Intensive Longitudinal Assessment of Cannabis Use and Related Experiences

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A dissertation

Submitted in partial fulfillment of the

Requirements for the degree of

Doctor of Philosophy

University of Washington

2020

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Program Authorized to Offer Degree:

Psychology

University of Washington

Abstract Page

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Cannabis misuse is a behavior associated with substantial negative life outcomes and is a growing public health concern. Epidemiology indicates cannabis misuse peaks during young adulthood, which has been identified as an important developmental period for intervention. Many young adults use cannabis to cope with unpleasant momentary experiences, and those who do frequently experience more substantial negative cannabis-related and mental health consequences. Based on behavioral theory, and the allostatic model (or self-medication hypothesis), recently developed effective treatments for substance misuse have focused on improving craving management by adjusting peoples' avoidant relationship with unpleasant momentary experiences such as craving and negative affect. Despite demonstrated effectiveness, there is limited empirical evidence to support craving management as a hypothesized mechanism of action for mindfulness-based treatments. The present dissertation project addresses this gap in the literature with a systematic review and two empirical research studies. The review compiles existing scientific research on the association between mindfulness, a primary hypothesized moderator of craving, and psychiatric outcomes. The first study investigates the longitudinal association between craving and use with single-time point assessment, and intensive

longitudinal assessment. The second study explores dispositional and momentary factors as hypothesized moderators of the association between craving and use. Results from the present dissertation project carry significant import for future trials of treatments targeting craving and craving management. Findings indicate that intensive longitudinal assessment of craving may produce more valid results than single time-point assessment alone, and dispositional non-judgment of experience may moderate the association between momentary craving and subsequent use for problematic cannabis users.

Acknowledgments:

This dissertation is the product of the countless hours of attention, care, and guidance provided by my profoundly generous and patient team of advisors, instructors, and consultants. This program of research began as a seed planted by Dr. Sarah Bowen during a conversation before I had begun training as a graduate student. Dr. Mary Larimer's mentorship and guidance helped that seed to germinate and grow, through advisement on the theoretical basis, grantsmanship, and practical application of research design and methods. Dr. Kevin Hallgren helped keep the growing plant healthy by providing essential statistical instruction and consultation as I worked to faithfully implement the methods of analysis used in this dissertation.

While these direct contributions have been fundamental to the current dissertation, the indirect contributions made by the people in my life are core elements of this work that deserve acknowledgment. They have provided the soil of a rich life that any seed needs to become something more.

I would like to thank my family for helping me to feel loved and safe in so many ways for so many years, and for teaching me to love learning. Kathy, for showing me devotion to kindness and justice in the world, and for always seeing the best in me. Neil, for teaching me to love the questions as much as the answers, and for letting me take the lead with patience. Mark, for gently pushing me to do be ambitious.

I would also like to thank my fiancé, Liz Bird. I admire you in so many ways, as a professional, as a friend, and as a partner. I'm filled with gratitude to have shared these years with you, and I know that your support has made me a better scientist and person. If a rich life provides soil for growth, then you have been the fertilizer.

The clinical program here at the University of Washington has also been a home to me for these many years. I want to thank Dr. Ron Smith for your diligence as the Director of Clinical Training, Dr. Corey Fagan for your clinical mentorship and professional support, Dr. Kevin King for your high research standards and crucial statistical instruction, particularly regarding multilevel modeling. The community of students has also been a fundamental support for me, and I'm proud to call each of you my colleagues.

Finally, I want to thank the institutional groups that have believed in me enough to support me financially. The systematic review was supported by a T32 Institutional National Research Service Award from the National Institute of Alcohol Abuse and Alcoholism (NIAAA), an arm of the National Institutes of Health (NIH). The 'Craving over time' and 'Surfing urges' studies were supported by funding from the Ruth L. Kirchstein National Research Service Award (Grant Number: F31DA042503) from the National Institute on Drug Abuse (NIDA) of the NIH, and the Alcohol and Drug Abuse Institute (ADAI) of the University of Washington.

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Contents

I. General introduction

Cannabis misuse during young adulthood is prevalent in the United States (Butterworth, Slade, & Degenhardt, 2014; Haberstick et al., 2014). Lifetime prevalence estimates indicate 8.3% of Americans will meet criteria for cannabis use disorder during their life (Haberstick et al., 2014). The peak onset for cannabis use disorders occurs in young adulthood (Haberstick et al., 2014), with average age of onset estimated to be between 18 and 19 years (Farmer et al., 2015). Over the past decade, there has been a substantial rise in daily/near-daily marijuana use in the United States (Caulkins, Kilmer, Reuter, & Midgette, 2015). The National Epidemiological Survey on Alcohol and Related Conditions (NESARC) indicates past-year prevalence of cannabis use more than doubled among 18-29 year olds over the last decade, from 10.5% in 2001 to 21.2% in 2013 (Hasin et al., 2015). Cannabis use disorder prevalence has also nearly doubled among 18-29 year olds, increasing from 4.4% in 2001 to 7.5% in 2013 (Hasin et al., 2015).

Cannabis misuse during young adulthood has been associated with substantial negative short-term and long-term consequences (Farmer et al., 2015). Among college students, any cannabis use is associated with anxiety disorders and substance use disorder, and frequent cannabis use (10 or more days in the past month) is associated with major depressive disorder, alexithymia, frontal lobe dysfunction, and impulsivity (Keith, Hart, McNeil, Silver, & Goodwin, 2015; Lyvers, Jamieson, & Thorberg, 2013). Cannabis use has also been linked to heavy episodic drinking and alcohol-related negative consequences including risky sexual behavior, legal problems, impaired driving, property damage and vandalism, physical illness, unintentional injury and death, interpersonal problems and substance use disorders (S. A. Brown et al., 2009; Hingson, Heeren, Winter, & Wechsler, 2005; Hingson & Zha, 2009; Keith et al., 2015; Molnar, Busseri, Perrier, & Sadava, 2009). Among young adults in college, cannabis use has been

positively associated with skipping class, and poor postsecondary academic achievement, even after controlling for demographic and psychological risk factors (Arria, Caldeira, Bugbee, Vincent, & O'Grady, 2015). As students use more cannabis, they experience more negative academic and mental health outcomes (Arria et al., 2015; Keith et al., 2015; Phillips, Phillips, Lalonde, & Tormohlen, 2015). Additionally, cannabis misuse among college students has been temporally linked to reduced academic motivation and performance, such that increases in use correspond with decreased academic motivation (Phillips et al., 2015). The recent increase in cannabis initiation, frequency of use, and cannabis use disorders among young adults is a rapidly growing public health concern.

Craving and models of problematic use

Craving for cannabis is a frequently reported symptom of cannabis use disorders (Heishman, Singleton, & Liguori, 2001), and is not limited to the occurrence of withdrawal (APA & DSM-5 Task Force., 2013). A growing body of literature has demonstrated that craving is associated with an increased risk for cannabis use among young adults, and may help explain the development and maintenance of cannabis use disorders (Buckner et al., 2015; Phillips et al., 2015). Craving is typically considered to be a psychological phenomenon comprised of cognitive and affective elements that are linked to a focus on pleasure or the relief of discomfort (Kavanagh et al., 2013). Craving is consistently included as an important consideration in models of the development and maintenance of addictive behaviors such as cannabis use disorders (Witkiewitz, Lustyk, & Bowen, 2013; Witkiewitz & Marlatt, 2007).

Craving and craving management as intervention targets

Interventions that focus on reducing craving or changing the consequences of craving have shown remarkable promise (Bowen et al., 2014). Treatments for substance use disorders

that have applied principles of cognitive and behavioral therapies, such as Relapse Prevention (RP: Marlatt & George, 1984) Cognitive Behavioral Therapy for Substance Use Disorders (CBT-SUD: McHugh, Hearon, & Otto, 2010), have substantial bodies of literature demonstrating effectiveness. These treatments focus on managing cravings and urges to use, as well as increasing self-efficacy and enhancing motivation for change.

Efforts to enhance the effectiveness of treatments by reducing the rates of relapse and increasing the duration of recovery have led to the incorporation of additional training in mindfulness and craving management skills. For example, Mindfulness Based Relapse Prevention (MBRP: Bowen et al., 2009), which focuses on development of awareness and acceptance of craving and other unpleasant experiences, has been shown to be more effective as aftercare for adults recovering from substance use disorders than cognitive behavioral therapies alone (Bowen et al., 2014). Other mindfulness-based interventions have demonstrated improvements in effectiveness in other randomized clinical trials, as well (Garland & Black, 2014; de Dios et al., 2012). While effectiveness trials have been promising, investigations into the hypothesized mechanisms of action for mindfulness-based interventions have been stymied by research design limitations related to the assessment of mindfulness (Witkiewitz et al., 2014), and a lack of ecologically valid assessments of craving and subsequent use behavior (Enkema & Bowen, 2017).

Intensive longitudinal assessment

Intensive longitudinal assessment, often called ecological momentary assessment (EMA) is a method for improving validity in measurement of phenomena that vary over time. Craving is an experience that is highly variable with time (Buckner et al., 2015; Shiffman et al., 2002). EMA is needed to evaluate factors that may alter craving directly, or influence the relationship

between craving and cannabis use, particularly during young adulthood. By producing a more ecologically valid and temporally sensitive measurement of craving, EMA may facilitate a more thorough and accurate examination of hypothesized moderators of the association between craving and use.

Current research

The current program of research began with a systematic review of the intensive longitudinal assessment literature on the association between mindfulness and psychiatric outcomes. Results informed research design and data collection in the subsequent research studies, which used established craving-related measures and intensive longitudinal assessment with a frequent cannabis using young adult sample interested in reducing their use. Data were used to investigate potential targets of intervention to prevent and treat cannabis use disorders. Procedurally, the first phase of the research program included baseline assessment of craving, as well as dispositional factors related to the relationship between craving and use. The second phase included a two-week follow-up period of ecological momentary assessment to examine the relationship between momentary craving and subsequent use at the within-person level. Data were used to examine the role of craving management constructs, such as coping and mindfulness, as moderators of the relationship between craving and use. Results from this program of research aim to clarify the influence of psychological processes on the association between craving and subsequent cannabis use. The 'Craving over time' study examined the associations between baseline, trait level measurement of craving and momentary reports of use, as well as momentary state level measurement of craving and subsequent use. The 'Surfing urges' study investigated the influence of craving management constructs on the association between craving and subsequent use. Results from the current studies revealed specific targets

for future interventions to reduce problematic use and enhance treatment outcomes, which may prevent the development and chronicity of disordered use.

II. Associations between mindfulness and psychiatric outcomes: A systematic review of intensive longitudinal research

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ABSTRACT

During the last several decades, psychological science has taken up investigations of the effectiveness of mindfulness-based interventions and mechanisms through which people benefit from mindfulness. Reliable and valid psychometric tools are essential components of psychological science, and efforts have been made to produce tools for the accurate measurement of mindfulness as a construct. Although somewhat mixed, results have been mostly promising. However, trait measurement methods, as opposed to intensive longitudinal methods, may not adequately assess the construct of mindfulness in a way that allows for hypothesized mechanisms to be tested. The current review provides a systematic review of published, peer-reviewed studies that used intensive longitudinal methods to investigate the effects of mindfulness on psychiatric outcomes. Articles were included in the systematic review if they included mindfulness measures and/or mindfulness interventions in the study design and utilized intensive longitudinal methods to assess psychiatric outcomes. Results consistently demonstrate a negative association between mindfulness and psychiatric symptoms. Findings also indicate that intensive longitudinal methods may increase sensitivity and validity when measuring psychiatric outcomes, and may be a more appropriate method for investigating hypothesized mechanisms of action in mindfulness-based interventions.

Keywords: Mindfulness; Psychiatric Outcomes; Systematic Review; Intensive Longitudinal Assessment

INTRODUCTION

Mindfulness in psychology

Over the past several decades, practices for intentionally turning kind attention toward current experience have received growing recognition as useful clinical interventions aimed at improving mental health (Creswell, 2017). Within the body of scientific literature produced by the field of psychology, investigators typically refer to these practices as mindfulness practice, mindfulness training, or mindfulness meditation (Creswell, 2017; Li, Howard, Garland, McGovern, & Lazar, 2017; Chiesa & Serretti, 2014, 2011). Mindfulness practices have provided a foundation for psychological treatments targeting chronic pain and stress (Mindfulness Based Stress Reduction; Kabat-Zinn, 1982, 2003), durable patterns of behavior and emotion dysregulation among people with borderline personality disorder (Dialectical Behavior Therapy; Linehan et al., 2015), anxiety disorders (Acceptance and Commitment Therapy; Hayes & Wilson, 1994), mood disorders (Mindfulness Based Cognitive Therapy; Teasdale et al., 2000), as well as substance use disorders (Mindfulness Based Relapse Prevention; Bowen et al., 2014). Research has demonstrated the integration of mindfulness practices into treatment has been beneficial for treatment seekers experiencing various forms of psychopathology (Creswell, 2017). Previous investigations found reliably comparable effect sizes by comparison with other empirically supported treatments, as well as improved durability of effects compared with controls and treatment as usual comparison conditions (Creswell, 2017; Chiesa & Serretti, 2014, 2011).

Recently, researchers have begun to investigate hypothesized mechanisms of action by which mindfulness training produces treatment effects and lengthens the maintenance of improvement (Creswell, 2017; Witkiewitz et al., 2014). However, results have been mixed

regarding the role of mindfulness in the risk, development, and maintenance of psychopathology, as well as the mechanisms through which participants experience benefits from mindfulness-based interventions (Creswell, 2017). For example, two studies evaluating the association between mindfulness and heavy drinking found a positive association in a non-treatment seeking college age sample (Leigh, Bowen, & Marlatt, 2005; Leigh & Neighbors, 2009). Although substantial research has utilized quantitative self-report measures of mindfulness and treatment outcomes, core hypothesized mechanisms of action remain largely untested, or have reported inconsistent findings (Creswell, 2017; Bowen & Enkema, 2014). Validity of the measurement of mindfulness has also been called into question by a recent meta-analysis that reported 37 of 72 trials of mindfulness based interventions failed to show an increase in trait mindfulness following training (Visted, Vøllestad, Nielsen, & Nielsen, 2015). Mixed results may be due to methodological limitations, such as reliance on assessment using retrospective self-report surveys that may not carry sufficient validity or precision to adequately assess mechanisms, an argument made early on by mindfulness psychometricians (Brown & Ryan, 2003).

Ecological momentary assessment (EMA) and experience sampling methods (ESM) are intensive longitudinal assessment methods that increase validity when measuring latent constructs that change over time (Shiffman, Stone, & Hufford, 2008). Intensive longitudinal designs facilitate data collection on cognitive, affective, and physiological phenomena, as well as coping behaviors, which may occur only briefly, and thus be difficult to capture using retrospective self-report methods (Shiffman et al., 2008). EMA and ESM minimize recall bias, maximize ecological validity, and track how behavior and experience change over time and context. During EMA assessment periods, the length of time that people are reporting on is typically quite short, a matter of hours at most, as compared to weeks or months.

The current review provides a brief description of mindfulness and psychiatric outcome assessment using retrospective trait measurement, as well as the relative strengths of intensive longitudinal assessment. A systematic review of the literature is then presented, evaluating research applying intensive longitudinal designs to investigate the effects of mindfulness on various psychiatric outcomes (i.e., depression, anxiety, affect, craving, and compulsive behaviors).

Quantifying mindfulness

Although a variety of operational definitions of mindfulness as a construct have been proposed (Creswell, 2017), investigators have consistently made reference to the construct as incorporating at least three components: (1) purposefulness or intentionality, (2) a focus on direct or present moment experience, and (3) non-judgmentalness or kindness (Baer, 2006, 2011; Kabat-Zinn, 2003; Bishop et al., 2006; Brown, 2004; Creswell, 2017; Li et al., 2017; Chiesa & Serretti, 2011). Extensive efforts have been made to measure mindfulness as a latent factor using retrospective self-report methods. The most frequently used measures are Brown & Ryan's (2003) Mindful Attention Awareness Scale (MAAS), and Baer's (2006) Five Facet Mindfulness Questionnaire (FFMQ). Both measures quantify mindfulness as a relatively stable trait, and have received extensive psychometric examination demonstrating satisfactory discriminant, and predictive validity (Baer, 2006; Brown & Ryan, 2003).

Limitations of retrospective self-report assessment methods

Although the MAAS and FFMQ are considered to be some of the strongest psychometric tools of measurement currently available to assess mindfulness, efforts to use self-report methods to quantify mindfulness have received pointed criticism (Grossman & Van Dam, 2011; Grossman, 2011, 2010; Brown, Ryan, Loverich, Biegel, & West, 2011). One primary critique is

related to skepticism about the extent to which people are able to accurately assess, recall, and report on their own attention with reliability between people and across populations (Grossman, 2011).

Additional concerns have been raised by findings from research investigating the effects of mindfulness training, which has relied primarily on trait-level assessment of the construct. While research demonstrating the effectiveness of mindfulness based interventions continues to be produced at a growing pace (Creswell, 2017), attempts to identify mechanisms of action using trait measurement methods have found mixed results (Creswell, 2017; Visted et al., 2015; Bergomi, Tschacher, & Kupper, 2013; Bowen & Enkema, 2014). Indeed, investigations into mechanisms of action for mindfulness training have often been dependent on retrospective self-report trait measurements of mindfulness such as the FFMQ and MAAS. For example, the review mentioned previously that reported over half of mindfulness training interventions found no effect of training on FFMQ scores (Visted et al., 2015). Unfortunately, inconsistent results have impaired understanding of active components of mindfulness-based interventions, leaving operationalization and measurement issues high on the list of priorities for mindfulness researchers (Witkiewitz et al., 2014).

Although there may be some stable features of mindfulness as a psychological construct that are measurable as traits, inconsistent findings may be understood as artifacts of two specific limitations of the typical method of assessment: (1) the use of trait-level measurement does not match the hypothesized effects of mindfulness training, which occur at the state-level, or under specific physiological, psychological and environmental conditions, (2) the availability and representativeness heuristics impair validity of self-reports of awareness and attention as the time between event and recall increases (Uttl & Kibreab, 2011; Brown & Moskowitz, 1997; Tversky

& Kahneman, 1973, 1974). Fortunately, intensive longitudinal assessment is uniquely suited to address these specific limitations.

Advantages of intensive longitudinal assessment methods

Intensive longitudinal assessment methods are capable of addressing the two specific methodological limitations listed above, related to peoples' ability to accurately assess, recall, and report on attention. Intensive longitudinal assessment is a way of improving validity in measurement of phenomena that change over time, and may be particularly protective against biases of attention and recall (Shiffman et al., 2008; Brown & Moskowitz, 1997). Methods include a variety of diary approaches and technologies for prompting and collecting information on a schedule (e.g., randomized prompts or daily diaries), or in response to clinically relevant events (e.g., substance use or negative affect.).

One of the strengths of EMA/ESM is the ability to track variability within a person over time. While assessments are still vulnerable to concerns related to self-report, the extent to which these limitations affect measurements is vastly reduced by minimizing recall bias and maximizing ecological validity. For example, craving may be more accurately measured, and with greater temporal resolution, by multiple estimates of past hour experience during the same day, over the course of a week, reported in the natural environment, than a single estimate of the past month average in the lab.

The goals of the current literature review are to summarize findings from research applying intensive longitudinal assessment methods to the measurement of mindfulness and the effects of mindfulness training on psychiatric outcomes. First, a description of search methods is provided, followed by a summary of findings from the published literature. Subsequently, a discussion of the apparent strengths and limitations of different methodological approaches to

measuring mindfulness in the context of the literature. Finally, recommendations are presented for future research using intensive longitudinal assessment methods to measure mindfulness and the effects of mindfulness training in psychological science.

METHOD

Protocol

The current review was conducted following the guidelines outlined in the PRISMA statement: http://www.prisma-statement.org (Page & Moher, 2016).

Search strategy

First, a search of PsycINFO and Web of Science was completed to identify already existing systematic reviews, meta-analyses, and literature reviews. None were found, thus search terms were refined and a new search was completed from the earliest available publications through September 2018.

Eligibility criteria

Articles were included if they (1) were published or in press before June 2018, (2) were written in English, (3) included both "mindfulness" and "ecological momentary assessment" or "experience sampling" in the text of the article, and (4) reported novel results related to the association between mindfulness and psychiatric outcomes from analysis of intensive longitudinal data.

Search outcome

A flow diagram detailing article selection is available in Figure 1. The search strategy produced a total of 51 articles. All articles were exported to Zotero referencing software, and were manually reviewed and selected or removed based on the four criteria described above. Thirteen articles were excluded because they did not utilize intensive longitudinal methods in the

study design, 14 articles were excluded because they did not report results from analysis of intensive longitudinal assessment of mindfulness and/or mental health outcomes and their association, and 2 additional articles were excluded because they were duplicates.

