

RESEARCH ARTICLE

A mindfulness-based, stress and coping model of craving in methamphetamine users

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Abstract

There is increasing interest in the role of mindfulness and mindfulness-based interventions to optimize recovery from a substance use disorder (SUD). However, relatively little is known about the theory-based psychological and social pathways whereby mindfulness could have beneficial effects for managing a chronic, relapsing SUD. Informed by Revised Stress and Coping Theory, the present cross-sectional study examined affective, cognitive, and social pathways whereby mindfulness is associated with lower methamphetamine craving. A total of 161 HIV-positive, methamphetamine-using sexual minority men completed a screening visit for a randomized controlled trial. Using a hybrid structural equation model, we examined pathways whereby mindfulness is associated with lower methamphetamine craving. We found that greater mindfulness was directly associated with lower negative affect and higher positive affect as well as indirectly associated with less methamphetamine craving. Interestingly, the indirect association between mindfulness and methamphetamine craving appeared to be uniquely attributable to positive affect. Only positive affect was indirectly associated with lower methamphetamine craving via higher positive re-appraisal coping and greater self-efficacy for managing triggers for methamphetamine use. Methamphetamine craving was supported by moderate associations with greater substance use severity and more frequent methamphetamine use. These findings support the role of mindfulness in cultivating positive affect, which could be crucial to build the capacity of individuals to manage methamphetamine craving as a chronic stressor that threatens recovery from SUD.

Introduction

Substance use disorders (SUD) are one of the most prevalent and costly public health challenges throughout the world. In the United States, approximately one in ten people will meet

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diagnostic criteria for a SUD in their lifetime [1]. In 2016, 20.1 million people aged 12 or older in the United States had a SUD related to their use of alcohol or other substances in the past year [2]. Of these, 684,000 people aged 12 or older had a methamphetamine use disorder [3]. Although evidence-based treatments such as cognitive-behavioral therapy and motivational interviewing are available for stimulant use disorders [4, 5], less than 15% of people living with a SUD seek formal treatment [3]. Among those who seek treatment, up to 40–70% relapse to substance use [6, 7]. Novel approaches are needed to engage the broader population of people living with a SUD that do not seek formal treatment and optimize the long-term recovery of those receiving SUD treatment.

There is increasing interest in the role of mindfulness and mindfulness-based interventions to optimize recovery from a SUD. Jon Kabat-Zinn, the founder of Mindfulness Based Stress Reduction, described mindfulness as, “the awareness that emerges through paying attention on purpose, in the present moment, and non-judgmentally to the unfolding of experience moment by moment” [8]. Previous studies have observed that dispositional mindfulness is associated with reduced substance use craving [9], especially in the presence of negative affective states [10, 11]. Prior randomized controlled trials (RCTs) also provide support for the efficacy of mindfulness-based interventions for individuals living with SUD [12–14]. Most recently, we observed that a mindfulness-based positive affect intervention achieved greater reductions in methamphetamine craving and self-reported stimulant use in HIV-positive, methamphetamine-using sexual minority men receiving contingency management [15].

Craving, the subjective experience of an urge or desire to use substances [16], has been conceptualized as an emotional and motivational state resulting from activation in brain networks relevant to attention, interoception, and reward processing [17–19]. The clinical relevance of craving is supported by its addition Diagnostic and Statistical Manual of Mental Disorders–Fifth Edition (DSM-5) as a diagnostic criteria for SUD [20]. Consistent with negative reinforcement models of addiction, substance use may become an over-learned behavioral response to escape negative affect or craving [21–23]. In fact, the benefits of mindfulness-based interventions for people living with a SUD may be most pronounced among those with elevated levels of negative affect [24]. An important gap is that relatively little is known about the affective, cognitive, and social pathways through which mindfulness modulates craving, which is crucial to inform the development of novel intervention approaches for people living with SUD.

Revised Stress and Coping Theory proposes that positive affect has unique adaptive significance in the midst of chronic stress such as managing methamphetamine craving [25]. Positive affect may be crucial to sustaining self-regulation efforts in the midst of chronic stress by re-energizing cognitive-behavioral coping responses and building social support to effectively manage a SUD [26, 27]. Consistent with the Revised Stress and Coping Theory, previous studies have substantiated the role of affective and cognitive mechanisms of mindfulness-based interventions [28–32]. Recent studies have found that positive affect shapes primary appraisals (i.e. perceptions of the stressful event as harmful, threatening, or challenging) and secondary stress appraisals (i.e. evaluation of ability and resources available to cope with the stressor) as well as buffers the effects of negative affect that is associated with substance use [31–33]. Positive affect and related cognitive processes are believed to energize and maintain one another through self-reinforcing dynamics that have been termed as an upward spiral [32, 34, 35]. There is also recognition that positive affect builds social support [36], which is crucial to support recovery from a SUD. Social factors such as supportive communications have been identified as mechanisms of action for mindfulness-based interventions [30], but their role in SUD craving has not been evaluated.

