	2.22 (1.59–3.08)	**<0.001**	1.82 (1.31–2.54)	**<0.001**
Daily	2.87 (1.98–4.16)	**<0.001**	2.24 (1.55–3.25)	**<0.001**
Regular opiate use [a]				
No	Ref	--	Ref	--
Yes	2.07 (1.06–4.04)	**0.032**	1.00 (0.50–2.01)	**1.00**
Sexual Risk Behavior				
Sexually transmitted infection				
No	Ref	--	Ref	--
Yes	2.09 (1.51–2.88)	**<0.001**	1.59 (1.14–2.21)	**0.006**
Anal intercourse while intoxicated [a]				
No	Ref	--	Ref	--
Yes	3.01 (2.27–3.98)	**<0.001**	1.64 (1.21–2.20)	**0.001**

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Transactional sex [a]				
No	Ref	--	Ref	--
Yes	4.17 (2.97–5.85)	**<0.001**	2.30 (1.60–3.30)	**<0.001**
Last Partner Characteristics				
Last partner was unknown person				
No	Ref	--	Ref	--
Yes	1.89 (1.27–2.83)	**0.002**	1.54 (1.03–2.32)	**0.037**
Last partner used stimulants				
No	Ref	--	Ref	--
Yes	3.55 (2.69–4.69)	**<0.001**	2.21 (1.62–3.00)	**<0.001**
Last partner used ecstasy				
No	Ref	--	Ref	--
Yes	2.45 (1.43–4.20)	**0.001**	1.25 (0.71–2.18)	**0.44**

[a] Last 6 months

Note: Bold indicates p-value <0.05

Table 3:

Unadjusted and adjusted odds ratios of factors associated with increased reported stimulant use at mSTUDY visits for participants living with HIV (N=1,199 visits)

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Age	0.97 (0.94–1.00)	0.07	0.99 (0.96–1.02)	0.34
Race/Ethnicity				
White	Ref	--	Ref	--
Black	0.78 (0.33–1.82)	0.56	1.28 (0.56–2.91)	0.56
Latinx	1.02 (0.45–2.32)	0.96	1.54 (0.69–3.43)	0.29
Other	0.54 (0.19–1.50)	0.23	0.96 (0.35–2.63)	0.93
Unstable housing [a]				
No	Ref	--	Ref	--
Yes	2.91 (1.88–4.48)	**<0.001**	2.25 (1.45–3.51)	**<0.001**
Substance Use				
Binge drinking [a]				
Never	Ref	--	Ref	--
Monthly or less	1.70 (1.16–2.48)	**0.006**	1.63 (1.12–2.38)	**0.011**
Weekly/daily	2.02 (1.05–3.88)	**0.035**	1.87 (1.00–3.51)	**0.05**
Vaping/Cigarette use [a]				
No	Ref	--	Ref	--
Yes	2.06 (1.41–3.00)	**<0.001**	1.99 (1.36–2.92)	**<0.001**
Regular poppers use [a]				
No	Ref	--	Ref	--
Yes	3.29 (2.01–5.40)	**<0.001**	2.28 (1.38–3.76)	**0.001**
Regular opiate use [a]				
No	Ref	--	Ref	--
Yes	1.40 (0.55–3.59)	0.48	0.80 (0.29–2.20)	0.67
Sexual Risk Behavior				
Having a regular partner [a]				
No	Ref	--	Ref	--
Yes	1.74 (1.20–2.51)	**0.003**	1.38 (0.95–2.02)	0.09
Transactional sex [a]				
No	Ref	--	Ref	--
Yes	3.28 (2.13–5.05)	**<0.001**	2.33 (1.48–3.65)	**<0.001**
Last Partner Characteristics				
Last partner was regular/main partner				
No	Ref	--	Ref	--
Yes	0.71 (0.50–1.00)	**0.05**	0.70 (0.49–0.99)	**0.043**
Last partner used ecstasy				
No	Ref	--	Ref	--

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Yes	1.52 (0.73–3.19)	0.27	1.28 (0.60–2.75)	0.52

[a]Last 6 months

Note: Bold indicates p-value <0.05

Table 4:

Unadjusted and adjusted odds ratios of factors associated with increased reported stimulant use at mSTUDY visits for HIV-negative participants (N=912 visits)

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Age	1.00 (0.96–1.04)	0.93	1.01 (0.97–1.05)	0.73
Race/Ethnicity				
White	Ref	--	Ref	--
Black	0.98 (0.30–3.20)	0.97	1.01 (0.34–3.00)	0.99
Latinx	1.86 (0.58–5.94)	0.29	1.54 (0.53–4.49)	0.43
Other	1.11 (0.23–5.37)	0.90	1.05 (0.24–4.56)	0.94
Education				
Less than high school	Ref	--	Ref	--
High school	0.30 (0.13–0.71)	**0.006**	0.40 (0.17–0.91)	**0.03**
More than high school	0.33 (0.15–0.75)	**0.008**	0.41 (0.19–0.92)	**0.03**
Annual income				
Less than $10,000	Ref	--	Ref	--
$10,000-$30,000	0.71 (0.43–1.16)	0.17	0.90 (0.54–1.50)	0.68
More than $30,000	0.53 (0.29–0.99)	**0.047**	0.64 (0.33–1.23)	0.18
Employment status [a]				
Employed	Ref	--	Ref	--
Unemployed	1.78 (1.08–2.94)	**0.024**	1.40 (0.81–2.42)	0.23
Unstable housing [a]				
No	Ref	--	Ref	--
Yes	3.06 (1.78–5.27)	**<0.001**	1.94 (1.09–3.45)	**0.025**
Substance Use				
Cannabis use [a]				
No	Ref	--	Ref	--
Weekly or less frequent	2.25 (1.32–3.82)	**0.003**	2.15 (1.26–3.66)	**0.005**
Daily	2.73 (1.51–4.96)	**0.001**	2.00 (1.11–3.59)	**0.02**
Sexual Risk Behavior				
Sexual partner concurrency [a]				
No	Ref	--	Ref	--
Yes	1.70 (1.11–2.62)	**0.016**	1.18 (0.75–1.87)	0.47
Anal intercourse while intoxicated [a]				
No	Ref	--	Ref	--
Yes	2.54 (1.60–4.02)	**<0.001**	1.59 (0.96–2.62)	0.07
Group sex while intoxicated [a]				
No	Ref	--	Ref	--
Yes	3.73 (2.26–6.15)	**<0.001**	1.81 (1.04–3.18)	**0.037**
Transactional sex [a]				
No	Ref	--	Ref	--

	OR (95% CI)	p-value	aOR (95% CI)	p-value
Yes	5.02 (2.88–8.76)	**<0.001**	2.53 (1.40–4.55)	**0.002**
Last Partner Characteristics				
Last partner used alcohol				
No	Ref	--	Ref	--
Yes	1.77 (1.09–2.88)	**0.021**	1.31 (0.81–2.13)	0.28
Last partner used poppers				
No	Ref	--	Ref	--
Yes	1.70 (1.00–2.91)	0.05	1.31 (0.77–2.23)	0.33
Last partner injected drugs				
No	Ref	--	Ref	--
Yes	2.90 (1.54–5.47)	**0.001**	1.96 (1.02–3.74)	**0.043**

[a]Last 6 months

Note: Bold indicates p-value <0.05