A total of 22 articles remained that met all four criteria for the current review, reporting results from 23 different studies.

RESULTS

Associations between mindfulness and mental health outcomes

A review of the 22 articles investigating the effect of mindfulness or mindfulness training on mental health outcomes measured using intensive longitudinal designs bore out results consistent with theory and prior research. Broadly, mindfulness was negatively associated with psychiatric symptoms, and positively associated with protective factors. Results from three studies suggest that intensive longitudinal assessment enhances statistical power to detect effects when compared with results using typical trait-level assessment approaches. Specifically, mindfulness and mindfulness training were associated with: decreases in negative affect, increases in positive affect, decreases in symptoms of depression, decreases in rumination, increases in emotional awareness and stability, decreases in craving, and decreases in unhealthy consumption of food or psychoactive substances. The majority of studies reported an association between mindfulness or mindfulness training with affect alone (7) or affect and at least one other outcome (9). A smaller number of studies reported results for outcomes that did not include affect (7). The sample sizes and demographic characteristics, study designs, measurement methods, and outcome variables are available in Table 1. Two studies collected both retrospective data and intensive longitudinal data (one measured outcomes, and one measured both mindfulness and the outcome), and reported increased power to detect an association with

the outcome using intensive longitudinal data than was found with trait-level panel data assessments alone (Moore, Depp, Wetherell, & Lenze, 2016; Brown & Ryan, 2003).

Decreases in negative affect and increases in positive affect

Intervention studies

In a randomized controlled trial comparing Mindfulness Based Cognitive Therapy (MBCT) to wait-list control, those in the mindfulness training condition experienced positive emotions more frequently, and also reported more frequent engagement in and increased responsiveness to pleasant activities (Geschwind, Peeters, Drukker, van Os, & Wichers, 2011). Participants were adults with a history of depression and current residual depressive symptoms, randomized to MBCT (n = 64), or waitlist control (n = 66). Intensive longitudinal assessment was used to assess momentary positive emotions and activity pleasantness during a six-day period before and after the intervention. Reward experience was calculated for each time point as the effect of pleasant activities on current positive affect (consistent with Wichers et al., 2009). Findings indicated that participants in the mindfulness training condition experienced significant increases in reported positive affect (b =.39, p < .01) and activity pleasantness (b =.22, p < .01), as well as a greater ability to boost current positive affect by engaging in pleasant activities (b = .08, p < .01). While the study was a randomized controlled trial, there was no active control, and thus it is impossible to attribute causality to the mindfulness intervention. The observed effects may have been driven by engagement in active treatment, and not necessarily the mindfulness component.

In a secondary analysis (Garland, Geschwind, Peeters, & Wichers, 2015) of data collected in the above-mentioned trial (Geschwind et al., 2011), results revealed a positive association between receiving mindfulness training and current moment positive affect (b = .39,

$p < .01$), as well as a negative association with negative affect ($b = .22$, $p < .01$). Findings indicated that participants in the MBCT group reported increased positive affect and momentary positive cognitions compared to individuals in the control group. Investigators also tested a hypothesized "upward spiral" model of interaction between positive affect and cognitions with intensive longitudinal data using an autoregressive latent trajectory model. Results, although preliminary, were promising (Garland et al., 2015). Specifically, findings suggested that positive affect was more tightly predictive of subsequent positive cognitions for individuals in the MBCT condition, although cognitions did not predict subsequent affect.

An RCT of Mindfulness-Oriented Recovery Enhancement (MORE) compared to a support group control condition investigated the effects of mindfulness on pain and affect for 55 chronic pain patients on opioid pharmacotherapy (Garland et al., 2017). Findings indicated that the MORE group had greater decreased momentary pain ($B = -0.003$, $SE = 0.001$, $p = 0.01$), decreased overall pain ($B = -0.002$, $SE = 0.001$, $p = 0.03$) and significantly increased positive affect over time ($B = 0.003$, $SE < 0.001$, $p = 0.001$) compared to the control group. Additionally, the MORE group was more likely to demonstrate positive affect regulation, defined as a greater ability to maintain and recover positive affect. MORE participants had significantly decreased opioid misuse scores at the end of treatment, ($B = 3.82$, $SE = 0.24$, $p < 0.001$). Improvements in positive affect, but not pain, were also significantly associated with reduced risk of opioid misuse at the end of treatment.

A pilot parallel group randomized controlled trial (Ruscio, Muench, Brede, & Waters, 2015) compared a brief mindfulness meditation practice intervention with control meditation practice in a sample of community smokers ($N = 44$). Participants were randomly assigned to the experimental ($n = 24$) or control ($n = 20$) group, and asked to report demographics, smoking

history, and affect. They were then trained in how to use a personalized digital assistant (PDA) that was programmed to randomly prompt four times per day to assess craving, state mindfulness, and positive and negative affect. Participants were also asked to meditate once per day using the pre-recorded guided meditations available on their PDA, and complete a daily diary of total cigarettes used, with the instruction to smoke as much or as little as they liked during the study. A main effect of the mindfulness meditation intervention was observed, such that individuals in the mindfulness intervention reported significantly less momentary negative affect than the control group (B = -2.78, $p < .001$). However, negative affect was not reduced following meditation practice, nor did it decrease over time. Investigators noted that these results are consistent with findings from urge surfing research (an approach to craving informed by acceptance and mindfulness as opposed to suppression and distraction), and may also be attributable to a floor effect for the negative affect measure, which was near the minimum level (Ruscio et al., 2015; Bowen & Marlatt, 2009; Rogojanski, Vettese, & Antony, 2011).

In an investigation of the effects of mindfulness training on mindfulness, decentering (learning to treat negative thoughts as events rather than truth), and affect, intensive longitudinal assessment was utilized during a three-week mindfulness training program (Shoham, Goldstein, Oren, Spivak, & Bernstein, 2017). Participants were 82 meditation-naive adults from the general community, who engaged in a structured mindfulness training protocol and intensive longitudinal assessments two to three times per day starting three days prior to the first mindfulness training session and throughout the duration of the program. Participants demonstrated significantly increased mindfulness and decentering over the course of the training, with larger effects during meditation practice (β = .47, SE = .05, $p < .001$) than during daily living (β = .25, SE = .04, $p < .001$). Increased mindfulness led to significantly increased positive

emotion both during meditative states (β = .45, *SE* = .09, $p < .001$) and in daily life (β = .17, *SE* = .06, p = .003). Decentering was not related to emotional valence.

Individuals with prior mindfulness experience who had completed either Mindfulness-Based Stress Reduction or Mindfulness-Based Cognitive Therapy (N=29) engaged in mindful walking beside the river Rhine accompanied by assessments of state mindfulness and affect (Gotink et al., 2016). Additional measures of depression, anxiety, stress, brooding, and mindfulness were also collected both before and after the mindful walking period, and before and after a control period one week prior. Participants walked either 1, 3, or 6 or more days. Those who walked either 1 or 3 days completed assessments 10 times per day, while those walking 6 or more days completed assessments 5 times per day. Compared to the control period, over the course of the mindful walking period participants experienced significant increases in positive affect (β=0.91, p<0.001) and state mindfulness (β=0.98, p<0.001), as well as decreased negative affect ($\beta = -0.71$, $p < 0.001$). State mindfulness at the previous assessment predicted positive affect in the next, even controlling for affect at the prior assessment (β=0.18, p<0.001). Likewise, positive affect at the previous assessment predicted state mindfulness at the next, even controlling for state mindfulness at the prior assessment (β=0.21, p<0.001). Negative affect had an opposite relationship, such that mindfulness predicted reduced later negative affect (β=−0.14, p<0.001), and negative affect predicted reduced state mindfulness at the next assessment (β = −0.19, p<0.001). Analyses between days showed an opposite relationship, as positive affect on the previous day significantly predicted reduced mindfulness on the next, controlling for mindfulness the day before (β =−0.36, p = 0.027), and negative affect on the previous day predicted increased mindfulness on the next day (β=0.41, p= 0.002). State mindfulness and positive affect also significantly improved with number of days walked.

Another recent study examined the effects of Compassion Cultivation Training (CCT) on affective states such as anxiety, calmness, fatigue, and alertness, as well as affective regulatory strategies (Jazaieri et al., 2018). Participants were 51 adults without psychiatric symptoms. This paper utilized a subsample from a larger RCT, including only those individuals who were randomized to the CCT condition. CCT comprised weekly two-hour classes and daily compassion-focused meditation for eight weeks, during which participants were assessed twice daily on their current affective state, affective regulation, and perceived ability to successfully regulate their affect. Additionally, they were assessed weekly on strategies used to regulate their affective states, with possible strategies including suppression, and acceptance. Over the duration of the course, participants had significant decreases in anxiety ($\gamma = -.02$, $p = .01$) and increases in calmness ($\gamma = .04$, $p < .01$), as well as increased self-efficacy to regulate affective states. However, participants endorsed less desire to regulate affective states, presumably because their affect became less aversive over the course of training. Finally, over the course of training, the use of suppressive affect regulation strategies decreased, while use of acceptance increased. Results must be interpreted with caution due to the lack of a control group for the study.

A comparison of the effectiveness of acceptance and avoidance-based emotion regulation strategies for different psychiatric populations indicated that mindfulness components may have variable effectiveness for different disorders (Chapman, Rosenthal, Dixon-Gordon, Turner, & Kuppens, 2017). Participants were 48 individuals diagnosed with Borderline Personality Disorder (BPD), 54 diagnosed with Major Depressive Disorder (MDD), and 50 non-psychiatric controls. Participants were randomly assigned to receive instructions on strategies for regulating emotions involving either acceptance or avoidance, then completed intensive longitudinal assessments at random time points eight times per day for six days. During the six-day

assessment period, the first two days had no specific emotion regulation instructions to establish a baseline. During the middle two days participants received specific instructions on which emotion regulation strategies to use, and the final two days also had no specific instructions. Individuals with BPD in the avoidance group reported significantly decreased negative affect on days they were instructed to use avoidance strategies (β = –.13, *SE* = .05, *p* = .01), as well as significantly decreased urges for maladaptive behavior (β = –.11, SE = .03, p < .001). Additionally, the MDD acceptance group had significantly decreased negative affect between the instruction phase and the final two days (β = –.10, *SE* = .05, *p* = .04) indicating that this strategy was helpful in the short term for individuals with MDD.

Non-intervention studies

Two samples were gathered to examine the relationship between mindfulness and affect for adult community members and young adult college students (Brown & Ryan, 2003). Participants were 83 adult community members recruited through newspaper and poster advertisements (Sample 1), and 92 young adult college students enrolled in introductory psychology courses (Sample 2). Dispositional mindfulness (MAAS; Brown & Ryan, 2003) and dispositional affect (Diener & Emmons, 1984) were measured at baseline, followed by a period of experience sampling assessing state mindfulness and state affect. Using aggregated intensive longitudinal data, baseline trait mindfulness was negatively associated with momentary negative affect (Sample 1: *r* = .28, Sample 2: *r* = .27, *p*s < .05) and was not associated with pleasant affect. Using a multilevel modeling approach, trait mindfulness was negatively associated with momentary negative affect (*p* < .01), and not significantly associated with momentary positive affect. Momentary mindfulness, however, was positively associated with current moment positive affect and negatively associated with current moment negative affect (*p*s < .0001).

Investigators noted that although the purpose of the studies was to assess the validity and reliability of the new trait mindfulness measure they had developed, the momentary measure demonstrated stronger psychometric qualities (Brown & Ryan, 2003). The contrast between trait-level and momentary measurement is discussed in more detail in a later section of the current review (*Comparing panel data outcomes to intensive longitudinal outcomes*).

The relationship between mindfulness, motivational conflicts, and affect was also investigated using intensive longitudinal assessment (Grund, Grunschel, Bruhn, & Fries, 2015). Participants were 58 university students, who completed measures of mindfulness and self control (Self-Control Scale; Tangney, Baumeister, & Boone, 2004) at baseline. Following baseline assessment, participants responded to questions about motivational conflicts and affect in their daily life during the intensive longitudinal assessment phase of the study. Intensive longitudinal assessment was comprised of 21 and 14 consecutive days of survey completion using identical paper survey forms that took approximately 1 minute to complete, and were completed 3 times per day on a quasi-random schedule (morning, afternoon, evening). Models used aggregated affect as the outcome (a summary score of positive activation, negative activation, and affect valence), as measured in the moment during intensive longitudinal assessment, and the Short Scale of Positive and Negative Activation and Valence, modeled on the Positive and Negative Affect Scales (PANAS, Watson, Clark, & Tellegen, 1988). Results indicated that mindfulness had a positive direct effect on aggregated affect ($\beta = 0.20$, $p < 0.01$) after controlling for self-control and motivational conflicts. Investigators concluded that the relationship between mindfulness and aggregated affect was strong, and not fully explained by self-control or mediated by motivational conflicts, or lack thereof.

Investigating the validity of a newly developed Multidimensional State Mindfulness Questionnaire (MSMQ), Blanke Riedeger & Brose (2018) found similar associations between two of three subscales and affect. The MSMQ includes three subscales: present-moment attention, acting with awareness, and nonjudgmental acceptance. Participants were 70 young adult college student and community member who completed 6 surveys per day for 9-12 days. There was a positive main effect of the attention (β =.27, *SE* = .03, 95% CI [0.22, 0.32]) and nonjudgment (β =.17, *SE* = .02, 95% CI [0.13, 0.21]) subscales of the MSMQ, and positive affect. Negative associations were observed between these same two subscales, attention (β =-.12, *SE* = .02, 95% CI [-0.16, -0.07]) and nonjudgment (β =-.26, *SE* = .02, 95% CI [-0.30, -0.23]), and negative affect. Interestingly, the acting with awareness subscale of the MSMQ was not significantly associated with positive or negative affect. There was also a significant interaction between these two subscales predicting negative affect, indicating that in moments of high nonjudgmental acceptance, variability in present-moment attention had no effect on negative affect. Finally, the nonjudgmental acceptance subscale also had a buffering effect, limiting the influence of life stressors on affect.

A study of mindfulness and social interactions (Quaglia, Goodman, & Brown, 2015) was conducted with 72 people in 37 romantic couple relationships. At baseline, participants completed measures of mindfulness (MAAS), and downloaded an app on their smartphone to complete intensive measurements of positive and negative affect following each social interaction they were involved in for the next six days. Trait mindfulness was negatively associated with momentary negative affect (R^2 =.241, $p < .001$), and positively associated with momentary positive affect (R^2 = .088, p = .007) following substantive social interactions (>5 minutes). Investigators concluded that participants who reported less inattention on the MAAS

experienced increased positive affect and decreased negative affect following social interactions (Quaglia et al., 2015).

Decreases in symptoms of depression and rumination

Intervention studies

In a RCT treatment comparison study (Moore et al., 2016), 67 people aged 65 or older with depression and anxiety were assigned to one of two intervention conditions: Mindfulness Based Stress Reduction, or a health education control. Study participants completed measures of mindfulness, depression, and anxiety at baseline, and during the 10-day pre-treatment EMA period. Participants then attended 8 once weekly group-delivered 90-minute sessions and completed follow-up measures during another 10-day post-treatment EMA period. While the effect of MBSR was in the expected direction, and superior for all three outcomes (trait and state mindfulness increased, and depression and anxiety symptoms decreased) compared with the health-education control, the effect of the intervention on mindfulness and depression symptoms were both substantially weaker when measured using paper-and-pencil retrospective self-report as compared to EMA. Specifically, the estimated Number-Needed-to-Treat (NNT) when using EMA measurement to evaluate the effect of the intervention on depression symptoms was 8.2, whereas the NNT was 31.1 when using the more standard method of single time panel data collection (Moore et al., 2016).

Felsman, Verduyn, Ayduk, & Kross (2017) used ESM over a week-long period to examine the effect of present moment awareness (as opposed to past or future) on how people felt (i.e. affect), negative and positive rumination, and how satisfied they were with their lives [N = 64; mean age 19.79 (SD = 1.51)]. Participants were community members and college students. Importantly, although how people felt and rumination were examined using ESM, life-

satisfaction was measured only at two time points, pre and post ESM data collection. The effect on how people felt was discussed previously in this review. This section will focus on results regarding life satisfaction and cognitive well-being. Focusing on the present was associated with life satisfaction over time through the reduction of negative rumination using a mediation analysis when controlling for average affect ($B = 0.011$, $SE = 0.006$, $\beta = 0.14$, $p = 0.062$). The indirect effect of momentary present-focused attention on changes in cognitive well-being through negative rumination suggested that the path was significant ($B = .005$, 95% CI [0.0002, 0.013]) The authors note that they did not study specific components of mindfulness, such as mindfulness of ongoing sensations or taking a nonjudgmental stance.

Non-intervention studies

A recent study by Naragon-Gainey & DeMarree(2017) investigated two different facets of decentering – a construct highly correlated with facets of mindfulness – and their relation to psychopathology and affect. The two factors were observer perspective (OP), defined as relating to thoughts in an objective, distant manner, and reduced struggle with inner experience (RS), defined as a decreased impact of thoughts and feelings on subsequent responses. Authors theorized that decentering would moderate the link between affect and dysphoria, worry, panic, and social anxiety. This was investigated in an adult community sample of 135 individuals currently receiving mental health treatment; participants completed laboratory baseline measures of decentering and a diagnostic interview, followed by 10 days of smartphone surveys 3 times per day, measuring positive and negative affect as well as symptoms. Decentering and daily affect were associated with daily symptomatology (dysphoria, worry, panic, and social anxiety). Significant interactions between both decentering constructs and NA were observed for both dysphoria and worry as outcomes. Only the RS factor interacted with NA for panic and social

anxiety as outcomes. In all cases, the interaction between decentering and negative affect indicated an attenuation of the association between negative affect and the outcome. As decentering increased, it reduced the strength of the link between affect and symptoms. There were no significant interactions between decentering and positive affect.

Another study examined the relationship between mindfulness, state and trait rumination, and state and trait anger (Borders & Lu, 2017). A total of 171 participants completed assessments either 2 or 6 times per day for 7 days, and these assessments were analyzed both concurrently and cross-lagged. State anger and rumination had complicated bidirectional associations. Cross lagged-analyses indicated that trait mindfulness was a significant negative predictor of current rumination and interacted with current anger to positively predict current rumination. Although the main effect of mindfulness on current anger was not significant, the interaction with current rumination was significant. The interaction indicated that for individuals with high levels of trait mindfulness, trait mindfulness attenuated the association between prior rumination and current anger. Current rumination was also a mediator of the relationship between current mindfulness and current anger. Findings suggested that individuals low in trait mindfulness rumination predicted increases in subsequent anger, and for those high in trait mindfulness rumination and anger co-occurred. This pattern of results points to a protective effect of mindfulness preventing the perseveration and spiraling downward into negative mood states, on the one hand. At the same time, the positive association between co-occurring anger and rumination may reflect increased awareness of current emotions.

Increases in emotional awareness and stability

Intervention study

A mindfulness-based intervention trial was conducted, focused on improving participants' ability to differentiate negative and positive emotions among a sample of 61 adults (after exclusion for attrition; Van der Gucht et al., 2019). A within-subjects design was used to examine participants pre-, post-, and at 4 months follow-up with regard to the intervention. During each assessment period, participants used ESM to report their current emotions and mindfulness skills on their smartphones up to 40 times across 4 consecutive days. Each phase was also accompanied by retrospective self-report measures, including a measure of emotional distress and the Comprehensive Inventory of Mindfulness Experiences (CHIME; Bergomi et al., 2013). Results showed an improvement in ability to differentiate negative emotions post-intervention (B = -0.10, p = .012) and at follow-up (B = -0.12, p = .028). However, this improvement was no longer significant after controlling for negative affect. There was also an improvement in ability to differentiate positive emotions at follow-up (B = -0.09, p = 0.43). Finally, posttreatment state and trait mindfulness skills mediated changes in ability to differentiate negative emotions even when controlling for negative affect. With regard to state mindfulness, nonjudgmental acceptance/decentering mediated the improvement in ability to differentiate negative emotions. With regard to trait mindfulness, the same was true for accepting and nonjudgmental orientation and decentering and non-reactivity .