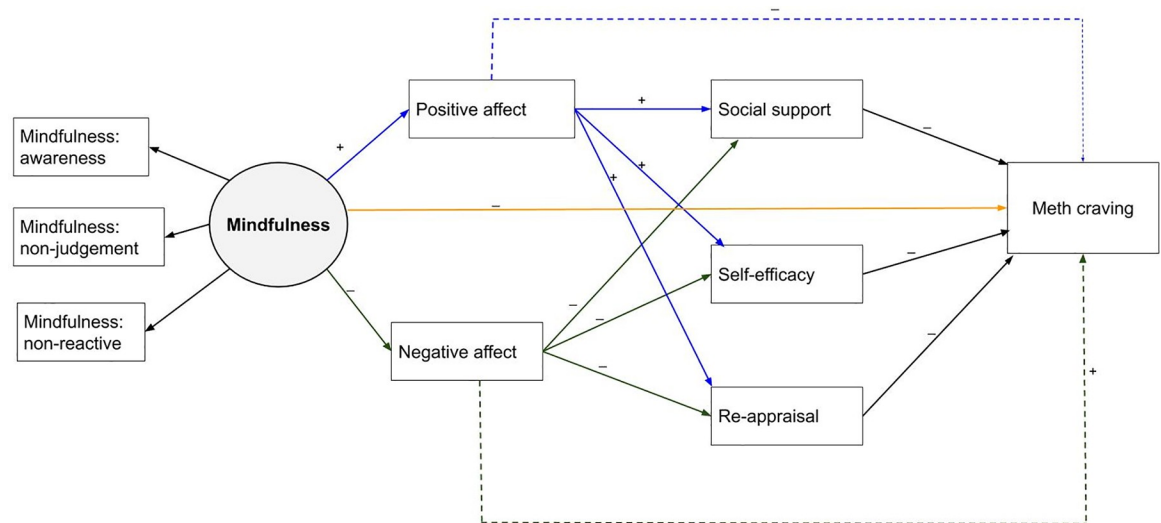


Fig 1. Theoretical pathways linking dispositional mindfulness to methamphetamine craving.

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The goal of the present cross-sectional study was to examine theory-based affective, cognitive, and social pathways that could explain the association of mindfulness with lower methamphetamine craving (see Fig 1). Our model conceptualized mindfulness as a trait and affect as a state that mediates the relationship between mindfulness and methamphetamine craving. We hypothesized that mindfulness facilitates metacognitive awareness of affective (i.e. positive and negative affect), cognitive (i.e. self-efficacy and re-appraisal) and social (i.e., social support for abstinence) responses to achieve greater depth of processing in primary and secondary stress appraisals, which in turn leads to more effective management of methamphetamine craving. Consistent with Revised Stress and Coping Theory, we hypothesized that positive affect would uniquely account for the beneficial association of mindfulness with lower methamphetamine craving because it re-invigorates key cognitive (i.e., positive re-appraisal, self-efficacy for managing methamphetamine triggers) and social (i.e., abstinence-specific social support) processes relevant to recovery from a SUD.

Materials and methods

Data collection

The present study leveraged data from the screening visit for a randomized controlled trial (RCT) of a mindfulness-based, positive affect intervention for HIV-positive, methamphetamine-using gay, bisexual, and other men who have sex with men (referred to here as sexual minority men), which was conducted in San Francisco, CA USA in collaboration with a community-based program (www.clinicaltrials.gov; NCT01926184). A detailed description of the study protocol is published elsewhere [37, 38]. All relevant procedures were approved by the Institutional Review Boards for the University of California, San Francisco with reliance agreements at the University of Miami and Northwestern University. This RCT received a certificate of confidentiality from the National Institute on Drug Abuse. The University of California, Los Angeles Data Safety and Monitoring Board for Addiction Medicine held annual meetings to review participant-related events and overall progress for this RCT. There were no adverse events or serious adverse events.

Data collection

Between 2013 and 2017, HIV-positive, methamphetamine-using sexual minority men were recruited through three primary sources. First, men initiating services at a community-based contingency management program completed a brief consent form to be contacted by study staff to learn more about the RCT. Second, direct recruitment was conducted using flyers and palm cards that were distributed in HIV medical clinics, AIDS service organizations, bars and clubs, bath houses, and via social media. Third, an incentivized snowball sampling method was employed where eligible participants received a maximum of \$30 for referring up to three individuals who were subsequently judged to be eligible for the RCT. Data for the present study were drawn from the screening visit completed by 161 participants. To be eligible for the screening visit, participants had to meet the following inclusion criteria: 1) 18 years of age or older; 2) identify as a sexual minority man; and 3) provide documentation of HIV-positive serostatus (i.e., letter of diagnosis or ART medications other than Truvada that are matched to their photo identification; and 4) report engaging in methamphetamine use in the past three months.

Measures

Dispositional mindfulness. Dispositional mindfulness was measured using the Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006), a 39-item scale comprising five domains: observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience. The present analyses focused on three sub-scales—acting with awareness (“awareness”), non-judging of inner experience (“non-judgmental”), and non-reactivity to inner experience (“non-reactive”), which have been associated with substance use. Participants rated items on a five-point Likert-type scale (1 = never or very rarely true, 5 = very often or always true), from which a total dispositional mindfulness score was computed. Reliability of each sub-scale used in the present investigation was adequate: awareness (Cronbach’s $\alpha = 0.78$; $M = 24.6$, $SD = 6.6$), non-judgement (Cronbach’s $\alpha = 0.87$; $M = 56.7$, $SD = 15.1$), and non-reactivity (Cronbach’s $\alpha = 0.77$; $M = 44.3$, $SD = 9.7$).

Methamphetamine craving. The Penn Alcohol Craving Scale (PACS; Flannery, Volpicelli & Pettinati, 1999), a five-item self-report measure, was adapted to assess craving for methamphetamine. The PACS measures frequency, intensity, and duration of craving as well as an overall rating of craving for the previous week. Reliability of the PACS was adequate (Cronbach’s $\alpha = 0.90$; $M = 2.79$, $SD = 1.4$).

Substance use. The Addiction Severity Index (ASI) was administered to assess the severity of alcohol and other substance use [21]. The ASI Drug composite score includes the self-reported number of days using multiple illicit substances during the past 30 days, perceived impairment related to substance use, and perceived need for SUD treatment. Using this scale, participants reported the number of days that they used methamphetamine in the past 30 days as well as how frequently they used methamphetamine in the past three months, with responses measured on a scale from Not at all (0) to daily (7).