Non-intervention studies

In an observational study to investigate the mechanisms of action in mindfulness training, investigators used the FFMQ to assess mindfulness at baseline, and intensive longitudinal methods to assess 21 different emotions throughout the day for 10 days (Hill & Updegraff, 2012). College students (N = 103) were recruited and completed baseline measurements of mindfulness and affect in the lab, after which they were provided with a PalmPilot set to

randomly prompt participants approximately every 2 hours to report levels of 21 different emotions throughout the day. Results indicated that overall mindfulness at baseline was positively associated with emotion differentiation (r = -.22, p = .03), or the ability to distinguish between similarly valenced emotions. Additionally, overall mindfulness was negatively associated with negative emotion lability (r = -.38, p < .05) and positive emotion lability (r = -.26, p < .05), or patterns of change from positive emotionality to negative emotionality. Follow-up analyses revealed that the non-reactivity sub-scale of the FFMQ was driving the effect for both emotion differentiation and emotion lability. Investigators concluded that results from this investigation suggested that self-reported mindfulness was associated with both increased momentary emotional awareness and stability (Hill & Updegraff, 2012).

In an earlier mentioned observational study of social interaction with 37 couples (N = 74), investigators (Quaglia et al., 2015) also assessed emotion lability. Consistent with the findings of Hill & Updegraff (2012), results revealed mindfulness to be strongly negatively associated with negative emotion lability (b = 12.83, p = .02). Positive emotion lability was not associated with MAAS scores at baseline.

Decreases in craving and unhealthy consumption

Intervention studies

Participants in a RCT were adult smokers (n = 176) interested in tobacco cessation (Nosen & Woody, 2013). At baseline, participants completed measures of metacognitive beliefs (Appraisal of Cravings Questionnaire: ACQ; Nosen & Woody, 2009, 2014), craving using a simple visual analogue scale, depression, anxiety, and stress (Depression-Anxiety-Stress Scale: DASS; Lovibond & Lovibond, 1995), and cigarette dependence (Cigarette Dependence Scale: CDS; Etter, Le Houezec, & Perneger, 2003). Craving and use were assessed using EMA during

the 24h period following the three-condition intervention (mindfulness psycho-education, psycho-education, and no psycho-education). Growth curve models were tested to assess craving trajectories reported by participants in all three conditions. Results indicated that on average, participants who received mindfulness psycho-education experienced a unique trajectory of craving over the 24h period, such that craving peaked mid-day, and was reported to be significantly less at end of day than control. Additionally, mean craving scores were significantly lower among abstainer participants in the mindfulness psycho-education group after being awake for 10 hours ($p < .05$). In sum, psycho-education encouraging participants to respond to the experience of craving and urges to use with acceptance facilitated eventual reduction in craving severity (Nosen & Woody, 2013).

A RCT evaluating the comparative and combinatory effectiveness of mindful decision-making training (MDT) and inhibitory control training (ICT) for eating behaviors found that only the two conditions that included mindful decision-making training were associated with decreases in hedonically motivated eating (Forman et al., 2016). Participants were 119 undergraduate students recruited through local advertising or psychology courses, who were then randomized to one of four training conditions: MDT, ICT, Combined MDT/ICT, and psycho-educational control. After completing seven days of EMA prompts during the week prior, participants received the intervention, and then completed seven days of EMA prompts during the subsequent week. Salty snack food consumption was assessed three times per day through participants' smartphones, and trait dietary disinhibition was assessed at baseline. Participants in all four conditions, including control, reported a reduction in frequency of salty snack consumption during the post-treatment phase of EMA. Only individuals in the combined MDT and ICT condition experienced significantly stronger effects compared to control ($p = .02$).

In a previously mentioned parallel group RCT (Ruscio et al., 2015), a main effect of the mindfulness meditation intervention was observed, such that individuals in the mindfulness intervention reported significantly less momentary craving than the control group after completing a meditation practice ($B = .81$, $p < .001$). Additionally, individuals in the mindfulness group reported declining rates of daily cigarette usage over the course of the study, whereas cigarette usage in the control group did not change ($B = -.29$, $p = .01$).

Chapman et al. (2017) studied the comparison between instructions to avoid versus accept negative emotions over a six-day period. Mood, urges to engage in maladaptive behaviors (e.g., binge eating, engaging in unprotected/risky sexual activity), and distress tolerance were measured using EMA. Acceptance based strategies share elements with mindfulness, or rather, mindfulness is arguably necessary to utilize acceptance. For example, instructions included phrases such as "Simply allow yourself to experience your negative emotions and negative thoughts. Accept them, and let them come and go." The impact of instructions on mood was previously discussed in the current review. In this section, we report on the results regarding urges to engage in maladaptive behaviors and on distress tolerance. Instructions to avoid negative emotions were associated with reduced urges for maladaptive behaviors ($\beta = -.11$, $SE = .03$, $p < .01$) among participants diagnosed with BPD (n = 48). This association was not found for participants with either major depressive disorder (n = 54) or no psychiatric diagnosis (n = 50). MDD participants in the accept condition also reported an increase in willingness to tolerate distress ($\beta = .19$, $SE = .10$, $p = 0.046$). Authors posit that these acceptance strategies take longer to learn and that for short term relief, avoidance strategies can be effective, at least for those with a BPD diagnosis.

Another study implemented a 28-day (self-paced) smartphone-delivered intervention for craving-related eating using mindful eating practices with 104 overweight or obese women (Mason, Jhaveri, Cohn, & Brewer, 2018). EMA via text message was used pre-intervention and 1-month post-intervention to assess food cravings. Participants (n = 78) completed the intervention, and experienced reductions in craving-related eating (OR = 0.729, p < .001) and trait craving (b = 14.27, p < .001). Implications of the results are tempered by the absence of randomization or a control condition.

Decreases in non-suicidal self-injury

One study examined the individual and combined effects of mindful emotion awareness and cognitive reappraisal interventions on non-suicidal self-injury (NSSI) in a sample of 10 self-injuring adults (Bentley, Nock, Sauer-Zavala, Gorman, & Barlow, 2017). Participants were randomized to a two- or 4-week baseline phase and an initial 4-week intervention (either mindful emotion awareness or cognitive reappraisal). Participants who responded to the intervention they were initially assigned started a 4-week follow-up non-treatment phase. Those who did not respond to the initial intervention entered the second, 4-week treatment phase of the other intervention. The two interventions used were the mindful emotion awareness and cognitive reappraisal and flexibility modules of the Unified Protocol for Transdiagnostic Treatment of Emotional Disorders (Farchione et al., 2012). Each module was delivered over four 50-60 minute sessions. EMA was used to assess daily ratings of NSSI urges and acts throughout the study. Results indicated that eight of the ten participants experienced clinically meaningful reductions in NSSI, though these must be interpreted with caution due to small sample size. Six participants responded to one intervention alone and two participants responded after participation in the additional intervention. Group analyses showed a significant effect of study phase on NSSI,

whereby NSSI urges ($p < .01$) and acts ($p < .01$) decreased following the introduction of the study phase. The interventions were also associated with large improvements in mindful emotion awareness as measured by the Southampton Mindfulness Questionnaire (Chadwick et al., 2008), and cognitive reappraisal skills, measures that were administered weekly.

Comparing trait mindfulness and state mindfulness as predictors

Only Brown & Ryan (2003) assessed baseline trait mindfulness in addition to momentary mindfulness using intensive longitudinal assessment methods. In a combined sample of community adults ($n = 83$) and college students ($n = 100$), participants completed the MAAS as a baseline trait mindfulness assessment, and then recorded their experience on 21 (community adults) or 14 (college students) consecutive days. Participants received multiple random prompts during the day to track current moment experience, including mindfulness. Results from multilevel modeling indicated that the majority of variance in state mindfulness was attributable to within-person variability as opposed to between-person variability. In other words, there was substantial variability in momentary mindfulness over time that was not accounted for by trait measurement. Specifically, only 29% of the variance in state mindfulness was attributed to between-person differences, and 71% was attributed to within-person differences. In addition, the associations between state mindfulness and both positive and negative affect were stronger than associations with trait mindfulness. Investigators hypothesized that this difference in observed effect maybe be due to the superior ecological validity of momentary assessment through increased temporal proximity (Brown & Ryan, 2003).

Comparing panel data outcomes to intensive longitudinal outcomes

Only one study was conducted that assessed outcomes using both intensive longitudinal methods and typical retrospective self-report measures (Moore et al., 2016), allowing for a

comparison between the assessment methods. Results from this trial revealed that the reported effects of mindfulness training were a significant reduction in depression, regardless of assessment method. However, the effect of the intervention was much larger for intensive longitudinal outcomes when compared with retrospective self-report measures completed at the research center. If the researchers had used only panel data, they would have found an effect more than three times smaller than the effect they found when using intensive longitudinal methods. The observed difference in outcomes was inconsistent, however. The difference in effect size between panel-assessed anxiety and intensively-assessed anxiety was not significantly different.

DISCUSSION

Summary of findings to date

A review of the literature investigating the associations of mindfulness and mindfulness training with psychiatric symptom outcomes measured using intensive longitudinal methods revealed a consistent pattern of results suggesting a negative association with outcomes across 23 studies. Results summarized in the current review include 15 studies reporting results following interventions, and 8 studies describing observational findings from non-interventions.

Across the studies described in the 22 articles, primary outcomes were positive and negative affect, depression symptoms, craving, and substance use. Findings revealed a consistent pattern of negative association between mindfulness or mindfulness training and psychiatric outcomes. These results are consistent with a much larger body of evidence demonstrating the effectiveness of mindfulness interventions for reducing problems in living. However, only two studies made a direct comparison of assessment methods (Moore et al., 2016; Brown & Ryan, 2003), and results indicated that intensive longitudinal methods might substantially increase

ability of investigators to detect the effect of mindfulness on psychiatric outcomes. It appears that intensive longitudinal assessment may provide a more sensitive, and potentially more valid measure of some primary outcomes (Brown & Ryan, 2003; Moore et al., 2016). More research to investigate the question of relative strengths of intensive longitudinal assessment is sorely needed.

Limitations

The results of the current review should be understood to be preliminary and come with substantial caveats. Firstly, it should be noted that few studies have used intensive longitudinal methods to assess effects of mindfulness-based interventions or the associations between trait mindfulness and specific outcomes outside of affect. Most of the studies that have been conducted using intensive longitudinal designs have focused on affect, or have targeted different primary outcomes. As a result, an already small sample is even further diminished through diffusion of focus. While this consideration does not necessarily indicate that the results reported are not valid, the reliability of the direction and magnitude of the effect of mindfulness on craving, unhealthy consumption of food and psychoactive substances, depression, rumination and emotional awareness and stability ought to be considered preliminary until more results have been reported.

Secondly, substantial concerns exist regarding the validity of current retrospective self-report measures in the context of intensive repeated assessment of behavior (Witkiewitz et al., 2014; Bergomi et al., 2013; Grossman, 2010; Uttl & Kibreab, 2011). Among studies assessing mindfulness in the current review, the majority used retrospective self-report tools such as the MAAS and FFMQ to measure the construct as a trait. Investigators have raised concerns regarding trait measurement (Visted et al., 2015; Grossman, 2011; Grossman & Van Dam,

2011). Indeed, the availability and representativeness heuristics may lead respondents to report in reliable, but not valid ways (Uttl & Kibreab, 2011; Tversky & Kahneman, 1974, 1973). Results support the hypothesis that biases of attention may influence retrospective self-report assessment of mindfulness, as the only two studies reporting both state and trait mindfulness found that momentary mindfulness scores differed substantially from trait scores (Brown & Ryan, 2003; Moore et al., 2016).

Implications

While the benefits of mindfulness practice have been described for millennia, efforts have only recently been made to operationally define mindfulness as a construct for the purpose of applying quantitative methods. Through operationalization and the subsequent development of psychometrically sound measurement tools, research on the role of mindfulness in mental health has matured substantially since it began late in the last century. However, methods could be improved by applying intensive repeated measures designs in the assessment of study variables. Mindfulness training has been incorporated into interventions targeting a wide variety of psychiatric diagnoses and problems in living, with strong evidence to indicate mindfulness training and practice may be a means of ameliorating psychiatric symptoms (Creswell, 2017; Chiesa & Serretti, 2014, 2011). Investigations aimed at identifying why people benefit from mindfulness training have been less conclusive (Witkiewitz et al., 2014; Bergomi et al., 2013), which has limited attempts to refine treatments and enhance observed effects. Indeed, there remains a substantial degree of uncertainty regarding the active ingredients of treatment (Witkiewitz et al., 2014), and questions will likely continue to be raised until hypothesized mechanisms are adequately measured and demonstrated to be related to treatment effects. Finally, increasing understanding of specific mechanisms of action may allow for a more

principle-based approach, and ultimately produce more parsimonious and accessible interventions. Eventually, this clarification may enhance the effectiveness of treatments for psychiatric diagnoses and problems in living.

Future directions

The current literature on the relationship between mindfulness and psychiatric outcomes using intensive longitudinal methods is limited to 22 articles, with the majority focused on affect. More intensive longitudinal studies are needed for each of the diverse outcome areas that mindfulness has been reported to be a factor (Creswell, 2017). Additionally, only 8 studies reported state measurements of mindfulness in relation to outcomes, none of which used the same items to assess the construct. Researchers seeking to increase validity of results should consider incorporating intensive longitudinal assessment methodology into their study designs. Using intensive longitudinal assessments will also increase measurement precision for highly variable experiential phenomena vulnerable to recall and cognitive biases, and thus increase the validity of findings by assessing change over time. For example, by reducing the time between experience and report the bias introduced by the availability and representativeness heuristics will be reduced. Future research on mindfulness and mindfulness training will benefit from enhanced assessment precision through utilizing intensive longitudinal assessment and may reveal a more clear and consistent picture of the role mindfulness plays in mental health.

Figure 1. Flow diagram detailing systematic review article selection.

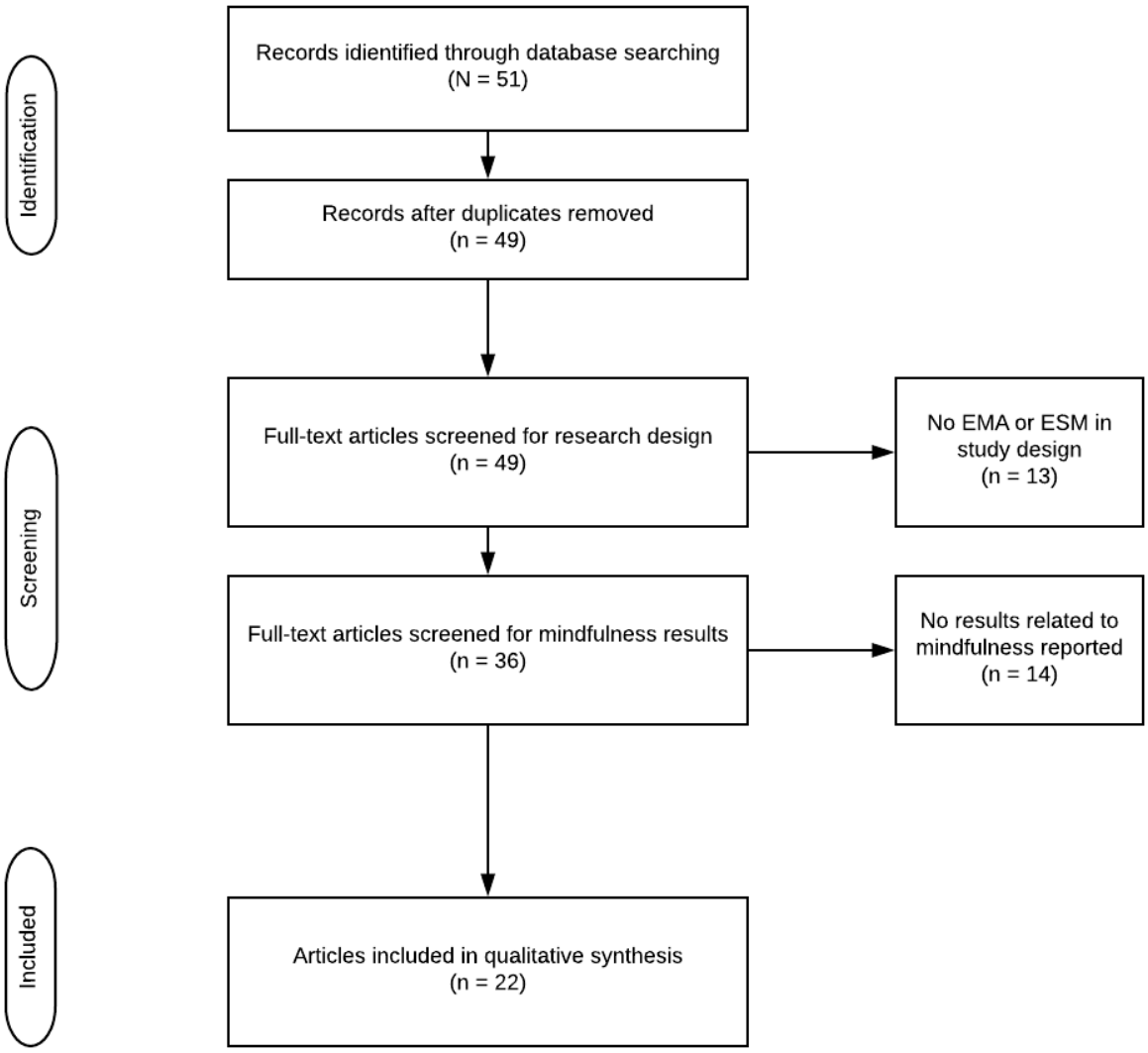


Table 1. Literature review of the effect of trait mindfulness and mindfulness-based interventions on psychiatric outcomes

Reference	Sample		Design	Mindfulness		Outcomes
	N	Characteristics		Type	Measure	
Bentley, 2017	10	Self-injurious adults	Intervention	None	None	NSSI
Blanke, 2018	70	Community adults	Observational	State	MSMQ	Affect
Borders, 2016	200	College students	Observational	Trait	FMI	Affect, Rumination
Brown & Ryan, 2003						
Study 1	92	College students	Observational	Trait	MAAS	Affect
Study 2	41	Community adults	Intervention	Trait/State	MAAS	Affect, Depression
Chapman, 2017	152	BPD, MDD, Controls	Intervention	State	None	Affect, Craving
Felsman, 2017	64	Community adults	Observational	State	None	Affect, Rumination
Forman et al., 2016	119	College students	Intervention	None	None	Craving, Use
Garland, 2017	55	Chronic pain	Intervention	None	None	Affect, Use
Garland et al. 2015	130	Prior MDD diagnosis	Intervention	None	None	Affect, Depression
Geschwind et al., 2011	130	Prior MDD diagnosis	Intervention	None	None	Affect, Depression
Gotink, 2016	29	Community adults	Intervention	State	FFMQ	Affect

Grund et al., 2015	58	College students	Observational	Trait	MAAS	Affect
Hill et al., 2012	96	College students	Observational	Trait	FFMQ	EA, EL
Jazaieri, 2018	51	Community adults	Observational	State	None	Affect
Mason, 2018	104	Community adults	Intervention	None	None	Craving, Use
Moore et al., 2016	67	Anxious/depressed seniors	Intervention	Trait	CAMS	Depression
Naragon-Gainey, 2017	135	Mental health tx seekers	Observational	Trait	TMS	Affect, Depression
Nosen et al., 2013	176	Community smokers	Intervention	None	None	Craving
Quaglia et al., 2015	72	College students	Intervention	Trait	MAAS	Affect
Ruscio et al., 2015	44	Community smokers	Intervention	None	None	Affect, Craving
Shoham, 2017	82	Community adults	Intervention	State	None	Affect
Van der Gucht, 2019	61	Community adults	Intervention	Trait/State	CHIME	EA

Note. EA = Emotional awareness. EL = Emotion lability. MSMQ = Multidimensional State Mindfulness Questionnaire. FMI = Freiburg Mindfulness Inventory. MAAS = Mindful Attention and Awareness Scale. CAMS = Cognitive and Affective Mindfulness Scale. TMS = Toronto Mindfulness Scale. CHIME = Comprehensive Inventory of Mindfulness Experiences.

III. Craving over time: Intensive longitudinal assessment of craving and cannabis use among young adults with problematic use

Matthew Enkema

ABSTRACT

Problematic cannabis use is associated with negative mental health and other life outcomes. Prevalence of problematic use has nearly doubled in prevalence over the last decade, and peak onset for cannabis use disorders occurs during young adulthood. Theory regarding the development and maintenance of problematic use suggests that the experience of craving is strongly associated with subsequent use behavior for individuals with problematic use. Typical panel data assessment methods to measure the strength of the longitudinal association between craving and use have had only limited success, and investigators have hypothesized that the time-varying nature of craving may be responsible for the absence of predicted results. Intensive longitudinal assessment methods are used to increase ecological validity of measurements of highly time-variant phenomena such as craving. The current study applied intensive longitudinal methods and typical retrospective self-report assessment methods (Marijuana Craving Questionnaire, MCQ; Heishman, Singleton, & Liguori, 2001) to investigate the comparative utility of the two methods for predicting subsequent cannabis use behavior. Results suggested that among young adult problematic cannabis users interested in reducing their use there was a strong positive relationship between momentary craving and subsequent cannabis use. Meanwhile, only one of four subscales of the MCQ was associated with subsequent use. Clarifying the comparative utility of momentary assessments of craving versus typical retrospective self-report methods demonstrates the value of intensive longitudinal assessment. Additionally, the strength of the association between craving and subsequent use for this population identifies a fruitful treatment target and may inform treatment development in future research.

Keywords: Craving; Cannabis Use; Measurement; Intensive Longitudinal Assessment

INTRODUCTION

Cannabis misuse is a behavior associated with substantial negative outcomes and is a growing public health concern (Butterworth et al., 2014; Haberstick et al., 2014). Epidemiology indicates cannabis misuse peaks during young adulthood, which has been identified as an important developmental period for early intervention (Caulkins et al., 2015; Farmer et al., 2015; Hasin et al., 2015). Cannabis use has been linked to a variety of negative mental health consequences and other life consequences (Keith et al., 2015; Lyvers et al., 2013). As students use more cannabis, they experience more negative academic and mental health outcomes (Arria et al., 2015; Keith et al., 2015; Phillips et al., 2015). Across substances of misuse, craving is hypothesized to function as a core element in the development and maintenance of cannabis misuse, and there is a strong risk of relapse to problematic use associated with craving (Serre, Fatseas, Swendsen, & Auriacombe, 2015).

Craving and models of misuse

Craving for cannabis is not limited to withdrawal from the drug (APA & DSM-5 Task Force., 2013), and craving may help explain cannabis misuse among young adults (Buckner et al., 2015; Phillips et al., 2015). Indeed, there is growing evidence that craving is associated with an increased probability of subsequent cannabis use among frequent using (10 or more days per month) young adults (Buckner, Crosby, Silgado, Wonderlich, & Schmidt, 2012; Buckner et al., 2015; Buckner, Zvolensky, & Ecker, 2013; Phillips et al., 2015).

Craving has been described as "an affectively charged cognitive event in which an object or activity that is associated with pleasure or relief of discomfort is in focal attention" (Kavanagh, Andrade, & May, 2004, p. 447). A variety of theoretical models have been

developed to explain psychological phenomena that factor into the experience of craving (Drummond, 2001; Kavanagh & Connor, 2013; Kavanagh et al., 2013; Skinner & Aubin, 2010). Although no single model currently accounts for all psychological aspects of craving, the behavioral, cognitive, and transdisciplinary/psychobiological models each inform current understanding of craving. Behavioral models focus on reinforcement, wherein people develop an association between their substance of choice and either positive experiences or relief from negative experiences (Elwafi, Witkiewitz, Mallik, Iv, & Brewer, 2013). Behavioral models have informed neurobehavioral research, which has provided evidence of substance-related changes in reward sensitivity at the neural level (e.g., the incentive sensitization theory) (Brewer, Elwafi, & Davis, 2014; Robinson & Berridge, 2008), and suggest that craving may evoke drug use behavior (Anton, 1999; Brewer et al., 2014; Robinson & Berridge, 2008; Robinson & Berridge, 1993). Cognitive models are based on social learning theory, hypothesizing that craving occurs primarily as a result of classical conditioning in relation to environmental cues, and a constellation of cognitive factors (e.g., abstinence self-efficacy; expectancies; coping) determine the meaning and consequence of craving (Drummond, 2001; Marlatt & George, 1984; Tiffany, 1990). Transdisciplinary and psychobiological models integrate research and theory from cognitive and behavioral approaches. Examples are the dual-process model of addiction, wherein substance-related stimuli may trigger implicit processes and automatic associations with substance use and lead to craving (Lindgren, Foster, Westgate, & Neighbors, 2013; Lindgren, Neighbors, Wiers, Gasser, & Teachman, 2015), and the biopsychosocial dynamic model, in which cognitive variables such as abstinence coping behaviors influence the relationship between craving and relapse (Witkiewitz & Marlatt, 2007). These models maintain the importance of reinforcement through operant conditioning, as well as automatic associations

from classical conditioning, allowing for consideration of moderators of the relationship between craving and use (Abrams, 2000; Drummond, 2001; Franken, 2003; Witkiewitz & Marlatt, 2007). These models have been widely adopted, and inform contemporary research on treatment mechanisms and craving as an intervention target (Connolly et al., 2013; Kavanagh & Connor, 2013; May et al., 2014; Moore et al., 2014; Witkiewitz, Bowen, Douglas, & Hsu, 2013).

Craving, and situations that elicit craving, have long been hypothesized to function as a driving force in substance use disorders and relapse (Brewer et al., 2014; Witkiewitz & Marlatt, 2007). Current research in clinical science, neurobiology, laboratory, and treatment outcomes continue to identify craving as an important construct for understanding the development and maintenance of addiction, and thus identify craving as a promising intervention target (Hopper et al., 2006; Marhe, Waters, van de Wetering, & Franken, 2013; Moore et al., 2014; Sinha, 2013; Waters, Marhe, & Franken, 2012).

Intensive longitudinal assessment of craving and cannabis use

Despite the assumed relationship between craving and use, explicit cross-sectional retrospective self-report measures of craving have proven to be less consistent than expected in predicting use. For example, a recent systematic review of the relationship between retrospective craving and relapse in tobacco users found mixed results in the literature (Wray, Gass, & Tiffany, 2013). Although authors noted that investigators frequently assume a relationship between craving and relapse, results from analysis of the predictive association between craving and outcomes are rarely reported, and may be a casualty of the file-drawer effect (Wray et al., 2013). Recently, investigators have begun to question whether mixed findings in the literature may be due to measures relying on retrospective self-report (Drummond, 2001; Kavanagh et al., 2013; Merikle, 1999). As a consequence of null results, and the improved feasibility of intensive

longitudinal assessment using personal computing devices and internet access over the last decade, interest has grown in the relationship between craving measured with increased ecological validity and substance use behavior (Shiffman, 2009).While retrospective measures of craving have demonstrated some degree of predictive validity, ecological momentary assessment has demonstrated a strong link between craving and use among individuals with more severe substance use disorders (Serre et al., 2015). Indeed, a recent systematic review of ecological momentary assessment of the relationship between craving and substance use points toward a strong predictive influence of craving on subsequent relapse (Serre et al., 2015). Examination of the momentary relationship between craving and illicit substance use among young adults is limited, however, with a small number of studies investigating momentary craving and cannabis use (Phillips et al., 2015). In a study with college student cannabis users, a temporal association between craving and cannabis use was found, such that craving at one time point significantly predicted quantity of time spent using cannabis, and frequency of use reported at the subsequent time point (Phillips et al., 2015). Another study, with non-treatment-seeking adolescent cannabis users, found that momentary craving was significantly positively associated with subsequent cannabis use (Buckner et al., 2015). Thus, a small but growing body of evidence indicates that momentary craving may be an important risk factor for young adults at risk of developing a cannabis use disorder, as it has for individuals with more severe substance use disorders (Donovan & Witkiewitz, 2012; Moore et al., 2014; Witkiewitz, Lustyk, et al., 2013).

Due to the limited number of studies utilizing intensive longitudinal assessment, further research is needed to replicate these results, and explore the association between different facets of craving and probability of subsequent use with a population interested in reducing their use. The mixed results from studies using cross-sectional retrospective self-report assessment of craving

indicate that a more direct comparison of intensive longitudinal assessment and cross-sectional retrospective self-report assessment is needed to clarify the relevant strengths and weaknesses of each method.

The current study

The purpose of the current study was to investigate the association between craving and use over time using intensive longitudinal methods. Specifically, the current study examined the hypothesis that craving would be positively associated with subsequent use. By collecting data about experience and behavior in naturally occurring contexts, the current study also aimed to examine the hypothesis that intensive ecological momentary assessment of craving and use would produce stronger craving-predictors of subsequent use behavior than cross-sectional retrospective self-reports of craving alone.

METHOD

An intensive repeated measure design was used to investigate the association between craving and use for young adults (N=86) who used cannabis regularly and were interested in reducing their use. The initial baseline phase of data collection was followed by a second phase consisting of a two-week period of intensive longitudinal data collection using ecological momentary assessment methodology (Laird, Donnelly, & Ware, 1992; Shiffman, 2009; Walls & Schafer, 2006). A two-week period has been demonstrated to be an appropriate period for monitoring substance use in this population (Buckner et al., 2015; Buckner, Crosby, Silgado, Wonderlich, & Schmidt, 2012).

Participants and recruitment

Participants were recruited from a large public university in the Northwestern United States. Interested participants completed a brief screening questionnaire to assess past month

level of cannabis use, readiness to change using the Readiness to Change Questionnaire (RCQ; Rollnick, Heather, Gold, & Hall, 1992) and cannabis-related problems using the Cannabis Use Disorder Identification Test-Revised (CUDIT-R; Adamson et al., 2010).

Eligible participants 1) were between ages 18-29, 2) reported using cannabis an average of at least two days per week during the previous month 3) were not in a pre-contemplation or maintenance stage of change (Rollnick et al., 1992), 4) met Cannabis Use Disorder Identification Test (CUDIT-R) criteria for problematic cannabis use (Adamson et al., 2010), and 5) owned a smartphone. Eligible students were contacted and invited to participate in the current study (N=86).

Procedures and retention

Eligible participants completed baseline data collection on study computers in the research lab, for which they received course credit. Upon completion of the baseline assessment, participants downloaded the EMA application 'mobile Ecological Momentary Assessment' (mEMA, by Ilumivu) to their phone, and received instructions on how to access assessments. mEMA collects de-identified, password protected data, is HIPAA compliant, and had demonstrated feasibility, usability, and ecological validity with young adults (Spook, Paulussen, Kok, & van Empelen, 2013). Craving and cannabis use were assessed using mEMA surveys. Following recommended guidelines (Shiffman, 2009), surveys were sent at random points during three discrete four-hour time-windows (10am-12pm, 3pm-5pm, 8pm-10pm), and participants had 2 hours to complete the survey.

After initial training, participants completed a 2-day period of compliance, and received feedback via phone at the end of the initial two day period, as well as daily email reminders with compliance feedback, which has been demonstrated to increase response rates among non-

treatment-seeking samples of substance users (Buckner et al., 2012; Hopper et al., 2006; Shiffman et al., 2002; Smyth et al., 2007). During the two-week period of active assessment, participants were compensated $1.00 for each completed survey, as well as an additional $1.00 for each day with all surveys completed, for a total of $5.00 possible per day and $70.00 possible per 14-days of EMA. Participants who complete all 56 surveys received an additional $10. Participants returned to the lab one month later to complete the final phase follow-up assessment, containing all time-variant measures (i.e., excluding demographics) completed during screening and baseline assessment.

Measures

Screening measures: Age and sex were assessed during screening. Additionally, average days of cannabis use per week, as well as problems and readiness to change were assessed.

Cannabis-related problems. Problems related to cannabis use were assessed using the Cannabis Use Disorder Identification Test – Revised (CUDIT-R, Adamson et al., 2010). The CUDIT-R is a brief 8-item measure of cannabis misuse with demonstrated reliability, sensitivity, and discriminant validity. A score of 8 or more indicates hazardous use, and 12 or more indicates a possible cannabis use disorder (Adamson et al., 2010). An example item from the scale is, "How often during the past 6 months did you fail to do what was normally expected from you because of using cannabis?", with response options ranging from "Never" (0) to "Daily or almost daily" (4).

Readiness to change. The Readiness to Change Questionnaire (RCQ: Rollnick et al., 1992) is a short, 12-item measure used to assess peoples' stage of change on three dimensions (pre-contemplation, contemplation, action) in relation to substance use. Summary scores for each of

the dimensions range from -3 to 3. An example item from the action dimension is, “I am trying to use less marijuana than I used to.”

Baseline assessment measures: All baseline measures were completed in study offices on lab computers.

Craving. Craving was assessed using the Marijuana Craving Questionnaire (MCQ: Heishman, Singleton, & Liguori, 2001). The MCQ is a 12-item self-report measure of four craving-related factors: compulsivity, emotionality, expectancy, and purposefulness. An example item from the purposefulness factor is the reverse scored response to the following, “Right now, I am not making any plans to use marijuana.”

Ecological momentary assessment items: Participants were taught to use the mEMA application on their mobile phone (Spook et al., 2013). Response options were categorical checkboxes or sliding scales corresponding to the nature of the item.

Craving was assessed with two items drawn from craving measures to assess thoughts about cannabis and urges or desire to use cannabis. Cannabis-related thoughts were assessed using the following item: “How much were you thinking about using marijuana or how it would make you feel?” Cannabis-related urges were assessed with the item: “When you wanted to use marijuana the most, how strongly did you want to use?”

Cannabis use was assessed with one item, "Since the last survey, approximately how many times did you use marijuana?" Using data from this single item, two separate binary outcomes were created: proximal use, and distal use. Proximal use was 1 in all cases where responses were greater than 0, and where the peak strength of craving occurred prior to use as assessed by a single item, "Did you use marijuana after your desire to use peaked?" Distal use was 1 in all cases where responses were greater than 0 on the subsequent survey. In summary, proximal use

was use during the subsequent 0-4 hour period, and distal use was during the subsequent 1-9 hour period. Because of the relatively extended period of time that elapsed between the previous night and the following morning, all morning cannabis use assessments were excluded from the distal use variable.

Time of day was the survey time point. Each time point was assigned a value based on the time of day that the survey was completed, with 1 = Morning (10am-12pm), 2 = Afternoon (3pm-5pm), 3 = Evening (8pm-10pm), and 4 = Last Night (after Evening survey). Surveys were sent at a random time within the two-hour window, and completed within the following two hours.

Data analytic plan

All data were entered on the web using DatStat Illume or collected through the mEMA website (http://www.mobileema.com) and subsequently downloaded for analysis using *R*. Response rates were examined to evaluate how compliance, attrition and fatigue may have affected the internal validity of the study.

Descriptive analyses. Frequency distributions, measures of central tendency and variation were explored to establish sample characteristics. Bivariate correlations were computed with all study variable combinations in order to identify zero-order relationships among variables and to inform subsequent model testing. Due to the clustered nature of the data, sample-wide zero-order correlational analyses of study variables were of limited utility to inform multilevel model testing.

Inferential analyses. Multilevel models were used to explore the associations between craving and use, consistent with best practices in model development (Snijders & Bosker, 2011). Multilevel modeling (MLM) is an analytic approach that accounts for outcomes that are clustered. Due to the use of within-person repeated measurement, it was assumed that clustering

by participant would occur. MLM more accurately models the characteristics of clustered variables, consistent with the underlying mechanisms generating the observed data. All MLMs were tested using the `glmer` function contained in the `lme4` package in `R`, which uses generalized linear models with a logistic response function to compare means of predictors at each observation with use (1) or no use (0). The prospective associations between craving and use were investigated using four baseline trait craving predictors (compulsivity, emotionality, expectancy, and purposefulness) and two momentary craving predictors (thoughts and urges), with two use outcomes (concurrent use and subsequent use). Person-mean craving was computed to create a Level 2 variable representing difference in mean scores on craving items between people. Time was included in modeling as a predictor to control for time as a known environmental factor related to use (Buckner et al., 2015). All steps in the model building process were compared to previous iterations using deviance testing; Akaike's Information Criteria (AIC), Bayesian Information Criteria (BIC), and Log-likelihood ratio tests (-2 LLR).

Missing data. Completion rates were examined to determine how non-completion affected the internal validity of the study. Survey completion and non-completion were compared on study variables to detect potential systematic attrition and missing data patterns. Using fully observed variables to predict frequency of missingness, no study variables were significant predictors of missingness (Snijders & Bosker, 2011). Rates of missing data in the current sample were similar to those reported in the literature (Buckner et al., 2012; M. M. Phillips, Phillips, Lalonde, & Dykema, 2014). Full information maximum likelihood (FIML) is a method for using all observations to produce the most accurate estimate given the specified model and the observed data (Hallgren & Witkiewitz, 2013). FIML was applied during all model fit procedures to limit the bias introduced by missing data and increase the accuracy of parameter estimates.

RESULTS

Means and standard deviations for all study variables are available in Table 1. The current sample was 41% women, and the average age was 19.6 (SD = 2.20) years. Cannabis use occurred on an average 3.76 (SD = 1.74) days per week, and the average CUDIT-R score was 18.8 (SD = 4.56), indicating substantial problems related to use (Adamson et al., 2010). On average, the sample endorsed the Action stage of change (M=0.92, SD = 3.61) more strongly than the contemplation stage (M=0.07, SD = 3.48). Of the 4,816 EMA surveys, 78% were completed.

Assessing clustering

The hypothesis that clustering had occurred in the outcome was tested by running an intercept only model, allowing the intercept to vary by participant. For the current study, the intra-class correlation coefficient (ICC) is an inferential statistic that summarizes how strongly observations from the same individual resemble one another. In this case, the ICC was computed by dividing the intercept residual by the total residual. Results indicated that 33% of variance in the proximal use outcome was shared by observations from the same participant, and 31% of distal use, which confirmed that a two-level MLM approach was an appropriate method for evaluating and exploring the associations between predictors and the outcome.

Determining the model

Given the hypothesis that trait and momentary craving would be associated with the outcome, each variable was added as a fixed effect in the random intercept model before specifying the full model with all predictor variables included. Level 1 variables are those that vary by observation. In this case, craving-related thoughts and urges were the two items that varied by observation. Time of day also varied by observation, and was included as a categorical

explanatory variable to control for the effect of time, which has been demonstrated to be a strong predictor of use in previous research (Buckner et al., 2012, 2015). Level 2 variables are those that vary by group (participant). In this case, trait compulsivity, emotionality, expectancy, and purposefulness varied by participant. Retaining all variables, the full model that was tested was as follows:

Level 1:

$$Use = \gamma_{01} + \gamma_{1j}CravingThoughts + \gamma_{2j}CravingUrges + \gamma_{3j}Time + e_{ij}$$

Level 2:

$$\gamma_{01} = \beta_{00} + \beta_{01}Compulsivity + \beta_{02}Emotionality + \beta_{03}Expectancy + \beta_{04}Purposefulness + r_{1j}$$

$$\gamma_{1j} = \beta_{10} + r_{2j}$$

$$\gamma_{2j} = \beta_{20} + r_{3j}$$

$$\gamma_{3j} = \beta_{30} + r_{4j}$$

Parameters were removed or retained in the final model based on whether or not the coefficient had a significant main effect ($p < .05$). Both momentary craving predictors were also evaluated as random effects, which allows the slope of the effect to vary between clusters (participants). Additional considerations were made if parameter inclusion or exclusion significantly altered model fit based on deviance testing. To simplify interpretation of results, all within-group predictors (momentary craving; thoughts and urges) were centered by group, and person-mean of both momentary craving predictors was also included to control for between-group variation All Level 2 predictors collected at baseline (MCQ) were centered at the population mean.

Specifying the model with each craving predictor separately

The primary goal of the current analysis was to explore the associations between two within-person level variables (Level 1), two between-person level variables that were aggregated from the two Level 1 variables, and four between-person level variables (Level 2) that were assessed at baseline and theoretically associated with subsequent cannabis use. First, Level 1 variables that were not substantively related to the primary study hypotheses but were controlled for in analysis were included in the model. Specifically, time of day, which was significantly associated with both proximal (OR = 2.37, 95% CI [2.15, 2.61]) and distal (OR = 2.35, 95% CI [2.09, 2.65]) use. Next, Level 1 variables that varied by individual, were entered separately as fixed effects, in order to begin developing and refining the model beyond the random intercept only model. Results indicated that within-person level craving variables, cannabis-related thoughts and cannabis-related urges, were both associated with proximal and distal use.

Momentary changes in cannabis-related urges were positively associated with proximal use and distal use. Person-mean level of urges was also positively associated with proximal use and distal use. Adding the random effect of momentary urges also significantly improved model fit. A similar pattern was observed for cannabis-related thoughts. Momentary changes in cannabis-related thoughts were positively associated with proximal use and distal use. Person-mean level of thoughts was also positively associated with proximal and distal use. Also, the random effect of thoughts improved model fit.

Finally, Level 2 variables that varied by individual but not with time were entered individually into the model to test for fixed effects on proximal and distal use. Three of four subscales of the baseline trait craving measure (MCQ) were positively associated with proximal and distal use: compulsivity, expectancy, and purposefulness.

The final models were tested for both proximal and distal use, which included all fixed effects that were associated with the outcome: time of day, cannabis-related thoughts and urges at the momentary level and person-mean level, and three of the subscales of the baseline craving measure: compulsivity, expectancy, and purposefulness. The final models also included a random effect for both urges and thoughts.