Positive and negative affect. An adapted version of the Differential Emotions Scale (DES) assessed the frequency of positive and negative affect [39]. The DES was modified to include more items assessing positive affect [40]. Reliability for the 14-item positive affect (Cronbach’s $\alpha = 0.89$; $M = 25.5$, $SD = 6.9$) and the 12-item negative affect (Cronbach’s $\alpha = 0.88$; $M = 13.3$, $SD = 5.8$) subscales of the DES was acceptable.

Abstinence-specific social support. The Processes of Change measure for cocaine users was adapted to include strategies that may be employed to avoid methamphetamine use [41]. The six items were drawing from the helping relationships and reinforcement management

subscales. These items had adequate internal consistency (Cronbach's $\alpha = 0.90$; $M = 18.4$, $SD = 6.4$).

Self-efficacy. The 8-item brief version of the Situational Confidence Questionnaire (SCQ) was adapted to examine participants' confidence to resist their urges to use methamphetamine with the original eight SCQ subscales (e.g. pleasant times with others, social pressure, physical discomfort). Items were measured on a scale ranging from 0–100% to measure self-efficacy for managing triggers for methamphetamine. The reliability for the 8-item scale was adequate: (Cronbach's $\alpha = 0.84$; $M = 460.9$, $SD = 167.4$).

Positive re-appraisal. An adapted version of the Ways of Coping questionnaire was administered that included additional items to examine positive re-appraisal coping. The 9-item measure includes items such as “you remind yourself of the good things that came out of the situation”, “you came out of the experience better than you went it”, and “you rediscovered what is important in life.” The reliability for the 9-item scale was adequate: (Cronbach's $\alpha = 0.92$; $M = 2.69$, $SD = 0.86$).

Analyses

For hypothesis testing, we used the following multi-stage analytic approach. First, we examined the bivariate associations between methamphetamine craving and substance use as a measure of the validity of our adapted measure of methamphetamine craving. Then, we computed Pearson's correlations to examine zero-order correlations between methamphetamine craving and the independent variables—mindfulness sub-scales, positive and negative affect, social support, situational confidence, and positive re-appraisal (Table 1).

Then, we tested a hybrid structural equation model (Fig 1) with full-information maximum likelihood estimation using STATA version 15 to examine the theory-based pathways that could account for the association of mindfulness with methamphetamine craving. This was a hybrid structural equation model because mindfulness was measured as a latent variable and all other variables were treated as observed variables due to the modest sample size. Model fit was determined using multiple descriptive indices of model fit: non-significant chi-square (χ^2), comparative fit index (CFI) values greater than or equal to 0.95, root mean square error of approximation (RMSEA) values less than or equal to 0.06, and standardized root-mean-

Table 1. Descriptive statistics and zero-order correlations between methamphetamine craving and the predictor variables.

	Zero-order correlations							
	1	2	3	4	5	6	7	8
1. Awareness								
2. Non-Reactive	0.27**							
3. Non-Judgement	0.47***	0.29**						
4. Re-Appraisal	0.11	0.28**	0.06					
5. Self-Efficacy	0.13*	0.36***	0.21**	0.28***				
6. Social Support	0.04	0.16*	0.11	0.31***	0.23**			
7. Positive Affect	0.22*	0.40***	0.28***	0.31***	0.37***	0.39***		
8. Negative Affect	-0.39***	-0.28***	-0.48***	-0.12**	-0.19**	-0.17***	-0.36***	
9. Meth Craving	-0.21**	-0.23**	-0.30***	-0.27***	-0.51***	-0.06	-0.29***	0.33***

Notes

***p value < .001

**p value < .05

* p value < .10.

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square residual (SRMR) values less than 0.08 [42]. We also computed the indirect pathways of the association of mindfulness with methamphetamine craving. The bias-corrected (BC) non-parametric bootstrap based on 5,000 bootstrap replications was used to compute the appropriate asymmetric 95% confidence intervals for the indirect pathways [43]. This strategy was used to ensure sufficient numbers of bootstrap replications at the tails of the distributions where the 2.5th and 97.5th percentiles are estimated. Statistical significance for indirect pathways was determined by the confidence interval excluding zero. In sensitivity analyses, we added frequency of methamphetamine use in the past three months, a proxy indicator of addiction severity, as a mediator in the model.

Results

Descriptive summary

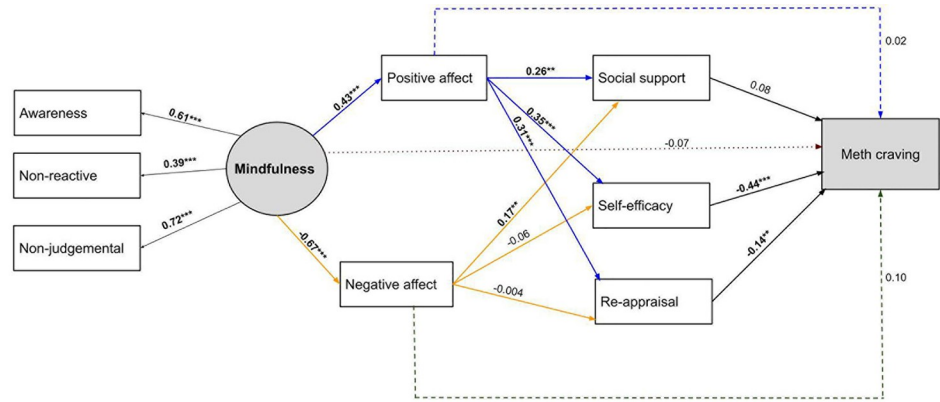
The sample consisted of 161 participants, 74% identifying as exclusively gay, 47% non-Hispanic/Latino white, and ranging in age from 22 to 69 years ($M = 43.8$, $SD = 8.9$). The average education among the participants was a college or trade school (46%) and the median income was between 5,000–11,999 dollars annually. The majority of participants reported using methamphetamine at least 3–6 times a week (41%) or daily (12%) during the past three months. The most prevalent mode of methamphetamine administration was smoking (77%), followed by injection use methamphetamine (52%), snorting (37%), anal insertions (26%), oral ingestion (23%) and snorting heated methamphetamine (17%). At baseline, 34% were receiving disability benefits and 32% were homeless in the last year.