Results of the final model predicting proximal cannabis use

As hypothesized, each of the two momentary craving predictors was uniquely positively associated with proximal cannabis use, controlling for time of day, person-mean craving, the other momentary craving predictor, and the trait craving predictors. Results from the final model predicting proximal use are available in Table 2. Two of the Level 2 variables also provided unique variance accounted for in proximal use: person-mean urges, and purposefulness. For Level 1 variables odds ratios (OR) represent the probability of cannabis use given a one person-SD increase in the predictor above a person's mean. Level 2 variable ORs represent the change in probability of cannabis use given a one population-SD increase above the population-mean.

For example, when all other predictors were at their mean, a one standard deviation increase in the Level 1 craving-related urges above an individual's mean urge was associated with a 3.28-fold increase in the odds of cannabis use during the next four hours (OR = 3.28, 95% CI [2.51, 4.27]). Similarly, when all other predictors were at their mean, a one person-SD increase above an individual's mean of cannabis-related thoughts was associated with a 1.65-fold increase in odds of cannabis use during the following four-hour period (OR = 1.65, 95% CI [1.31, 2.08]). For the Level 2 person-mean urges predictor, a one population-SD increase above the population-mean was associated with a 4.48-fold increase in odds of cannabis use (OR = 4.48, 95% CI [1.80, 11.12]).

Results of the final model predicting distal cannabis use

For the final model predicting distal use only person-mean urges was associated with use. Results from the final model predicting distal use are available in Table 3. When all other predictors were at their mean, a one population-SD increase in urges above the population-mean was associated with a 3.29-fold increase in odds of cannabis use (OR = 3.29, 95% CI [1.70, 6.39]).

Summary of results investigating the association between craving and use

Momentary and average craving were strongly associated with proximal use, and distal use. When measured at baseline, the effect of craving on probability of use was not as strong. Baseline compulsivity, expectancy, and purposefulness were all associated with probability of use, although effect sizes were smaller. Additionally, when all craving predictors were included in a single model, purposefulness was the only of the baseline craving predictors that remained associated with use, and only with proximal use. The lack of an association between baseline craving and use suggests that the four baseline craving predictors did not provide unique variance accounted for when controlling for predictors produced by the EMA measurements.

Additionally, momentary craving was associated with proximal use in the final model, but this was not the case for distal use. Momentary thoughts and urges, and average urges were all strongly positively associated with proximal use (Table 2). Only average urge was a predictor of distal use in the final model (Table 3).

DISCUSSION

The primary aim of the current study was to investigate the hypothesized association between craving and use through analysis using both trait-level dispositional craving and momentary craving measurements as predictors. The utility of dispositional craving measures as

predictors of subsequent substance use behavior has been in doubt, with systematic reviews reporting mixed results (Wray et al., 2013). Meanwhile, intensive longitudinal methods such as EMA have demonstrated the strength of craving as a predictor of use, with consistent and sizable positive associations between craving and use (Serre et al., 2015 for review).

The results from the current study indicate that the measurement of momentary craving provides substantial predictive utility over and above what baseline craving measures are able to produce. Momentary craving was a strong predictor of subsequent cannabis use. Estimates of the effect of both thoughts and urges provided significant predictive utility when modeling the probability of subsequent cannabis use, controlling for time of day and baseline craving factors. EMA is an approach to assessment that enhances ecological validity by asking participants to report on their experiences frequently throughout the day (Shiffman, 2009). Ecological validity, and variance over time are hypothesized to be particularly relevant features of craving reports, when investigating the longitudinal association between craving and use (Shiffman et al., 2002). When using EMA, investigators have consistently reported a positive association between craving and use (Serre et al., 2015).

The current study investigated the predictive utility of momentary craving at proximal (within the same survey window, but after a peak in craving), and distal (at the next survey window, about 5 hours later) time points. The strong positive association between craving and proximal use suggests that craving is a robust predictor of subsequent use when it is measured with ecological validity using EMA. The fact that momentary craving was only weakly associated with subsequent use in the model predicting distal use serves to underscore the important role of ecological validity in the assessment of craving and use.

The only dispositional craving predictor that provided unique variance accounted for in subsequent use was the purposefulness subscale of the MCQ (Heishman et al., 2001). The purposefulness subscale has been linked with the cognitive theory of craving, which proposes that conscious intention and planning are crucial components that lead to substance use behavior (Heishman et al., 2001; Tiffany, 1990). Purposefulness is also related to behavioral theories. Prior studies have found a positive association between purposefulness and liking marijuana, as well as positive mood, indicating reinforcement may play a role in purposefulness scores. The absence of an effect for the other three subscales of the MCQ in the final model is notable, but not altogether surprising. In validation studies, the purposefulness subscale has been more weakly correlated with cannabis use than other subscales, and yet it was the only factor that remained significant when the momentary predictors were included in the model.

Modeling the probability of substance use behaviors in the context of attempts to reduce use when use has become a source of trouble for individuals has stymied researchers for decades (Witkiewitz & Marlatt, 2007). Critics of the use of craving as a predictor of substance use cite weak associations between measurements of craving and subsequent use behavior (Tiffany, 1990; Wray et al., 2013). Although craving has consistently played a fundamental role in theories that purport to predict substance use behavior, attempts to measure this phenomenon have largely failed to achieve validity. However, the application of intensive longitudinal assessment methods such as EMA represents a paradigmatic shift in how craving is understood (Serre et al., 2015). Findings from the current study, namely the strong positive association between craving and proximal cannabis use, are consistent with those reported by the only two other published EMA investigations of the association between craving and cannabis use (Buckner et al., 2015; Phillips et al., 2015). Additionally, the pattern of findings is similar to

reports for other substances of abuse (Serre et al., 2015). The shift in assessment methods indicated by results of the current study may also facilitate an improvement in understanding how craving relates to not only relapse, but also treatment effectiveness.

Limitations

While the current study utilized intensive longitudinal assessment to evaluate the dispositional and momentary associations between craving and subsequent cannabis use, there are important limitations to acknowledge when interpreting the implications of results. First, a direct comparison of effect sizes between dispositional craving and momentary craving is not possible from the data collected. The scale for the MCQ and the momentary items was not the same. Although attempts to achieve direct congruence were considered, the current research elected to use the strongest psychometric measure available for assessing marijuana craving (MCQ), and adapted items to assess momentary craving.

Another factor to consider was the sample selection. Data from the current study has limited generalizability outside of college student cannabis users interested in reducing their use. Although findings from the current study may be relevant for individuals with other substances of choice, at different stages of development, and in other socio-cultural contexts, the current study does not provide evidence to support this sort of generalization. Research with a more diverse population is needed to address the extent to which findings generalize.

Substance use research using ecological momentary assessment frequently faces difficulties with noncompliance and missing data (Shiffman, 2009). Appropriate steps were taken to identify missing data patterns, and evaluate the likelihood that data were missing at random (Little & Rubin, 1987). Additionally, while missingness was comparable to other studies with similar designs (Buckner et al., 2012; Phillips, Phillips, Lalonde, & Dykema, 2014),

methods for increasing survey completion rates during intensive longitudinal assessment are continuing to improve. Future research may benefit from applying additional and improved methods to increase survey completion rates.

Conclusions

The current study investigated dispositional craving and momentary craving as predictors of subsequent cannabis use among college student frequent users interested in reducing their use. Overall, there was evidence that momentary craving was strongly associated with subsequent cannabis use, and some evidence that baseline craving was also predictive of use. While time of day was a strong predictor of use, average level of urges, and momentary changes in urges and thoughts about using remained strongly positively associated with subsequent use after accounting for the effect of time of day. None of the other three factors of craving measured by the MCQ (compulsivity, emotionality, and expectancy) were associated with use. The pattern of results consistently indicated that momentary changes in urge to use were a stronger predictor of subsequent use than thoughts about use. Also, the strength of the effect of momentary craving appears to be highly sensitive to the timing of follow-up assessment. Momentary craving was strongly associated with proximal use, however, distal use (occurring up to 9 hours later) was not predicted by momentary craving.

Findings from the current study suggest that craving is indeed a powerful predictor of cannabis use. However, the strength of the association between craving and use appears to be highly sensitive to time between assessments. Theories that situate craving as an important factor in the development and maintenance of cannabis use disorder are supported by results from the current study. Many treatments aim to target craving. With a target such as craving, where temporal proximity is highly relevant to measurement of effects, it would behoove researchers to

enhance ecological validity and ensure that the target is as large in the data as it is in participants' experience. Efforts to evaluate the effectiveness of treatments that do target craving may benefit from applying intensive longitudinal assessment methods to research trials, and enhancing the temporal resolution with which the effect is measured to increase the validity of observed effects and our understanding of the development, maintenance, and recurrence of substance use disorders.

Table 1. Means, standard deviations, and zero-order correlations.

Variable	n	*M*	*SD*
1. Proximal use	3728	0.28	0.45
2. Distal use	2868	0.32	0.47
3. Time of day	3728		
4. Craving (Urges)	3700	1.92	2.44
5. Craving (Thoughts)	3702	1.91	2.33
6. Compulsivity	86	1.68	.94
7. Emotionality	86	3.06	1.51
8. Expectancy	86	3.70	1.47
9. Purposefulness	86	3.89	1.70

Note. Craving and use were assessed using EMA. In total, 78% of EMA surveys were completed. Variables 6-9 were Level 2 variables measured using the Marijuana Craving Questionnaire.

Table 2. Final multilevel model results, clustered by participant, predicting proximal use.

Predictor	*b*	*SE*	*p*	OR	95% CI
(Intercept)	-4.24	0.28	<.001	0.01	[0.01, 0.03]
Time of day	0.81	0.07	<.001	2.24	[1.97, 2.55]
Momentary urges	1.19	0.14	<.001	3.28	[2.51, 4.27]
Person-mean urges	1.50	0.47	<.001	4.48	[1.80, 11.12]
Momentary thoughts	0.50	0.12	0.001	1.65	[1.31, 2.08]
Person-mean thoughts	-0.71	0.49	0.148	0.49	[0.19, 1.29]
Compulsivity	-0.04	0.20	0.832	0.96	[0.64, 1.43]
Expectancy	-0.34	0.18	0.051	0.71	[0.51, 1.00]
Purposefulness	0.37	0.15	0.012	1.45	[1.09, 1.93]

Note. Proximal use was cannabis use that was reported at the same survey prompt, but as having occurred after craving was strongest. Craving-related urges and thoughts were assessed using a single item on each EMA survey. Momentary variables were Level 1 momentary reports. Person-mean variables were Level 2 variables created using the aggregated mean of each person on the momentary item. Craving predictors that had no main effect on use when tested independently were not included in the final model.

Table 3. Final multilevel model results, clustered by participant, predicting distal use.

Predictor	*b*	*SE*	*p*	OR	95% CI
(Intercept)	-2.93	0.22	<.001	0.05	[0.04, 0.08]
Time of day	0.96	0.08	<.001	2.60	[2.24, 3.03]
Momentary urges	0.11	0.09	0.216	1.12	[0.94, 1.33]
Person-mean urges	1.19	0.34	<.001	3.29	[1.80, 6.39]
Momentary thoughts	0.14	0.08	0.094	1.15	[0.98, 2.08]
Person-mean thoughts	-0.66	0.36	0.067	0.52	[0.28, 1.05]
Purposefulness	0.026	0.09	0.771	1.03	[0.86, 1.23]

Note. Distal use was cannabis use that was reported at the subsequent survey prompt. Craving-related urges and thoughts were assessed using a single item on each EMA survey. Momentary variables were Level 1 momentary reports. Person-mean variables were Level 2 variables created using the aggregated mean of each person on the momentary item. Craving predictors that had no main effect on use when tested independently were not included in the final model.

IV. Surfing urges: An investigation of factors that influence craving-related risk of use among young adults with problematic cannabis use

Matthew Enkema

ABSTRACT

Frequent cannabis use has become an increasingly prevalent pattern of behavior, and many frequent users find it difficult to reduce their use. A strong link between momentary craving and subsequent use behaviors among individuals with problematic substance use behaviors has been reported in the literature, and this pattern of an effect of craving on use appears to be present for cannabis users. Treatments to reduce the prevalence of problematic substance use have focused on altering the association between craving and use by increasing craving management skills such as mindfulness, reducing unhelpful responding such as avoidance or suppression, and modifying related automatic processes such as implicit identity. However, this same approach to treatment and prevention has not been applied to non-treatment seeking young adult cannabis users. In a sample of young adults with problematic use interested in reducing their use, the current study examined the influence of craving management and other hypothesized moderators of the effect of craving on use through analysis of ecologically valid assessments of craving and subsequent use behavior. Results demonstrated that several moderators influenced the relationship between craving and use. Understanding the factors that influence the momentary association between craving and use will improve treatments to reduce the prevalence and severity of cannabis use disorders.

Keywords: Craving; Cannabis Use; Mindfulness; Implicit Identity; Intensive Longitudinal Assessment

INTRODUCTION

Problematic cannabis use is linked to negative health outcomes (Haberstick et al., 2014). The prevalence of problematic use peaks during young adulthood, with the majority of cannabis use disorder diagnoses occurring by age 23 (Butterworth et al., 2014). Young adulthood is a sensitive biopsychosocial developmental period, and thus an important period for prevention and intervention programs to reduce vulnerability to and severity of disorders (Butterworth et al., 2014; Lee et al., 2013).

Treatments for problems related to substance use often focus treatment around triggers such as craving, due to the hypothesized relevance of craving to substance relapse (Kavanagh & Connor, 2013). Studies of craving have typically utilized retrospective self-reports of typical craving or average craving; even studies using the strongest retrospective self-report psychometric methods have produced mixed results for craving as a predictor of substance use (Wray et al., 2013). In contrast, studies using ecological momentary assessments (EMA) to measure craving have produced results supporting the hypothesis that craving is predictive of relapse. A recent systematic review of craving and substance use concluded that craving was a strong positive predictor of subsequent substance use when assessed in close temporal proximity (Serre et al., 2015).

Individuals attempting to reduce their substance use receive a number of messages regarding craving management that may sometimes appear contradictory. Typically, the recommendation is to reduce exposure to potentially high-risk situations that may trigger use (Hone-Blanchet, Wensing, & Fecteau, 2014; Litvin, Kovacs, Hayes, & Brandon, 2012; Murphy & MacKillop, 2014). Another approach that is common among treatments for substance misuse is based on behavioral theory and exposure therapy, and incorporates components of training that

focus on acceptance, or altering peoples' avoidant response to unpleasant momentary experiences such as craving (Bowen et al., 2014; Witkiewitz et al., 2014). Previous investigations have identified acceptance coping, behavioral disengagement, and self-distraction as factors which moderate the momentary craving-related risk of relapse in a population with alcohol use disorders following treatment (Moore et al., 2014). Acceptance coping was found to be protective, while behavioral disengagement and self-distraction both increased risk of relapse (Moore et al., 2014).

Craving management as an intervention target

Prevention and treatment approaches typically do not address craving, possibly because it is not considered relevant to the early developmental stages of problematic use. Motivational enhancement and normative interventions have shown promise for non-treatment-seeking cannabis using young adults (Lee et al., 2013; Walker et al., 2011). However, we need more powerful interventions targeting specific mechanisms of problematic use in order to achieve larger effects, and improve maintenance of changes beyond the current 3-month and 6-month drop-offs (Walker et al., 2016; Bowen et al., 2014).

Interventions targeting craving have demonstrated significant benefit for individuals recovering from more severe substance use disorders, and craving management may be an important target for the enhancement of interventions for young adults (de Dios et al., 2012; Donovan & Witkiewitz, 2012; Moore et al., 2014; Witkiewitz, Bowen, et al., 2013). Among treatment-seeking adults, several efficacious treatment approaches have focused on how participants relate to craving (Brewer et al., 2014; Elwafi et al., 2013; Garland & Black, 2014; Witkiewitz, Bowen, et al., 2013). Treatments targeting craving aim to improve craving management behaviors, and provide participants with helpful and effective ways to respond

when craving arises (Elwafi et al., 2013; Garland & Black, 2014; Witkiewitz, Bowen, et al., 2013; Zgierska et al., 2009). Outcomes for treatment programs focused on improving craving management have been consistently positive (Chiesa & Serretti, 2014; Elwafi et al., 2013; Garland & Black, 2014; Witkiewitz et al., 2014). Results indicate that interventions to increase acceptance and mindfulness reduce the craving-related risk of use for tobacco users (Elwafi et al., 2013) and polysubstance users (Enkema & Bowen, 2017). One combined intervention incorporating motivational enhancement and training related to acceptance and mindfulness for young-adult female cannabis users with co-occurring anxiety reported promising results from a pilot test of the efficacy (de Dios et al., 2012).

Craving management variables influence the relationship between momentary craving and use (Elwafi et al., 2013; Enkema & Bowen, 2017; Farris, Zvolensky, DiBello, & Schmidt, 2015; Moore et al., 2014; Witkiewitz, Bowen, et al., 2013). Seeking relief from unpleasant or unwanted experiences is thought to be one of the strongest factors in the development and maintenance of problematic substance use, as identified by the allostatic model of addiction (McCarthy, Curtin, Piper, & Baker, 2010; Baker, Piper, McCarthy, Majeskie, & Fiore, 2004; Khantzian, 1997). Cannabis users report that coping is a primary motive for use (Hathaway, 2003; Lee, Neighbors, & Woods, 2007), and experiential avoidance, or "the tendency to engage in behaviors that result in reduction or avoidance of internal distress" (Minami, Bloom, Reed, Hayes, & Brown, 2015, p. 400) has been linked to substance use disorders (Levin et al., 2012; Luoma, Kohlenberg, Hayes, Bunting, & Rye, 2008). Current treatments for substance use disorder frequently propose that coping style and method are crucial to reducing problematic substance use (Witkiewitz et al., 2014; Witkiewitz, Marlatt, & Walker, 2005; Witkiewitz & Marlatt, 2007), and outcome studies have supported this hypothesis (Enkema & Bowen, 2017; T.

M. Moore et al., 2014; Elwafi et al., 2013; Garland et al., 2014). Recent research has also begun to explore the role of craving management, or psychological constructs that may influence the relationship between craving and relapse (i.e., *Coping style*: Moore et al., 2014; *Experiential avoidance*: Farris, Zvolensky, DiBello, et al., 2015; *Mindfulness*: Enkema & Bowen, 2017). This growing body of literature indicates craving management variables may significantly moderate the relationship between craving and substance use, which points to dispositional craving management factors being a beneficial target for treatment.

Coping style

In a recent clinical trial using ecological momentary assessment, the strongest proximal predictor of relapse among individuals who recently completed treatment at an inpatient treatment center was craving (Moore et al., 2014). When looking at coping style as a moderator of the relationship between craving and use, findings indicated that trait level acceptance-based coping was protective during and subsequent to periods of increased craving, while avoidant coping (i.e., 'self-distraction' and 'behavioral disengagement') increased the risk of subsequent substance use (Moore et al., 2014).

Experiential avoidance

Consistent with the allostatic model of addiction (or self-medication hypothesis), distressing internal states may lead to a habit of distress management via engaging in behaviors which provide relief, such as cannabis use (Khantzian, 1997). In this way, cannabis use and craving for use may be understood as experiential avoidance (Hayes, Wilson, Gifford, Follette, & Strosahl, 1996; Minami et al., 2015). Psychological inflexibility is the degree to which an individual holds to rigid thoughts or beliefs, such as, "Thoughts about using will lead me to smoke" (Minami et al., 2015). One recent investigation of experiential avoidance among tobacco

users indicates that the construct may measure a phenomenon that moderates the relationship between internal distress and substance use (Farris, Zvolensky, DiBello, et al., 2015; Farris, Zvolensky, & Schmidt, 2015; Minami et al., 2015).

Mindfulness

Mindfulness is a psychological phenomenon often described as a kind and curious awareness of current experience (Enkema & Bowen, 2017). Training intended to increase mindfulness has been demonstrated to effectively reduce the likelihood and severity of relapse following treatment for substance use disorders (Bowen et al., 2014; Creswell, 2017). The effectiveness of mindfulness training as an intervention is based on the hypothesis that mindfulness increases awareness of craving and other conditioned responses that would typically lead to use, and thus reduces the automaticity with which substance use behaviors occur for people with problematic use (Enkema & Bowen, 2017; Garland et al., 2014; Witkiewitz, Bowen, et al., 2013). A growing body of literature suggests that training in mindfulness may produce protective effects via reduction of the strength of the association between craving and subsequent use (Enkema & Bowen, 2017; Elwafi et al., 2013). However, no studies have yet investigated the moderating effect of mindfulness using ecological momentary assessment.

Automatic processes influence craving and use

Automatic processes may be additional risk factors for cannabis use, moderating the influence of craving. While explicit reports of baseline craving have demonstrated limited predictive utility for substance use (Wray et al., 2013), automatic processes have demonstrated consistent associations with negative substance use outcomes (Field, Munafò, & Franken, 2009; Franken, 2003; Lindgren, Foster, Westgate, & Neighbors, 2013). There are at least two reasons why the measurement of automatic processes is important to understanding cannabis use

behavior. Firstly, individuals may not be willing or able to report directly on all psychological phenomena relevant to use (Lindgren, Neighbors, et al., 2013). Additionally, measures of automatic processes may assess underlying processes that are unique from those assessed using explicit measures (Lindgren, Neighbors, et al., 2013). These two considerations are particularly relevant in relation to cannabis misuse, considering the proposed dual process model of addiction (Stacy & Wiers, 2010; Wiers et al., 2007), wherein substance-related stimuli trigger implicit processes and automatic associations that may be risk factors for craving and cannabis use (Lindgren, Neighbors, et al., 2013).

Implicit marijuana identity

Implicit identity is a measure of how strongly a person identifies with a behavior (e.g., identifying with smoking cannabis), and has been shown to be a strong predictor of how much a person will engage in that behavior and associated behaviors (Lindgren, Foster, et al., 2013). The Drinking Identity Implicit Association Test (IAT) (Greenwald, McGhee, & Schwartz, 1998) has demonstrated an ability to predict unique variance in alcohol use outcomes for young adults in college (Lindgren, Foster, et al., 2013; Lindgren, Neighbors, et al., 2015). Among implicit constructs related to alcohol use, implicit identity has been an especially strong predictor of consumption, cravings, and problems associated with alcohol use (Lindgren, Foster, et al., 2013; Lindgren, Neighbors, et al., 2013). For an implicit measure, the Drinking Identity IAT has demonstrated robust test-retest reliability (r = .70), as well as consistent predictive validity (Lindgren, Foster, et al., 2013; Lindgren, Neighbors, Westgate, & Salemink, 2014; Lindgren, Neighbors, et al., 2015). Preliminary data from an adaptation of the Drinking Identity IAT for young adult cannabis users has indicated that this measure is appropriate for assessment with this population (Lindgren, personal communication, 2015). Direct implicit identity retraining has

shown promise for treatment-seeking adults recovering from alcohol use disorders (Stacy & Wiers, 2010), but trials with young adults without disorder have reported null results (Lindgren, Wiers, et al., 2015). Further research is needed to clarify the relationship between implicit marijuana identity, momentary craving, and subsequent use, as momentary craving may be an important access point for future interventions.

Marijuana attentional bias

Attentional bias for cannabis use is a measure of the extent to which exposure to external and internal stimuli associated with cannabis may produce an enhanced attention to further cues, which may increase craving, and thus increase the likelihood of cannabis use (Fatseas et al., 2015; Field, 2015; Field, Mogg, & Bradley, 2004). The incentive sensitization theory of addictive behavior suggests that repeated substance use results in neurological alterations in reward circuitry, leading to sensitization for substance related cues which may in turn lead to craving (Robinson & Berridge, 2008; Robinson & Berridge, 1993). The attentional bias model of addictive behavior builds on incentive sensitization theory, suggesting that attention may become biased toward substance related cues leading to the development of a feedback loop, which may serve to increase substance use by increasing the salience and effect of craving on use (Franken, 2003). Indeed, a link between attentional bias and self-reported craving has been demonstrated across substances (Field et al., 2009). This theory may also apply to non-treatment seeking young adults, as laboratory cue exposure research indicates that in-vivo exposure to alcohol cues biases attention for heavy drinking young adults to subsequent alcohol-related cues, with a small but stable association between attentional bias and craving (Field, 2005; Ramirez, Monti, & Colwill, 2015a, 2015b; van Hemel-Ruiter, de Jong, Oldehinkel, & Ostafin, 2013).

The current study

The purpose of the current study was to investigate factors that are thought to influence the association between craving and use. Specifically, the current study tested the hypothesis that explicit trait and state level factors (i.e., coping style, mindfulness, and psychological flexibility) as well as automatic processes (i.e., implicit identity and attentional bias) would moderate the association between craving and use for young adult cannabis users interested in reducing their use.

METHOD

Young adults who used cannabis regularly and were interested in reducing their use (N = 86) were recruited to participate in a longitudinal study assessing cannabis use and related experiences using ecological momentary assessment (EMA). Participants first completed a series of questionnaires on study computers at baseline, and then completed brief surveys on their smartphone 4 times per day for the following 14 days (Morning, Afternoon, Evening, Night).

Participants and recruitment

Participants were undergraduate students at a large university in the Northwestern United States. Eligible participants were between ages 18-29, used cannabis an average of at least two days per week during the previous month, met problematic cannabis use criteria, and indicated that they were in either contemplation or action stages of change related to cannabis use.

Procedures and retention

Participants completed baseline questionnaires in the lab, after which they were trained to complete brief surveys on their phone using the 'mobile Ecological Momentary Assessment' application (mEMA) on their phone (Spook et al., 2013). Participants then completed an initial 2-day period of EMA surveys, followed by feedback on compliance, and a full 14-day period of assessments. Investigators followed recommended guidelines for enhancing survey completion

(Buckner et al., 2012; Hopper et al., 2006; Shiffman et al., 2002; Smyth et al., 2007), and provided feedback and regular reminders via email and phone calls regarding compliance and study protocol throughout the EMA period.

Measures

Screening measures: Demographic variables were assessed, in addition to past month cannabis use. Problems related to cannabis use were assessed using the Cannabis Use Disorder Identification Test-Revised (CUDIT-R, Adamson et al., 2010). The CUDIT-R is an 8-item measure of cannabis use and related problems with established reliability, sensitivity, and discriminant validity. Readiness to change was assessed using the Readiness to Change Questionnaire (RCQ, Rollnick, Heather, Gold, & Hall, 1992). The RCQ is a 12-item measure that assesses identification with each of three unique substance use related stages of change (Pre-contemplation, Contemplation, Action).

Baseline assessment measures: Automatic processes and dispositional trait factors were assessed once at baseline.

Implicit marijuana identity was measured using the Implicit Association Test for Drinking Identity, adapted for cannabis users (Lindgren, Neighbors, et al., 2013). The original Drinking Identity IAT was based on the theory of planned behavior, which states that norms, attitudes, and perceived control all influence intentions, which effects behavior (Ajzen, 1991), as well as evidence that strength of explicit identification with drinking was associated with use (Fekadu & Kraft, 2002). The Drinking Identity IAT produces a measure of speed at which one associates alcohol-related stimuli with words representing the self compared with words representing others. The Drinking Identity IAT has predicted unique variance in alcohol-related outcomes (Lindgren, Neighbors, et al., 2013). In the current study, the Marijuana Identity IAT produced a

measure of whether one was faster at associating marijuana-related stimuli with words representing the self or with others.

Attentional bias was measured using the Alcohol Dot Probe, revised for cannabis (Field, 2005). During the adapted Marijuana Dot Probe task, a fixation cross is presented in the center of the screen, and participants are presented with two pictures from two categories (marijuana and neutral pictures). The position of the pictures is randomly selected (right or left), and after a brief period the two pictures disappear, and a probe stimulus appears in one of the two locations (right or left). Participants are instructed to press one key if the probe is on the right, and another key if the probe is on the left. One's attentional bias score is the average duration from the time the probe stimulus is presented to the time they respond. Attentional bias for cannabis has been demonstrated to be related to both craving and cannabis use (Field et al., 2004).

Coping was measured using the Brief COPE (Carver, 1997). The Brief COPE is a short form, 28-item version of the original COPE, which is used to assess how an individual has been coping with stress. The Brief COPE assesses 14 unique coping styles, using two items for each coping style. Each item is measured on a 4-point Likert-type scale ranging from 1, "I haven't been doing this at all", to 4, "I've been doing this a lot." Three of the 14 total coping styles were used in the current analysis, due to their effect on the association between craving and use reported in previous investigations (Moore et al., 2014): behavioral disengagement, self-distraction, and acceptance. A sample item measuring behavioral disengagement is, "I've been giving up trying to deal with it."

Experiential avoidance was measured using the Avoidance and Inflexibility Scale (AIS: Farris, Zvolensky, & Schmidt, 2015), which was originally designed to be a tobacco smoking-specific measure of experiential avoidance, and was adapted for cannabis users. The AIS is a

unidimensional measure made up of 13 items on a five-point Likert-type scale, broken into three sub-sections: thoughts, feelings, and bodily sensations. Studies of the AIS with tobacco users have demonstrated that the scale produces a valid and reliable smoking-specific measurement of experiential avoidance (Farris, Zvolensky, DiBello, et al., 2015). An example of an item from the section on managing thoughts about using is, “To what degree must you reduce the intensity of these thoughts in order not to use marijuana?”

Mindfulness was measured using the Five Facet Mindfulness Questionnaire (FFMQ: Baer, 2006). The FFMQ is made up of five subscales (acting with awareness, non-judgmentalness, non-reactivity, describing, observing). Each subscale is comprised of 7 or 8 items on a five-point Likert-type scale of frequency ranging from 1, “never or very rarely true” to 5, “very often or always true”. A sample reverse-scored item from the non-judgmentalness subscale is, “I tell myself I shouldn’t be feeling the way I’m feeling.”

Ecological momentary assessment measures: Participants completed surveys four times per day on their smart phones using the mEMA application (Spook et al., 2013). Items used in the current study fell into three general categories; cannabis use, craving-related questions, and coping-related questions.

Cannabis use was assessed using a single item, "Approximately how many times did you use marijuana?" Scores were then transformed into a binary variable with 0 representing no use, and 1 representing use.

Craving was assessed using two different items adapted from the Penn Alcohol Craving Scale, a well-established measure of craving for alcohol and other drugs with demonstrated reliability and validity (Flannery, Volpicelli, & Pettinati, 1999). One item assessed thoughts related to cannabis: "How much were you thinking about marijuana, or how it would make you feel?" The second

item assessed urges with the question: "When you wanted to use marijuana the most, how strongly did you want to use?" Cases where participants indicated that their urge to use marijuana had peaked after using marijuana were excluded from analysis, to ensure temporal precedence of the predictor.

Coping was assessed using three items drawn from the Brief COPE (Carver, 1997), one item from the Avoidance and Inflexibility Scale (AIS). *Behavioral disengagement*, *self-distraction*, and *acceptance* were each assessed using a single item from the named subscale of the Brief COPE. *Valued action* was assessed with a single item drawn from the AIS.

Analytic plan

Descriptive analyses. Mean and variance was explored for all study variables. Results are available in Table 1.

Inferential analyses. Due to the use of within-person repeated measurement in the data generation process, it was expected that EMA outcomes would cluster by participants. Multilevel modeling (MLM) is an analytic approach that accounts for outcomes that are clustered. A series of multilevel models were performed, consistent with best practices in multilevel model development (Snijders & Bosker, 2011) to explore the association between craving and use, as well as hypothesized moderators. All MLMs were tested using the `glmer` function contained in the `lme4` package in `R`, specifically using generalized logistic mixed effects models due to the binary nature of the outcome variable (marijuana use). Each step in the model building process was compared to the previous iteration using deviance testing (-2LLR, AIC, and BIC).

All level one variables were tested using two variables: one variable that was within-person centered and standardized (a momentary variable, representing reports above or below a person's mean level of the variable across all time points), and a second variable that was the

person-mean of the level one variable centered and standardized using the population mean and standard deviation (a person-level mean variable). All level two variables were centered and standardized using the population mean and standard deviation. All centering and standardizing transformations were completed to simplify interpretation of main effects and interactions (Snijders & Bosker, 2011). Thus, a one unit increase in the momentary predictor variable (Level 1) represented an increase of one personal standard deviation above a person's average rating on the variable. A one unit increase in the person-mean variable (Level 2) represented an increase of one population standard deviation above the population mean.

Interactions between the primary predictor of interest (momentary craving) and each hypothesized moderator (types of coping, facets of mindfulness, psychological flexibility, attentional bias, and implicit marijuana identity) were tested separately by evaluating the stepwise improvement in model fit with the addition of moderator variables first as main effects only, then with interaction terms. The stepwise process of model development was completed in four general phases: (1) craving variables (momentary craving, and person-mean craving) and the moderator were added as explanatory variables to test for main effects, (2) the interactions between the moderator and craving variables were tested, (3) effects were trimmed if they did not improve model fit and were not significant during any phase of model development, (4) the random effect of momentary craving was included in the final model (5) interactions were probed using simple slopes analysis to illustrate the general trend of the effect (Figures 3-10). The graphs should be interpreted with the understanding that the specific point estimates of the lines are not precisely matched to observed data.

Missing data. Data missingness was investigated to determine how missing data may have affected the internal validity of the study. Missingness was tested for associations with study

variables to detect potential systematic attrition and missing data patterns. Using observed data to predict frequency of missingness, no study variables were significantly associated with missingness. Rates of missing data in the current sample were also consistent with typical missingness reported in the literature (Buckner et al., 2012; Phillips et al., 2015). Full information maximum likelihood (FIML) is a method for reducing bias in estimates related to data missing at random (Hallgren & Witkiewitz, 2013). FIML uses complete cases to produce the most accurate estimate given the available observations and the specified model. FIML is a feature included in the `glmer` function and was applied in all tested models to reduce bias in estimates. FIML will increase the accuracy of estimates if the data are missing at random, or missing completely at random.

RESULTS

Means and standard deviations for all study variables are presented in Table 1. The sample included 41% women, and the average age was 19.6 (SD = 2.2) years. Average cannabis use in the current sample was 3.76 (SD = 1.74) days per week, and the mean CUDIT-R score was 18.8 (SD = 4.56), indicating the majority of participants were at risk of having a cannabis use disorder (Adamson2010). In general, the sample leaned more strongly toward being in an "Action" phase of change (M = 0.92, SD = 3.61), than a "Contemplation" stage of change (M=0.07, 3.48). In total, 78% of EMA surveys were completed by participants, for a total of 3,728 observations.

The intercept-only model was used to compute the intra-class correlation coefficient (ICC). For these data, the ICC is a descriptive statistic that represents how strongly measurements from the same individual vary together. Results indicated that 32% of the variance in the outcome was due to between-person clustering of the data, confirming that multilevel

modeling was an appropriate analytic approach.

Determining the model.

The primary hypothesis for the current study was that craving management variables (coping, experiential avoidance, and mindfulness) and automatic processes (implicit marijuana identity and attentional bias) would influence the associations between craving and use. Thus, model development began with testing the fixed effect of the two dimensions of the two craving predictors (both momentary and person-mean variables) on use. Momentary and person-mean values for both thoughts and urges were significantly positively associated with use (see Tables 2 and 3). Each momentary craving predictor was subsequently entered as a random effect, allowing the effect of the predictor to vary by participant. Deviance testing indicated that the inclusion of the random effect significantly improved model fit for both thoughts and urges. A plot of the data and the estimated intercept and slope for each participant illustrates the between-person variability in the effect of urges on use (Figure 1) and thoughts on use (Figure 2).

In order to complete phase one of model development, each hypothesized moderator was subsequently entered individually into the craving-only models. Each Level 1 moderator was separately entered stepwise into the craving model to examine the influence of Level 1 variables on the craving and use association, and to evaluate the change in model fit using deviance tests. Level 2 moderator variables (dispositional trait factors and automatic processes) were also entered separately and stepwise into the craving model to investigate whether the between-person variables explained variability in use.

Phase two of model development was to test interactions between all variables in each model. Each Level 1 moderator was separately entered stepwise into the craving model to individually examine the influence of Level 1 variables on the craving and use association, and

to evaluate the change in model fit using deviance tests. Level 2 moderator variables (automatic processes, dispositional trait factors, and person-mean aggregates of momentary moderators) were also entered separately and stepwise into the craving model to investigate whether the between-person variables explained variability in individual slopes.

Phase three of model development was completed by trimming interactions that were not significant at any stage of model development, and did not improve model fit.

Phase four was completed by including momentary craving as a random effect in the model. Including momentary craving as a random effect allowed the parameter estimate for the association between momentary craving and the probability of use to vary by individual. Phase five was completed by probing interactions at the mean of the predictor variable (craving), as well as one standard deviation above and below the mean (Aiken & West, 1991). All analysis was conducted using the `glmer` function in the `lme4` package in *R*.

Moderators of the association between urges and use

First, the four EMA moderators (behavioral disengagement, self-distraction, acceptance, and valued actions) were entered as fixed effects predicting subsequent use (both momentary and person-means). In the final models, there were interactions nearing significance between momentary urges and person-mean behavioral disengagement (OR = 0.75, 95% CI [0.54, 1.05]), and person-mean self-distraction (OR = 0.83, 95% CI [0.68, 1.03]). Probing the interaction between behavioral disengagement and urges revealed that for people with a lower than average mean on the moderator, there was a protective effect when urges was low, but the protective effect was reduced as urges increased (Table 2, Figure 3). For people with a high person-mean on self-distraction, the association between momentary urges and use was less strong than for people lower than average in self-distraction (Table 2, Figure 4). Momentary acceptance and

momentary valued actions were not associated with cannabis use when momentary urges was included in the model.

Next, the nine individual trait level dispositional craving management variables were investigated, of which two were significant. There were main effects of non-judgment (OR = 0.25, 95% CI [0.13, 0.47]) and non-reactivity (OR = 0.40, 95% CI [0.19, 0.84]) on subsequent use in the final model, indicating a negative association between both moderators and use. Additionally, there was an interaction between non-judgment and urges (OR = 1.81, 95% CI [1.08, 3.02]). Probing the interaction between non-judgment and urges revealed that the strong negative association between non-judgment and use was weakened as urges increased (Table 2, Figure 5).

Three out of the remaining seven trait level moderators were nearing significance in the final models as either main effects or interactions and are reported below. There was an interaction between trait self-distraction from the Brief COPE and momentary urges (OR = 0.73, 95% CI [0.54, 1.00]). Probing the interaction revealed that there was a similar association between momentary urges and use at lower levels of urges, but as urges increased, coping via self-distraction reduced the strength of the association between urges and use (Table 2, Figure 6).

There was a main effect of the observing subscale of the FFMQ (OR = 2.53, 95% CI [0.83, 7.22]), indicating a positive association between observing and subsequent use. There was also an interaction between the acting with awareness subscale and urges (OR = 1.86, 95% CI [0.96, 3.59]). Probing the interaction showed that at lower levels of urges, higher acting with awareness was associated with reduced probability of use. However, as urges increased the attenuating effect of acting with awareness was reversed such that higher levels of acting with

awareness were associated with a higher probability of use when urges were high (Table 2, Figure 7).

Trait behavioral disengagement, trait acceptance, trait inflexibility, and describing were not associated with use as main effects or moderators of urges.

Finally, for the two automatic processes, implicit marijuana identity (IMI) moderated the association between person-mean urges and use (OR = 1.71, 95% CI [1.14, 2.55]) such that people with stronger IMI had stronger associations between average urge levels and use. However, for people with weaker IMI there was a weaker association between person-mean urges and use (Table 2, Figure 8). There was no association between attentional bias and use as a main effect or as a moderator of urges.

Moderators of the association between thoughts and use

A slightly different pattern of effects for the EMA moderators was found with thoughts as the predictor. There was a main effect of momentary self-distraction on the probability of use (OR = 1.14, 95% CI [1.02, 1.27]), and a main effect of momentary behavioral disengagement (OR = 1.10, 95% CI [0.99, 1.22]). In both cases, the momentary moderators were positively associated with the probability of subsequent use, and there was no interaction between the moderator and the craving predictor. Neither momentary acceptance nor valued actions were associated with subsequent use as a main effect or a moderator when momentary thoughts was included in the model.

The nine trait and dispositional moderators were tested next. Again, a main effect was observed for both non-judgment (OR = 0.33, 95% CI [0.19, 0.60]) and non-reactivity (OR = 0.42, 95% CI [0.21, 0.85]), indicating a negative association between each variable and the probability of subsequent use. There was also an interaction between observing and momentary

urges (OR = 0.60, 95% CI [0.35, 1.03]) that was nearing significance. Probing the interaction revealed that being low in observing reduced the probability of use when thoughts were low. However, as thoughts about use increased the moderating effect of being low in observing became weaker (Table 3, Figure 9). There were no main or interaction effects for acting with awareness, describing, trait behavioral disengagement, trait self-distraction, trait acceptance, or avoidance and inflexibility.