Bivariate associations

In the bivariate analyses, greater methamphetamine craving was moderately associated with a higher ASI Drug composite score ($r = 0.56$; $p < 0.001$) and greater methamphetamine use in the past 30 days ($r = 0.47$; $p < .001$), but modestly associated with frequent methamphetamine use in the past three months ($r = 0.32$; $p < .001$). As shown in Table 1, results of the zero-order correlations demonstrated significant, inverse associations between methamphetamine craving with the awareness ($r = -0.21$, $p = 0.008$), non-reactive ($r = -0.23$, $p = 0.004$), and non-judgmental ($r = -0.30$, $p < 0.001$) mindfulness subscales, although the strength of these association was modest. Methamphetamine craving was positively associated with negative affect ($r = 0.33$, $p < 0.001$) and negatively associated with positive affect ($r = -0.29$, $p < 0.001$), and the strength of these relationships was modest. For the psychosocial mediators, methamphetamine craving was negatively (and modestly) associated with positive re-appraisal ($r = -0.27$, $p < 0.001$) and negatively (and moderately) associated with self-efficacy for managing methamphetamine triggers ($r = -0.51$, $p < 0.001$). However, methamphetamine craving was not significantly associated with social support for methamphetamine abstinence ($r = -0.01$, $p = 0.44$).

Direct pathways

As shown in Fig 2, the mindfulness-based, stress and coping model of methamphetamine craving had adequate fit to the data: $\chi^2(16) = 23.16$, $p = 0.110$; CFI = 0.974; RMSEA = 0.053; SRMR = 0.055. Mindfulness was significantly associated with higher positive affect ($B = 0.74$; 95% CI = 0.39, 1.1; $\beta = 0.43$; $p < 0.001$) and lower negative affect ($B = -0.99$; 95% CI = -1.34, -0.64; $\beta = -0.67$; $p < .001$). Positive affect, in turn, was significantly associated with greater social support for abstinence ($B = 0.25$, 95% CI = 0.09, 0.40; $\beta = 0.26$; $p = 0.001$), self-efficacy for managing methamphetamine triggers ($B = 8.65$, 95% CI = 4.86, 12.4; $\beta = 0.35$; $p < .001$)



Notes: ***p value < .001; **p value < .05; * p value < .10

Fig 2. Standardized path analysis coefficients for the model examining the relationship between dispositional mindfulness and methamphetamine craving.

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and positive re-appraisal coping (B = 0.04; 95% CI = 0.02, 0.06; β = 0.31; p < .001). Negative affect was positively associated with social support for abstinence (B = 0.18; 95% CI = 0.01, 0.36; β = 0.17; p = 0.041), but not significantly associated with self-efficacy for managing methamphetamine triggers and positive re-appraisal coping. Self-efficacy for managing methamphetamine triggers (B = -0.004; 95% CI = -0.01, -0.003; β = -0.44; p < 0.001) and positive re-appraisal coping (B = -0.23; 95% CI = -0.46, -0.001; β = -0.14; p = 0.049) were independently associated with lower methamphetamine craving.

Indirect pathways

As shown in **Table 2**, the total indirect pathway for the association of mindfulness with methamphetamine craving via positive affect was statistically significant (B = -0.04; 95% CI = -0.05, -0.01; β = -0.17). On the other hand, the total indirect pathway for the association of mindfulness with methamphetamine craving through negative affect was not statistically significant

Table 2. Indirect pathways of mindfulness on methamphetamine craving (N = 161).

	Coef ¹	95% CI [BC] ²
Specific indirect pathways		
Mindfulness -> Positive affect -> Social support -> Methamphetamine craving	0.003	-0.003–0.01
Mindfulness -> Negative affect -> Social support -> Methamphetamine craving	-0.003	-0.01–0.03
Mindfulness -> Positive affect -> Self efficacy -> Methamphetamine craving	-0.02**	-0.04 –-0.01
Mindfulness -> Negative affect -> Self efficacy -> Methamphetamine craving	-0.07	-0.02–0.01
Mindfulness -> Positive affect -> Re-appraisal -> Methamphetamine craving	-0.01	-0.15–0.001
Mindfulness -> Negative affect -> Re-appraisal -> Methamphetamine craving	-0.0001	-0.01–0.01
Total indirect pathways		
Mindfulness -> Positive affect -> Mediators -> Methamphetamine craving	-0.03**	-0.05 - -0.01
Mindfulness -> Negative affect -> Mediators -> Methamphetamine craving	-0.01	-0.03–0.01

Notes

*** p value < .001

** p value < .05

* p value < .10. Sensitivity analyses.

¹Unstandardized coefficients.

²95% confidence intervals derived from bootstrap analyses.

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($B = 0.01$; 95% CI = -0.03, 0.01; $\beta = 0.04$). Of the specific indirect pathways examined, only the pathway from mindfulness through positive affect and self-efficacy was statistically significant: ($B = -0.02$; 95% CI = -0.04, -0.01).

Supplemental analyses

As shown in the [S1 Fig](#) and [S1 Table](#) (appendices), adding frequency of methamphetamine use to the model did not change the estimated direct and indirect path coefficients, or improve the model fit parameters.