Implicit marijuana identity again moderated the association between person-mean thoughts and use (OR = 1.52, 95% CI [1.02, 2.26]). Probing the interaction revealed that the association between person-mean thoughts and probability of use was weak for people low in IMI. However, for people with strong IMI, the positive association between person-mean thoughts and use was strong (Table 3, Figure 10). Attentional bias was not associated with probability of cannabis use as a main effect or moderator.

Summary of moderation results for both craving predictors

The pattern of effects was consistent for both thoughts and urges as predictors of subsequent use. In the final models evaluating the fifteen hypothesized moderators, eight were associated with use as either main effects or moderators of the association between craving and subsequent cannabis use. Three subscales of the FFMQ, (acting with awareness, non-judgmentalness, and non-reactivity), were all negatively associated with subsequent cannabis use as a main effect or moderator of the association between craving and use. The observing subscale of the FFMQ was an exception to this pattern, as observing was positively associated with use.

Momentary measurements of self-distraction and behavioral disengagement attenuated the association between craving and use. Baseline measurement of self-distraction also moderated the association between urges and use.

Implicit marijuana identity amplified the effect of craving on probability of subsequent use. Momentary and trait acceptance, momentary valued action, trait describing, trait avoidance and inflexibility, and attentional bias were not associated with probability of use as a main effect or as a moderator of the association between either of the two craving variables and probability of use in the final models.

In general, the constructs which were hypothesized to attenuate the association between craving and use performed as expected (acting with awareness, non-judgment, non-reactivity). Contrary to theory, self-distraction and behavioral disengagement also attenuated the association between craving and use. As hypothesized, as the strength of implicit marijuana identity increased, there was an amplification of the association between craving and subsequent use.

DISCUSSION

The current study investigated hypothesized moderators of the longitudinal association between craving and use by applying a variety of measurement techniques: ecological momentary assessment, retrospective self-report, and response-time tasks. Results indicate that non-judgmentalness, and implicit marijuana identity (IMI) were both moderators of the association between craving and use. Consistent with theory on the protective effects of mindfulness for problematic substance use behaviors broadly (Creswell, 2017; Elwafi et al., 2013; Enkema & Bowen, 2017; Garland & Black, 2014), non-judgmentalness attenuated the risk of marijuana use associated with craving (Figure 5). Findings also support theories that IMI plays an important role in marijuana use behaviors, as people who reported stronger IMI experienced an amplification of risk of use as craving increased (Figures 8 & 10).

Mindfulness has been hypothesized to reduce problematic substance use (Witkiewitz et al., 2005), and a growing body of literature has come to support this hypothesis (Creswell, 2017;

Chiesa & Serretti, 2014), for review). Only one previous study has investigated the effect of mindfulness on craving and substance use outcomes using intensive longitudinal methods with a population of tobacco users attempting to quit (Nosen & Woody, 2014). After randomization to one of three conditions (mindfulness psycho-education, psycho-education, and no psycho-education), participants received the intervention and completed surveys that assessed craving and use throughout the following 24 hours. Participants in the mindfulness group reported significantly lower mean craving scores (Nosen & Woody, 2014). Differences in use between groups were not reported. Three other studies have used intensive longitudinal assessment methods to investigate the association between mindfulness and craving for and consumption of unhealthy foods (Mason et al., 2018; Forman et al., 2016; Ruscio et al., 2015). All three studies found evidence supporting the hypothesis that mindfulness training reduced craving, reduced craving-related consumption, or both.

Finally, two studies have directly tested the moderating effect of mindfulness training on the association between craving and use for individuals attempting to reduce problematic substance use (Enkema & Bowen, 2017; Elwafi et al., 2013). In both cases, results indicated that mindfulness practice reduced the strength of the association between craving and use, such that as practice increased, the association between craving and use decreased. However, investigators noted the use of retrospective self-report measurements of craving at baseline as the predictor to be a significant limitation. The current study provides further evidence that supports the hypothesized attenuating effect of mindfulness on problematic consumption and craving-related risk of consumption.

Results from the current study provide preliminary evidence that implicit marijuana identity may indeed function as a craving amplifier. Implicit marijuana identity is based on the

implicit drinking identity adaptation of the implicit association task (IAT, Greenwald et al., 1998). Identity IATs provide a measure of relative strength of associations between the self and constructs consciously held in memory (Lindgren, Neighbors, et al., 2013). Studies of implicit drinking identity have shown a positive association between the construct and typical alcohol consumption, as well as alcohol-related problems and craving (Lindgren et al., 2014). The exteroceptive model of addiction suggests that identity may affect the association between craving and use by increasing the effect of self-relevant exteroceptive stimuli (DeWitt, Ketcherside, McQueeny, Dunlop, & Filbey, 2015).

According to this framework, the occurrence of reward-based motivation (e.g., craving) that is perceived as self-relevant (i.e. congruent with identity) is more likely to influence subsequent behavior due to identity-congruence (DeWitt et al., 2015). In a similar theory, a model of identity-based motivation suggests that behaviors that are congruent with one's identity are more likely to be chosen than behaviors that are incongruent (Oyserman, 2009). This identity-based motivation model also theorizes that when behaviors become identity-linked they become automatized (Oyserman, 2009).

Contrary to theory (Witkiewitz, Bowen, et al., 2013) and results from other trials (T. M. Moore et al., 2014), findings from the current study suggest that avoidant coping, such as behavioral disengagement and self-distraction, may perform a protective function particularly at higher levels of craving. While theory suggests that suppression or avoidance ultimately leads to an ironic rebound effect (Wegner & Zanakos, 1994), short-term effectiveness of suppression in the context of craving has been reported. For example, a randomized controlled alcohol cue-exposure trial compared coping via distraction to acceptance coping, and found that distraction coping was more effective at reducing acute craving (Murphy & MacKillop, 2014).

Limitations

There are several important limitations of the current study that ought to be addressed. Firstly, due to the lack of baseline FFMQ data for many participants, the sample size for moderation analysis using the different mindfulness facets may have been underpowered to detect some of the effects of interest.

Another limitation of the current study is that many of the moderating constructs of interest that were measured at the momentary level (i.e., acceptance, behavioral disengagement, self-distraction, valued actions) may benefit from item revision to reduce response bias. Survey items used in the current study were drawn from well-validated cross-sectional measures, and further testing in an intensive longitudinal assessment context may improve validity. While concern regarding a floor effect and lack of variability in the items appears to be unfounded, the mixed results may be an unfortunate artifact of response bias.

Finally, the current study aimed to test potential moderators to identify treatment intervention targets to reduce craving-related risk of problematic use but did not directly test any intervention. Although results provide evidence that measurable intervention targets may be used as targets to improve treatment outcomes (e.g., tailoring treatments for people with strong implicit identities as marijuana users, or by increasing non-judgmentalness through mindfulness training), the lack of a direct intervention limits the direct application of these results to treatments.

Implications

Findings from the current study suggest that craving is an important intervention target for young adults with problematic cannabis use behaviors. Additionally, results indicate that the effect of craving on use is influenced by a variety of measurable phenomena that represent

possible intervention targets to reduce the prevalence, severity, and persistence of problematic cannabis use during young adulthood. Future interventions might focus on increasing non-judgmentalness through mindfulness training, practicing the wise application of self-distraction during periods of particularly strong craving, or reducing implicit self-identification with marijuana.

Table 1. Means and standard deviations.

Variable	n	*M*	*SD*
1. Cannabis use	3728	.28	0.45
2. Craving (Urges)	3702	1.92	2.44
3. Craving (Thoughts)	3700	1.91	2.33
4. Acting with Awareness	19	3.00	0.74
5. Non-judgmentalness	19	3.39	0.83
6. Non-reactivity	19	3.22	0.73
7. Observe	19	3.61	0.57
8. Describe	19	3.39	0.88
9. Behavioral disengagement	86	1.33	0.48
10. Self-distraction	86	2.33	0.70
11. Acceptance	86	2.09	0.62
12. Avoidance and inflexibility	86	2.25	0.72
13. Marijuana attentional bias	86	5.19	20.29
14. Implicit marijuana identity	84	0.00	0.65
15. Behavioral disengagement (EMA)	3693	2.10	2.40
16. Self-distraction (EMA)	3691	3.61	2.87
17. Acceptance (EMA)	3692	4.49	2.78
18. Valued Actions (EMA)	3692	5.15	2.81

Note. Craving was assessed using EMA. 78% of EMA surveys were completed. Variables 4-8 were measured using the Five Facet Mindfulness Questionnaire. Variables 9-11 came from the Brief COPE. Variable 12 from the Avoidance and Inflexibility Scale. 13 from the Marijuana Dot Probe. 14 from the Marijuana Identity Implicit Association Task.

Table 2. Final multilevel model results with urges predicting subsequent use, and a separate model for each moderator.

Predictor	*b*	*SE*	*p*	OR	95% CI
Craving: Urges (EMA)					
(Intercept)	-1.80	0.18	<.001	0.17	[0.12, 0.24]
Momentary urges	**1.59**	**0.12**	**<.001**	**4.88**	**[3.88, 6.15]**
Person-mean urges	**0.77**	**0.14**	**<.001**	**2.16**	**[1.64, 2.85]**
Five Facet Mindfulness Questionnaire (FFMQ)					
(Intercept)	-1.81	0.33	<.001	0.16	[0.09, 0.31]
Acting with awareness	-0.19	0.45	0.664	0.82	[0.34, 1.98]
Momentary urges	**1.48**	**0.25**	**<.001**	**4.38**	**[2.68, 7.16]**
Person-mean urges	0.45	0.34	0.186	1.56	[0.81, 3.02]
Momentary urges * Acting with awareness	0.62	0.34	0.065	1.86	[0.96, 3.59]
(Intercept)	-1.86	0.24	<.001	0.16	[0.10, 0.25]
Non-judgmentalness	**-1.38**	**0.43**	**<.001**	**0.25**	**[0.13, 0.47]**
Momentary urges	**1.54**	**0.25**	**<.001**	**4.68**	**[2.87, 7.61]**
Person-mean urges	-0.09	0.28	0.313	0.92	[0.53, 1.58]
Momentary urges * Non-judgmentalness	**0.59**	**0.26**	**0.024**	**1.81**	**[1.08, 3.02]**
(Intercept)	-1.81	0.32	<.001	0.16	[0.09, 0.30]
Non-reactivity	**-0.91**	**0.37**	**0.015**	**0.40**	**[0.19, 0.84]**
Momentary urges	**1.47**	**0.27**	**<.001**	**4.35**	**[2.58, 7.35]**
Person-mean urges	0.05	0.33	0.897	1.04	[0.56, 1.96]
(Intercept)	-1.83	0.31	<.001	0.16	[0.09, 0.30]
Observing	0.93	0.54	0.083	2.53	[0.89, 7.22]
Momentary urges	**1.51**	**0.26**	**<.001**	**4.52**	**[2.70, 7.55]**
Person-mean urges	0.45	0.32	0.166	1.56	[0.83, 2.93]
Momentary urges * Observing	-0.67	0.45	0.138	0.51	[0.21, 1.24]

Brief COPE					
(Intercept)	-1.81	0.18	<.001	0.16	[0.12, 0.23]
Self-distraction	-0.21	0.26	0.430	0.81	[0.49, 1.36]
Momentary urges	**1.57**	**0.12**	**<.001**	**2.18**	**[1.65, 2.87]**
Person-mean urges	**0.78**	**0.14**	**<.001**	**4.81**	**[3.84, 6.04]**
Momentary urges * Self-distraction	-0.31	0.16	0.052	0.73	[0.54, 1.00]
Automatic Processes					
(Intercept)	-1.83	0.18	<.001	0.16	[0.11, 0.23]
Implicit marijuana identity (IMI)	0.34	0.26	0.191	1.40	[0.84, 2.33]
Momentary urges	**1.52**	**0.12**	**<.001**	**4.59**	**[3.66, 5.75]**
Person-mean urges	**0.73**	**0.14**	**<.001**	**2.07**	**[1.55, 2.76]**
Person-mean urges * IMI	**0.53**	**0.21**	**0.009**	**1.71**	**[1.14, 2.55]**
Momentary moderators					
(Intercept)	-1.80	0.18	<.001	0.17	[0.12, 0.23]
Momentary urges	**1.59**	**0.15**	**<.001**	**2.04**	**[1.53, 2.73]**
Person-mean urges	**0.72**	**0.12**	**<.001**	**4.92**	**[3.92, 6.18]**
Person-mean behavioral disengagement (PMBD)	0.32	0.28	0.260	1.38	[0.79, 2.40]
Momentary urges * PMBD	-0.29	0.18	0.094	0.75	[0.54, 1.05]
(Intercept)	-1.80	0.18	<.001	0.17	[0.12, 0.24]
Momentary urges	**1.59**	**0.12**	**<.001**	**1.62**	**[1.62, 2.87]**
Person-mean urges	**0.77**	**0.15**	**<.001**	**4.91**	**[3.91, 6.15]**
Person-mean self-distraction (PMSD)	-0.02	0.18	0.909	0.98	[0.70, 1.38]
Momentary urges * PMSD	-0.18	0.11	0.089	0.83	[0.68, 1.03]

Note. Craving related urges were assessed using a single item on each EMA survey. Momentary variables were Level 1 momentary reports. Person-mean variables were Level 2 variables created using the aggregated mean of each person on the momentary item. Moderators that had no main effect or interaction were not included in the table.

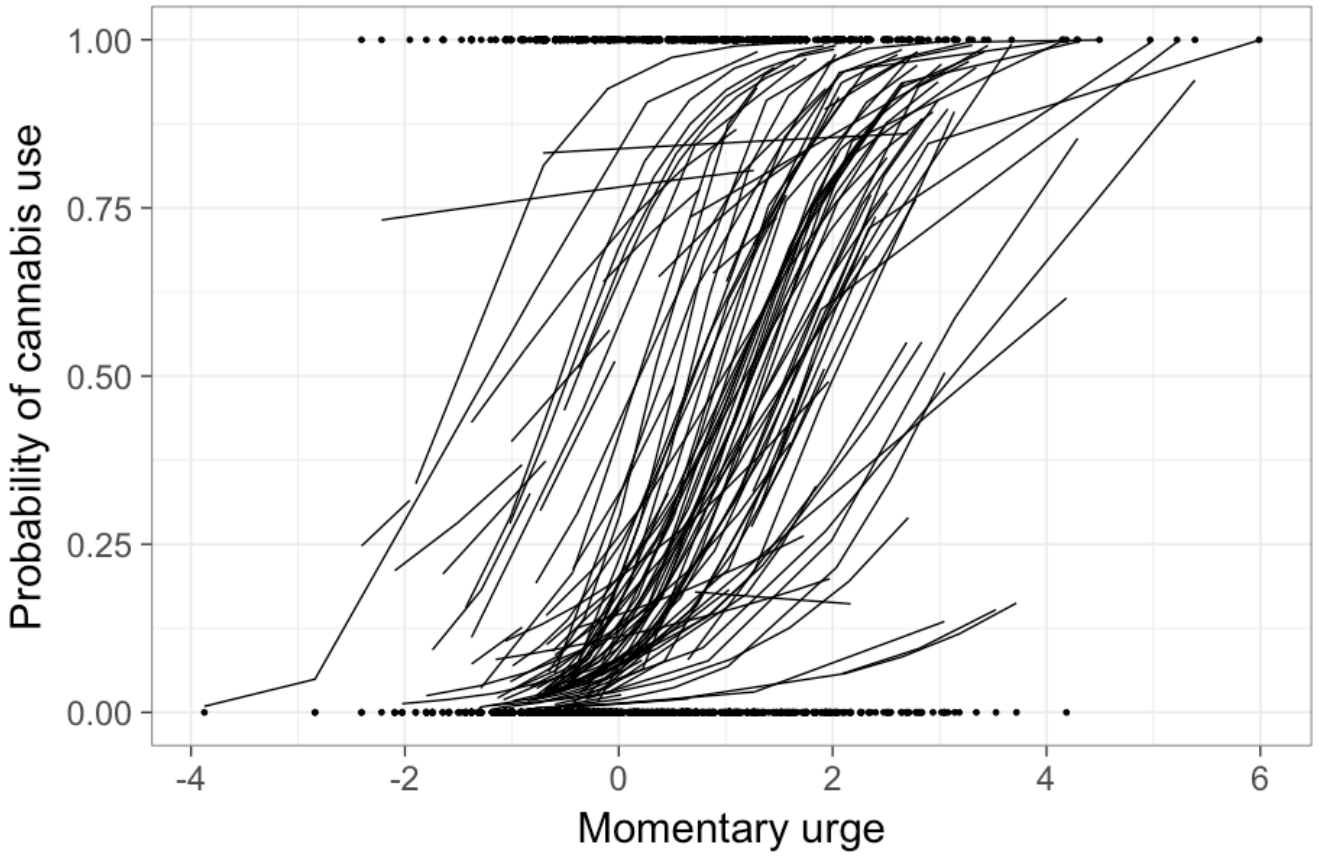
Table 3. Final multilevel model results with thoughts predicting subsequent use, and a separate model for each moderator.

Predictor	*b*	*SE*	*p*	OR	95% CI
Craving (EMA)					
Intercept	-1.70	0.17	<.001	0.18	[0.13, 0.25]
Momentary Thoughts	**1.24**	**0.09**	**<.001**	**3.44**	**[2.89, 4.10]**
Person-mean Thoughts	**0.62**	**0.13**	**<.001**	**1.85**	**[1.42, 2.40]**
Five Facet Mindfulness Questionnaire (FFMQ)					
(Intercept)	-1.59	0.21	<.001	0.20	[0.13, 0.31]
Non-judgment	**-1.10**	**0.31**	**<.001**	**0.33**	**[0.19, 0.60]**
Momentary thoughts	**1.03**	**0.16**	**<.001**	**2.80**	**[2.06, 3.82]**
Person-mean thoughts	-0.06	0.33	0.860	0.94	[0.50, 1.80]
MT * Non-judgment	0.23	0.18	0.200	1.26	[0.89, 1.79]
(Intercept)	-1.59	0.25	<.001	0.20	[1.24, 0.33]
Non-reactivity	**-0.87**	**0.36**	**0.017**	**0.42**	**[0.21, 0.85]**
Momentary thoughts	**1.03**	**0.18**	**<.001**	**3.21**	**[2.99, 3.55]**
Person-mean thoughts	0.34	0.29	0.245	1.40	[0.79, 2.49]
Momentary thoughts * Non-reactivity	0.09	0.24	0.711	1.09	[0.68, 1.75]
(Intercept)	-1.58	0.25	<.001	0.21	[0.13, 0.34]
Observing	0.79	0.44	0.071	2.20	[0.93, 5.20]
Momentary thoughts	**1.04**	**0.16**	**<.001**	**2.82**	**[2.06, 3.85]**
Person-mean thoughts	**0.66**	**0.32**	**0.039**	**1.93**	**[1.03, 3.59]**
Momentary thoughts * Observing	-0.51	0.27	0.063	0.60	[0.35, 1.03]
Automatic Processes					
(Intercept)	-1.86	0.24	<.001	0.18	[0.13, 0.25]
Implicit marijuana identity (IMI)	0.45	0.24	0.059	1.57	[0.98, 2.51]
Momentary thoughts	**1.19**	**0.14**	**<.001**	**3.28**	**[2.75, 3.92]**

Person-mean thoughts	**0.60**	**0.09**	**<.001**	**1.83**	**[1.40, 2.38]**
Person-mean thoughts * IMI	**0.42**	**0.20**	**0.038**	**1.52**	**[1.02, 2.26]**
Momentary moderators					
(Intercept)	-1.74	0.17	<.001	0.18	[0.13, 0.24]
Person-mean thoughts	**0.61**	**0.15**	**<.001**	**1.83**	**[1.37, 2.44]**
Person-mean behavioral disengagement	0.26	0.28	0.342	1.30	[0.76, 2.22]
Momentary thoughts	**1.24**	**0.09**	**<.001**	**3.45**	**[2.88, 4.11]**
Momentary behavior. disengage. (MBD)	0.09	0.05	0.079	1.10	[0.99, 1.22]
Momentary thoughts * MBD	-0.02	0.05	0.647	0.98	[0.99, 1.08]
(Intercept)	-1.71	0.17	<.001	0.18	[0.13, 0.25]
Person-mean thoughts	**0.63**	**0.14**	**<.001**	**1.86**	**[1.41, 2.47]**
Person-mean self-distraction	-0.04	0.16	0.806	0.96	[0.69, 1.33]
Momentary thoughts	**1.23**	**0.09**	**<.001**	**3.43**	**[2.87, 4.09]**
Momentary self-distraction (MSD)	**0.13**	**0.05**	**0.018**	**1.14**	**[1.02, 1.27]**
Momentary thoughts * MSD	-0.05	0.05	0.343	0.95	[0.86, 1.05]