Discussion

Although there is increasing interest in mindfulness-based interventions to optimize the recovery of individuals living with SUD, relatively few studies have examined the mechanisms of action linking mindfulness to substance use craving. To our knowledge, this study is among the first study to examine theory-based affective, cognitive, and social processes linking mindfulness and methamphetamine craving. Consistent with Revised Stress and Coping Theory, greater positive affect emerged as a unique pathway for lower methamphetamine craving through its association with appraisal processes such as self-efficacy and positive re-appraisal coping. Although greater mindfulness was associated with lower negative affect, there was no evidence that negative affect was directly or indirectly associated with lower methamphetamine craving in the multivariate model. Findings highlight the potential benefits of leveraging mindfulness-based approaches to cultivate positive affect to build the capacity of individuals to effectively manage the chronic stressor of methamphetamine craving [15, 44].

The vast majority of prior research has focused on examining the relationship between negative affect and craving, which is consistent with negative reinforcement models of addiction. Previous studies have also shown that dispositional mindfulness is associated with reduced substance use craving [9], especially in the presence of negative affective states [10, 11]. However, the theory-based psychosocial processes mediating the relationship between mindfulness and decreased methamphetamine craving have not been adequately examined [29, 30, 45]. Unlike prior studies [10, 11], negative affect and abstinence-specific social support did not emerge as significant psychosocial mediators [44]. Our study differs in two meaningful ways that could account for these notable differences. First, we included both positive and negative affect in the model, while prior studies have focused exclusively on negative affect. Second, approach to modeling mindfulness as a trait and affect as state also differs from previous studies that have modeled mindfulness as mediating variable [11]. It may be that co-occurrence of positive and negative affect has important consequences for methamphetamine craving. This underscores the importance of differentiating the potentially distinct pathways whereby mindfulness-associated decreases in positive and negative affect could assist individuals with managing craving. As our findings are based on cross-sectional data, there is a need for future research to examine the potentially bidirectional associations among mindfulness, positive and negative affect, and methamphetamine craving in longitudinal studies.

Lastly, we also found that positive affect was independently associated with self-efficacy for managing methamphetamine triggers, social support for abstinence, and positive re-appraisal coping. These findings are consistent with the Revised Stress and Coping Theory and prior research that underscores the unique adaptive significance of positive affect. They are also consistent with results of previous studies indicating the positive affect increases adherence to HIV treatment and HIV viral suppression among stimulant users [46, 47]. Positive affect is thought to sensitize individuals to rewards within their environment and facilitate attainment of desirable outcomes [48]. Positive affect also shapes appraisal processes and individuals who

experience positive emotions are more likely to adopt a positive attitude towards the self or others when making evaluative judgments [49, 50]. In addition, positive affect may increase the frequency and intensity of positively valenced cognitions [51] by biasing attention and memory recall toward positive information, promoting positive interpretations of ambiguous situations [32, 49, 52–54], and assigning positive value to objects or thoughts during the cognitive appraisal process [49]. As such, positive affect may be central to counteracting the deleterious effects of negative affect on the cognitive processes associated with craving. Further clinical research testing the efficacy of mindfulness-based, positive affect interventions for supporting recovery from a SUD and optimizing HIV treatment outcomes will assist with elucidating these mechanisms.

Our findings should be interpreted within the limitations of this study. First, our analyses are based on cross-sectional data that could not adequately model the potentially bi-directional associations between psychosocial factors and methamphetamine craving. Feedback loops between negative affect, positive affect, social support, self-efficacy, re-appraisal and methamphetamine craving could affect the directionality and statistical significance of our findings. Additionally, the data were collected using retrospective self-reports which are easily affected by recall bias. Therefore, there is a need for longitudinal analyses to further our understanding of the mechanisms whereby mindfulness could assist with managing craving and reducing substance use. Previous studies have found that the influence of craving on substance use varies with time, and the proximal effects of craving and related moderating factors fluctuates rapidly [55, 56]. Moreover, there is evidence to suggest that single point assessments may not provide an accurate assessment of mindfulness and existing self-report measures cannot accurately capture the central quality of mindfulness [57]. Research methodologies such as the ecological momentary assessment [55, 58] that provide repeated real-time assessments of participants behaviors while in their natural environments could remedy the methodological challenges associated with measuring complex time varying constructs such as craving and mindfulness, to better inform our understanding of the causal relationships between craving, substance use and associated moderating variables. Future longitudinal studies should also examine whether key demographic factors such as gender, different classes of substance use (e.g., opioids), substance use disorder severity, or health status modify the theory-based pathways whereby mindfulness is associated with lower craving. Taken together, our findings underscore the need to examine this model in other substance using populations such as opioid users and with more diverse groups with respect to gender and sexual orientation. Second, participants were recruited in San Francisco, a well-resourced setting with extensive services for HIV-positive methamphetamine-using sexual minority men [59]. Further research is needed to replicate these findings in more representative populations of methamphetamine users.

Despite these limitations, our findings make an important contribution to the burgeoning literature on mindfulness and mindfulness-based interventions for individuals living with a SUD. First, the results provide important insights regarding the theory-based pathways that could link mindfulness with lower methamphetamine craving. These findings could be leveraged to enhance the therapeutic effects of mindfulness-based interventions for individuals living with SUD. Second, the unique adaptive significance of positive affect for reduced methamphetamine craving is consistent with Revised Stress and Coping Theory. Findings will catalyze further clinical research to examine the potential benefits of explicitly leveraging mindfulness-based approaches to cultivate positive affect in people living with SUD.

Supporting information

S1 Fig. Standardized path analysis coefficients for the model examining the relationship between mindfulness and methamphetamine craving, with addition of frequency of methamphetamine use.

(TIFF)

S1 Table. Indirect pathways of mindfulness on methamphetamine craving, with addition of frequency of methamphetamine use (N = 161).

(DOCX)

S1 File.

(DOCX)

S2 File.

(DOCX)

S1 Dataset.

(ZIP)

Author Contributions

Conceptualization: Massy Mutumba, Torsten B. Neilands, Adam W. Carrico.

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References

1. Grant BF, Saha TD, Ruan WJ, Goldstein RB, Chou SP, Jung J, et al. Epidemiology of DSM-5 drug use disorder: Results from the National Epidemiologic Survey on Alcohol and Related Conditions–III. *JAMA psychiatry*. 2016; 73(1):39–47. <https://doi.org/10.1001/jamapsychiatry.2015.2132> PMID: 26580136
2. Lipari RN, Van Horn SL. Trends in substance use disorders among adults aged 18 or older. Rockville, MD: Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration, 2017.
3. Substance Abuse and Mental Health Services Administration (SAMHSA). Key substance use and mental health indicators in the United States: Results from the 2016 National Survey on Drug Use and Health (HHS Publication No. SMA 17–5044, NSDUH Series H-52). Rockville, MD: Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration, 2017.
4. Colfax G, Santos GM, Chu P, Vittinghoff E, Pluddemann A, Kumar S, et al. Amphetamine-group substances and HIV. *Lancet*. 2010; 376(9739):458–74. Epub 2010/07/24. [https://doi.org/10.1016/S0140-6736\(10\)60753-2](https://doi.org/10.1016/S0140-6736(10)60753-2) PMID: 20650520.
5. Carrico AW, Zepf R, Meanley S, Batchelder A, Stall R. Critical Review: When the Party is Over: A Systematic Review of Behavioral Interventions for Substance-Using Men Who Have Sex with Men. *J Acquir*

- Immune Defic Syndr. 2016; 73(3):299–306. Epub 2016/06/04. <https://doi.org/10.1097/QAI.0000000000001102> PMID: 27258233; PubMed Central PMCID: PMC5065362.
6. Brecht M-L, Herbeck D. Time to relapse following treatment for methamphetamine use: a long-term perspective on patterns and predictors. *Drug and alcohol dependence*. 2014; 139:18–25. <https://doi.org/10.1016/j.drugalcdep.2014.02.702> PMID: 24685563
 7. McLellan AT, Lewis DC, O'brien CP, Kleber HD. Drug dependence, a chronic medical illness: implications for treatment, insurance, and outcomes evaluation. *Jama*. 2000; 284(13):1689–95. <https://doi.org/10.1001/jama.284.13.1689> PMID: 11015800
 8. Kabat-Zinn J. Mindfulness-based interventions in context: past, present, and future. *Clinical psychology: Science and practice*. 2003; 10(2):144–56.
 9. Garland EL, Boettiger CA, Gaylord S, Chanon VW, Howard MO. Mindfulness is inversely associated with alcohol attentional bias among recovering alcohol-dependent adults. *Cognitive therapy and research*. 2012; 36(5):441–50. <https://doi.org/10.1007/s10608-011-9378-7> PMID: 23280000
 10. Witkiewitz K, Bowen S. Depression, craving, and substance use following a randomized trial of mindfulness-based relapse prevention. *Journal of consulting and clinical psychology*. 2010; 78(3):362. <https://doi.org/10.1037/a0019172> PMID: 20515211
 11. Enkema MC, Hallgren KA, Neilson EC, Bowen S, Bird ER, Larimer ME. Disrupting the path to craving: Acting without awareness mediates the link between negative affect and craving. *Psychology of Addictive Behaviors*. 2020. <https://doi.org/10.1037/adb0000565> PMID: 32134279
 12. Bowen S, Chawla N, Collins SE, Witkiewitz K, Hsu S, Grow J, et al. Mindfulness-based relapse prevention for substance use disorders: a pilot efficacy trial. *Subst Abus*. 2009; 30(4):295–305. Epub 2009/11/12. <https://doi.org/10.1080/08897070903250084> PMID: 19904665; PubMed Central PMCID: PMC3280682.
 13. Bowen S, Witkiewitz K, Clifasefi SL, Grow J, Chawla N, Hsu SH, et al. Relative efficacy of mindfulness-based relapse prevention, standard relapse prevention, and treatment as usual for substance use disorders: a randomized clinical trial. *JAMA Psychiatry*. 2014; 71(5):547–56. Epub 2014/03/22. <https://doi.org/10.1001/jamapsychiatry.2013.4546> PMID: 24647726; PubMed Central PMCID: PMC4489711.
 14. Witkiewitz K, Bowen S, Douglas H, Hsu SH. Mindfulness-based relapse prevention for substance craving. *Addict Behav*. 2013; 38(2):1563–71. Epub 2012/04/27. <https://doi.org/10.1016/j.addbeh.2012.04.001> PMID: 22534451; PubMed Central PMCID: PMC3408809.
 15. Carrico AW, Gomez W, Jain J, Shoptaw S, Discepola MV, Olem D, et al. Randomized controlled trial of a positive affect intervention for methamphetamine users. *Drug Alcohol Depend*. 2018; 192:8–15. Epub 2018/09/09. <https://doi.org/10.1016/j.drugalcdep.2018.07.029> PMID: 30195243.
 16. Kozlowski LT, Wilkinson DA. Use and misuse of the concept of craving by alcohol, tobacco, and drug researchers. *British journal of addiction*. 1987; 82(1):31–6. <https://doi.org/10.1111/j.1360-0443.1987.tb01430.x> PMID: 3470042
 17. Carter BL, Tiffany ST. Meta-analysis of cue-reactivity in addiction research. *Addiction*. 1999; 94(3):327–40. PMID: 10605857
 18. Koob GF, Volkow ND. Neurobiology of addiction: a neurocircuitry analysis. *The Lancet Psychiatry*. 2016; 3(8):760–73. [https://doi.org/10.1016/S2215-0366\(16\)00104-8](https://doi.org/10.1016/S2215-0366(16)00104-8) PMID: 27475769
 19. Naqvi NH, Gaznick N, Tranel D, Bechara A. The insula: a critical neural substrate for craving and drug seeking under conflict and risk. *Annals of the New York Academy of Sciences*. 2014; 1316(1):53–70. <https://doi.org/10.1111/nyas.12415> PMID: 24690001
 20. American Psychiatric Association (APA). *Diagnostic and Statistical Manual of Mental Disorders (5th edition)* American Psychiatric Association. Arlington, VA: merican Psychiatric Association, 2013.
 21. Baker TB, Piper ME, McCarthy DE, Majeskie MR, Fiore MC. Addiction motivation reformulated: an affective processing model of negative reinforcement. *Psychological review*. 2004; 111(1):33–51. Epub 2004/02/06. <https://doi.org/10.1037/0033-295X.111.1.33> PMID: 14756584.
 22. Carter BL, Lam CY, Robinson JD, Paris MM, Waters AJ, Wetter DW, et al. Real-time craving and mood assessments before and after smoking. *Nicotine & tobacco research: official journal of the Society for Research on Nicotine and Tobacco*. 2008; 10(7):1165–9. Epub 2008/07/17. <https://doi.org/10.1080/14622200802163084> PMID: 18629726; PubMed Central PMCID: PMC4346280.
 23. Shiffman S, Waters AJ. Negative affect and smoking lapses: a prospective analysis. *Journal of consulting and clinical psychology*. 2004; 72(2):192. <https://doi.org/10.1037/0022-006X.72.2.192> PMID: 15065954
 24. Roos CR, Bowen S, Witkiewitz K. Baseline patterns of substance use disorder severity and depression and anxiety symptoms moderate the efficacy of mindfulness-based relapse prevention. *Journal of consulting and clinical psychology*. 2017; 85(11):1041–51. Epub 2017/10/31. <https://doi.org/10.1037/ccp0000249> PMID: 29083220; PubMed Central PMCID: PMC5679292.

25. Folkman S, Moskowitz JT. Positive affect and the other side of coping. *Am Psychol*. 2000; 55(6):647–54. Epub 2000/07/13. <https://doi.org/10.1037//0003-066x.55.6.647> PMID: 10892207.
26. Tice DM, Baumeister RF, Shmueli D, Muraven M. Restoring the self: Positive affect helps improve self-regulation following ego depletion. *Journal of Experimental Social Psychology* 2007; 43(3):379–84.
27. Carrico AW, Woods WJ, Siever MD, Discepola MV, Dilworth SE, Neilands TB, et al. Positive affect and processes of recovery among treatment-seeking methamphetamine users. *Drug Alcohol Depend*. 2013; 132(3):624–9. Epub 2013/05/21. <https://doi.org/10.1016/j.drugalcdep.2013.04.018> PMID: 23684632; PubMed Central PMCID: PMC4302392.
28. Hanley AW, Garland EL. Dispositional mindfulness co-varies with self-reported positive reappraisal. *Personality and Individual Differences*. 2014; 66:146–52. <https://doi.org/10.1016/j.paid.2014.03.014> PMID: 24904191
29. Garland EL, Roberts-Lewis A, Kelley K, Tronnier C, Hanley A. Cognitive and affective mechanisms linking trait mindfulness to craving among individuals in addiction recovery. *Substance use & misuse*. 2014; 49(5):525–35. <https://doi.org/10.3109/10826084.2014.850309> PMID: 24611848
30. Jones SM, Hansen W. The impact of mindfulness on supportive communication skills: Three exploratory studies. *Mindfulness*. 2015; 6(5):1115–28.
31. Chang VY, Palesh O, Caldwell R, Glasgow N, Abramson M, Luskin F, et al. The effects of a mindfulness-based stress reduction program on stress, mindfulness self-efficacy, and positive states of mind. *Stress and Health: Journal of the International Society for the Investigation of Stress*. 2004; 20(3):141–7.
32. Garland EL, Geschwind N, Peeters F, Wichers M. Mindfulness training promotes upward spirals of positive affect and cognition: multilevel and autoregressive latent trajectory modeling analyses. *Frontiers in psychology*. 2015; 6:15. <https://doi.org/10.3389/fpsyg.2015.00015> PMID: 25698988
33. Geschwind N, Peeters F, Drukker M, van Os J, Wichers M. Mindfulness training increases momentary positive emotions and reward experience in adults vulnerable to depression: a randomized controlled trial. *Journal of consulting and clinical psychology*. 2011; 79(5):618. <https://doi.org/10.1037/a0024595> PMID: 21767001
34. Kok BE, Fredrickson BL. Upward spirals of the heart: Autonomic flexibility, as indexed by vagal tone, reciprocally and prospectively predicts positive emotions and social connectedness. *Biological psychology*. 2010; 85(3):432–6. <https://doi.org/10.1016/j.biopsycho.2010.09.005> PMID: 20851735
35. Garland EL, Gaylord SA, Fredrickson BL. Positive reappraisal mediates the stress-reductive effects of mindfulness: An upward spiral process. *Mindfulness*. 2011; 2(1):59–67.
36. Fredrickson BL, Tugade MM, Waugh CE, Larkin GR. What good are positive emotions in crisis? A prospective study of resilience and emotions following the terrorist attacks on the United States on September 11th, 2001. *Journal of personality and social psychology*. 2003; 84(2):365. <https://doi.org/10.1037//0022-3514.84.2.365> PMID: 12585810
37. Carrico AW, Gómez W, Jain J, Shoptaw S, Discepola MV, Olem D, et al. Randomized controlled trial of a positive affect intervention for methamphetamine users. *Drug and alcohol dependence*. 2018. <https://doi.org/10.1016/j.drugalcdep.2018.07.029> PMID: 30195243
38. Carrico AW, Jain J, Discepola MV, Olem D, Andrews R, Woods WJ, et al. A community-engaged randomized controlled trial of an integrative intervention with HIV-positive, methamphetamine-using men who have sex with men. *BMC Public Health*. 2016; 16:673. Epub 2016/08/01. <https://doi.org/10.1186/s12889-016-3325-1> PMID: 27476110; PubMed Central PMCID: PMC4967339.
39. Izard CE. *Human emotions*: Springer Science & Business Media; 2013.
40. Fredrickson BL. Positive emotions broaden and build. *Advances in experimental social psychology*. 47: Elsevier; 2013. p. 1–53.
41. Prochaska JO, Velicer WF, Rossi JS, Goldstein MG, Marcus BH, Rakowski W, et al. Stages of change and decisional balance for 12 problem behaviors. *Health psychology*. 1994; 13(1):39. <https://doi.org/10.1037//0278-6133.13.1.39> PMID: 8168470
42. Hu L-t, Bentler PM. Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychological methods*. 1998; 3(4):424.
43. MacKinnon DP, Lockwood CM, Williams J. Confidence Limits for the Indirect Effect: Distribution of the Product and Resampling Methods. *Multivariate Behavioral Research*. 2004; 39(1):99–128. https://doi.org/10.1207/s15327906mbr3901_4 PMID: 20157642.
44. Carrico AW, Woods WJ, Siever MD, Discepola MV, Dilworth SE, Neilands TB, et al. Positive affect and processes of recovery among treatment-seeking methamphetamine users. *Drug and alcohol dependence*. 2013; 132(3):624–9. <https://doi.org/10.1016/j.drugalcdep.2013.04.018> PMID: 23684632

45. Hölzel BK, Lazar SW, Gard T, Schuman-Olivier Z, Vago DR, Ott U. How does mindfulness meditation work? Proposing mechanisms of action from a conceptual and neural perspective. *Perspectives on psychological science*. 2011; 6(6):537–59. <https://doi.org/10.1177/1745691611419671> PMID: 26168376
46. Carrico AW, Johnson MO, Colfax GN, Moskowitz JT. Affective correlates of stimulant use and adherence to anti-retroviral therapy among HIV-positive methamphetamine users. *AIDS and Behavior*. 2010; 14(4):769–77. <https://doi.org/10.1007/s10461-008-9513-y> PMID: 19125321
47. Carrico AW, Johnson MO, Moskowitz JT, Neilands TB, Morin SF, Charlebois ED, et al. Affect regulation, stimulant use, and viral load among HIV-positive persons on anti-retroviral therapy. *Psychosomatic medicine*. 2007; 69(8):785–92. <https://doi.org/10.1097/PSY.0b013e318157b142> PMID: 17942835
48. Tamir M, Robinson MD. The happy spotlight: Positive mood and selective attention to rewarding information. *Personality and Social Psychology Bulletin*. 2007; 33(8):1124–36. <https://doi.org/10.1177/0146167207301030> PMID: 17578934
49. Clore GL, Huntsinger JR. How emotions inform judgment and regulate thought. *Trends in Cognitive Sciences*. 2007; 11(9):393–9. <https://doi.org/10.1016/j.tics.2007.08.005> PMID: 17698405
50. Clore GL, Palmer J. Affective guidance of intelligent agents: How emotion controls cognition. *Cognitive systems research*. 2009; 10(1):21–30. <https://doi.org/10.1016/j.cogsys.2008.03.002> PMID: 19255620
51. Macleod AK, Moore R. Positive thinking revisited: Positive cognitions, well-being and mental health. *Clinical Psychology & Psychotherapy: An International Journal of Theory & Practice*. 2000; 7(1):1–10.
52. Allard ES, Wadlinger HA, Isaacowitz DM. Positive gaze preferences in older adults: assessing the role of cognitive effort with pupil dilation. *Aging, Neuropsychology, and Cognition*. 2010; 17(3):296–311. <https://doi.org/10.1080/13825580903265681> PMID: 19890752
53. Roberts-Wolfe D, Sacchet M, Hastings E, Roth H, Britton W. Mindfulness training alters emotional memory recall compared to active controls: support for an emotional information processing model of mindfulness. *Frontiers in human neuroscience*. 2012; 6:15. <https://doi.org/10.3389/fnhum.2012.00015> PMID: 22347856
54. Mathews A. Effects of modifying the interpretation of emotional ambiguity. *Journal of Cognitive Psychology*. 2012; 24(1):92–105.
55. Serre F, Fatseas M, Swendsen J, Auriacombe M. Ecological momentary assessment in the investigation of craving and substance use in daily life: A systematic review. *Drug and alcohol dependence*. 2015; 148:1–20. <https://doi.org/10.1016/j.drugalcdep.2014.12.024> PMID: 25637078
56. Wray JM, Gass JC, Tiffany ST. A systematic review of the relationships between craving and smoking cessation. *Nicotine & Tobacco Research*. 2013; 15(7):1167–82.
57. Visted E, Vøllestad J, Nielsen MB, Nielsen GH. The Impact of Group-Based Mindfulness Training on Self-Reported Mindfulness: a Systematic Review and Meta-analysis. *Mindfulness*. 2015; 6(3):501–22. <https://doi.org/10.3340/jkns.2015.57.3.215> PMID: 25810864
58. Stone AA, Shiffman S. Ecological momentary assessment (EMA) in behavioral medicine. *Annals of Behavioral Medicine*. 1994.
59. Carrico AW, Flentje A, Gruber VA, Woods WJ, Discepola MV, Dilworth SE, et al. Community-based harm reduction substance abuse treatment with methamphetamine-using men who have sex with men. *Journal of urban health: bulletin of the New York Academy of Medicine*. 2014; 91(3):555–67. Epub 2014/04/20. <https://doi.org/10.1007/s11524-014-9870-y> PubMed Central PMCID: PMC4074324. PMID: 24744105