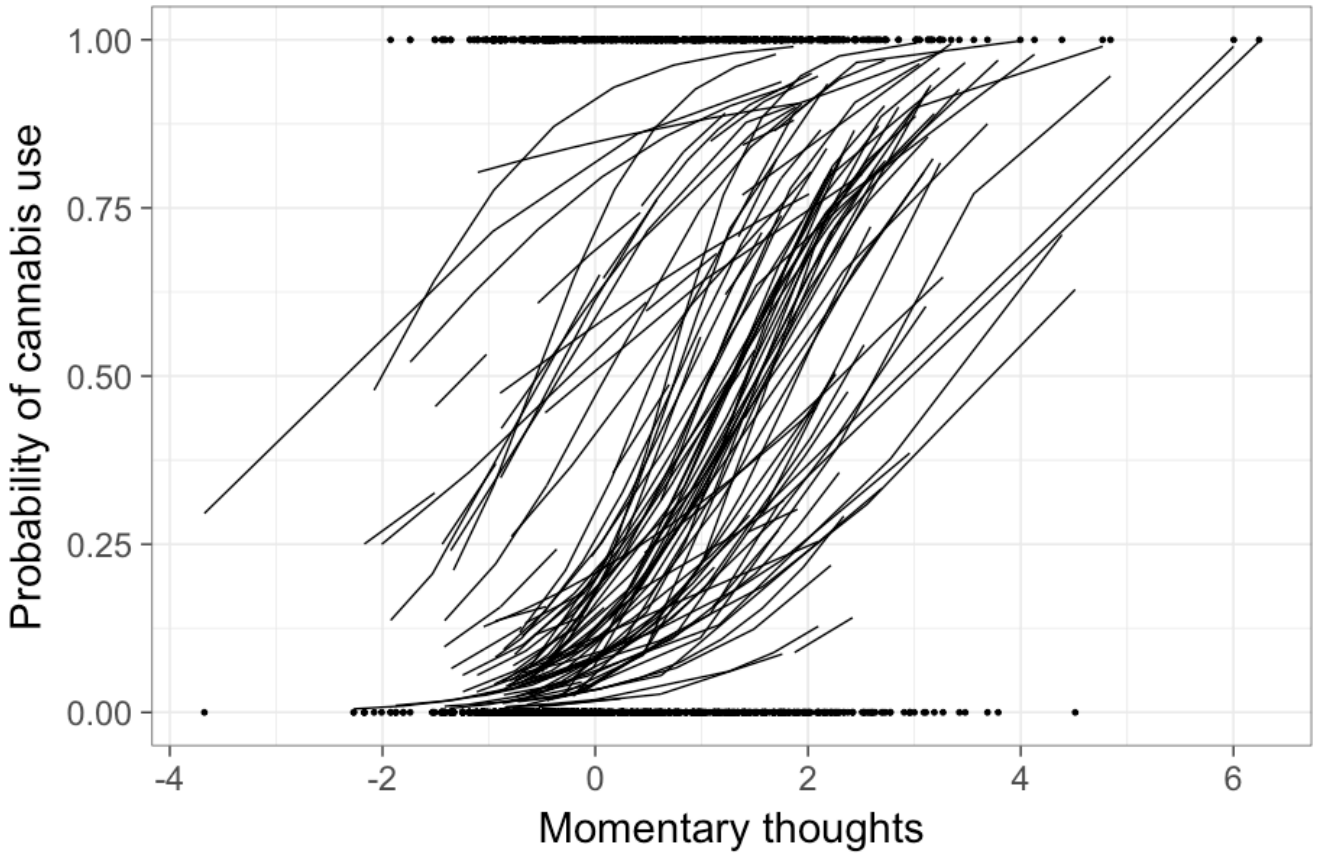
Note. Craving related thoughts were assessed using a single item on each EMA survey. Momentary variables were Level 1 momentary reports. Person-mean variables were Level 2 variables created using the aggregated mean of each person on the momentary item. Moderators that had no main effect or interaction were not included in the table.

Figure 1. The random effect of momentary craving-related urges on cannabis use.



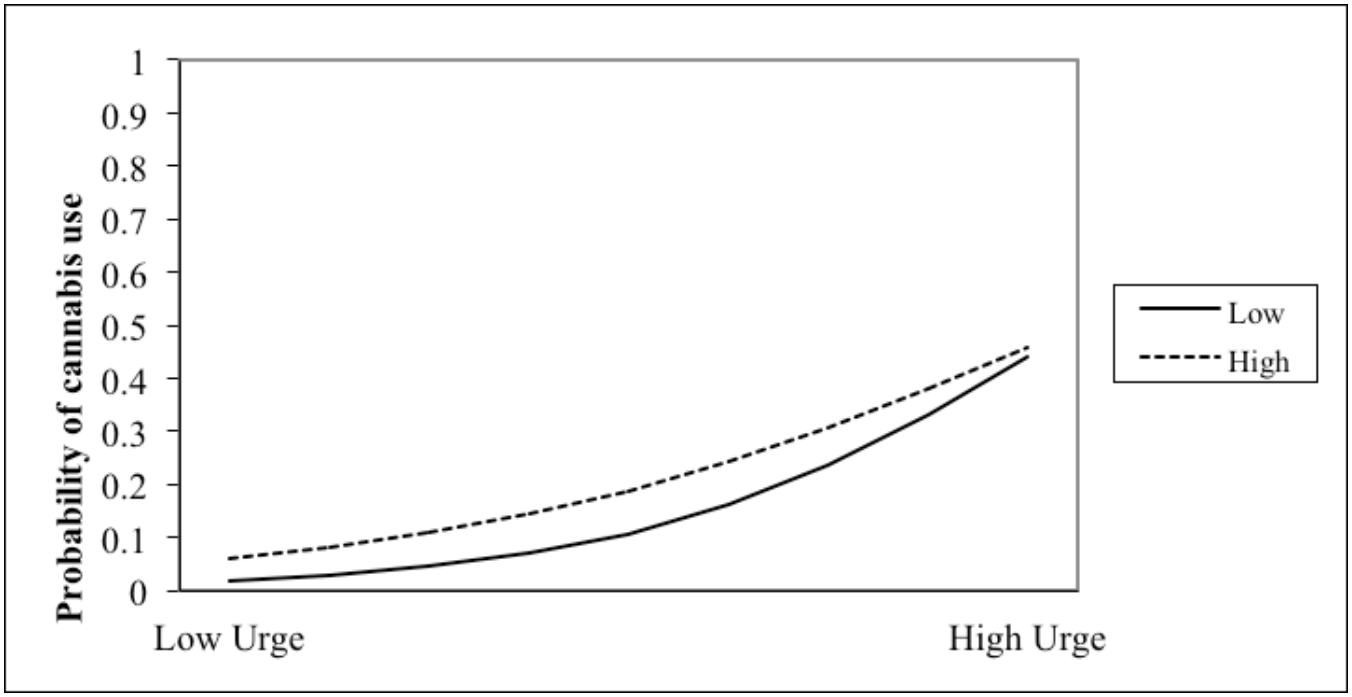
Note. Each line represents a participant. Each participant has a unique intercept and slope for the effect of craving-related urges on probability of subsequent use. Each dot represents the reported data (0 = no cannabis use, 1 = cannabis use)

Figure 2. The random effect of momentary craving-related thoughts on cannabis use.



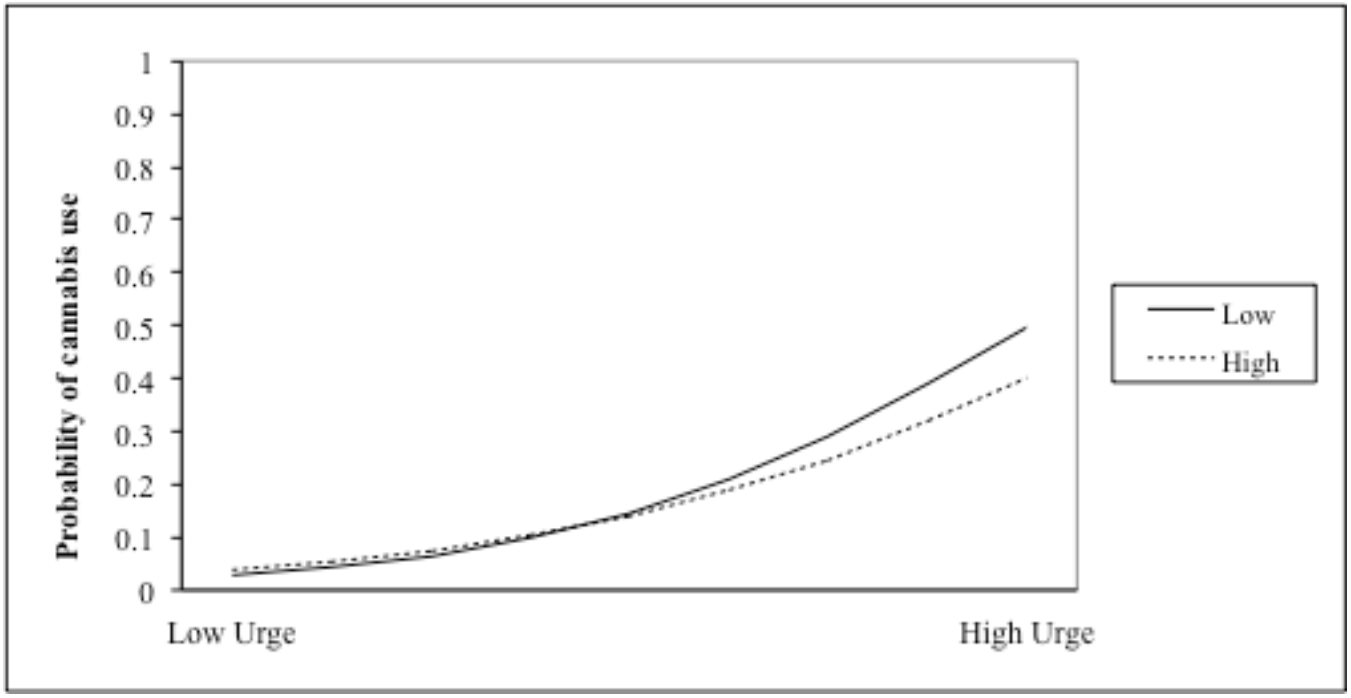
Note. Each line represents a participant. Each participant has a unique intercept and slope for the effect of craving-related thoughts on probability of subsequent use. Each dot represents the reported data (0 = no cannabis use, 1 = cannabis use)

Figure 3. Person-mean behavioral disengagement moderates the association between momentary urges and cannabis use.



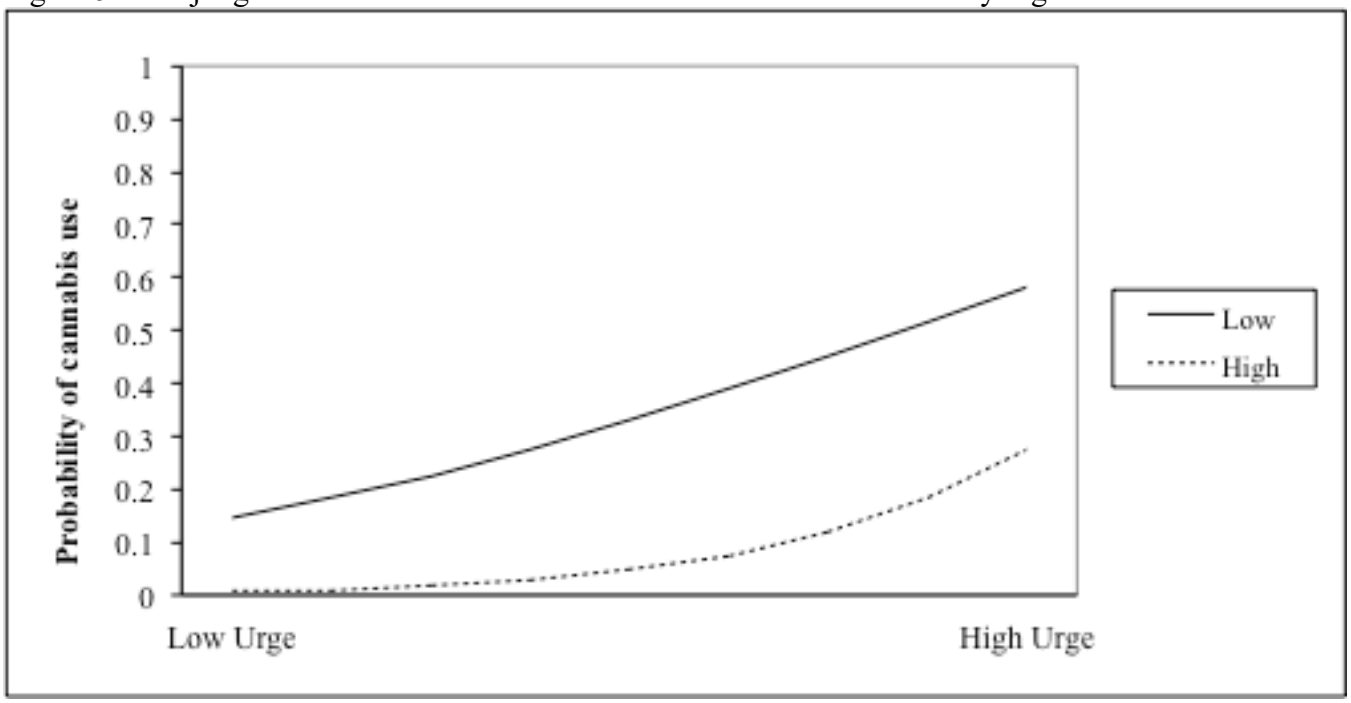
Note. The two lines represent different levels of person-mean behavioral disengagement. The solid line represents predicted probability of cannabis use for individuals 1 SD below the population mean on their person-mean behavioral disengagement. The dotted line represents the predicted probability for participants 1 SD above the population mean.

Figure 4. Person-mean self-distraction moderates the association between momentary urges and cannabis use.



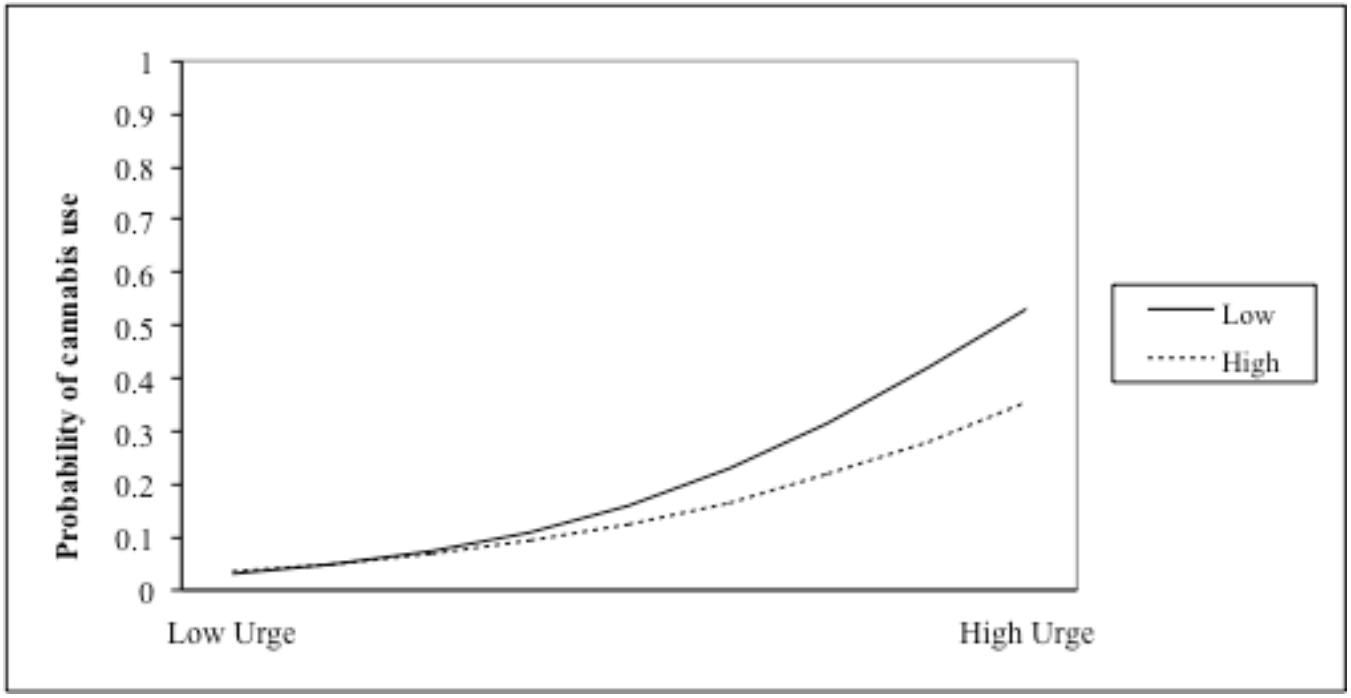
Note. The two lines represent different levels of person-mean self-distraction. The solid line represents predicted probability of cannabis use for individuals 1 SD below the population mean on their person-mean self-distraction. The dotted line represents the predicted probability for participants 1 SD above the population mean.

Figure 5. Non-judgmentalness moderates the association between momentary urges and cannabis use.



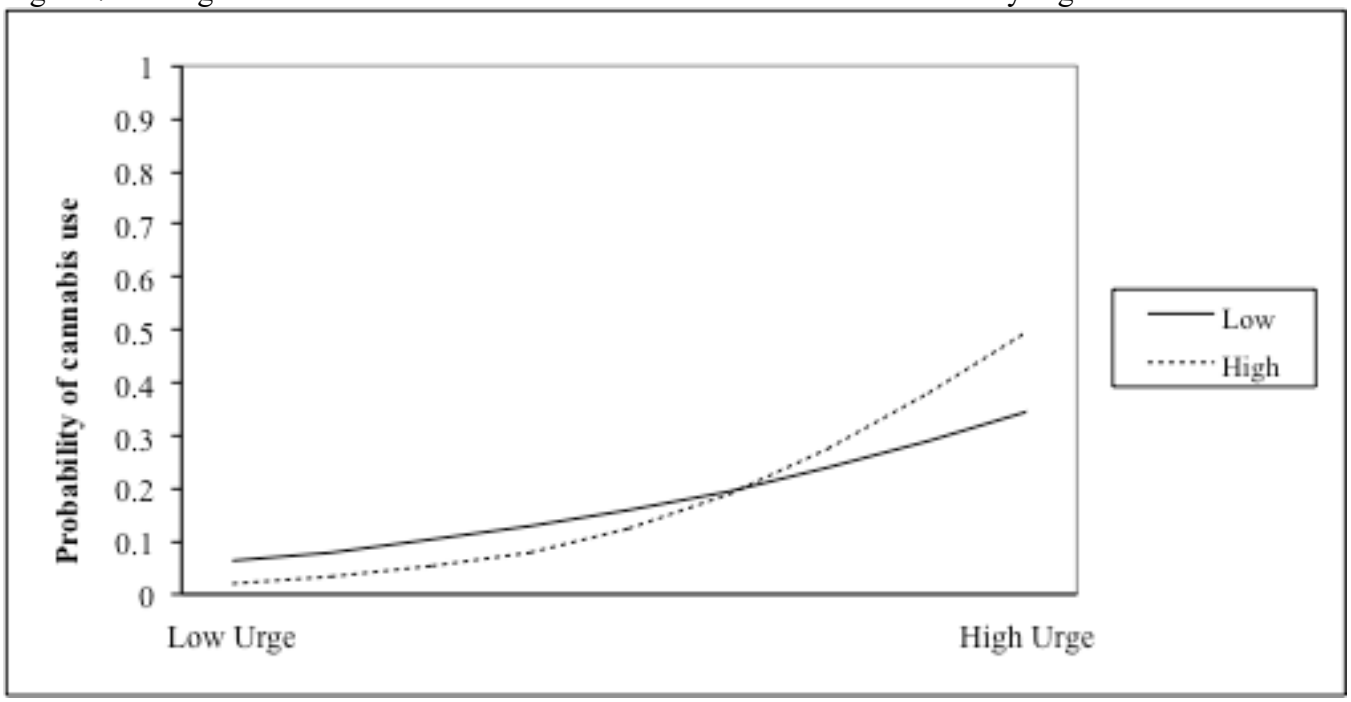
Note. The two lines represent different levels of baseline non-judgmentalness. The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on non-judgmentalness. The dotted line represents the predicted probability for participants 1 SD above the mean.

Figure 6. Trait self-distraction coping moderated the association between momentary urges and cannabis use.



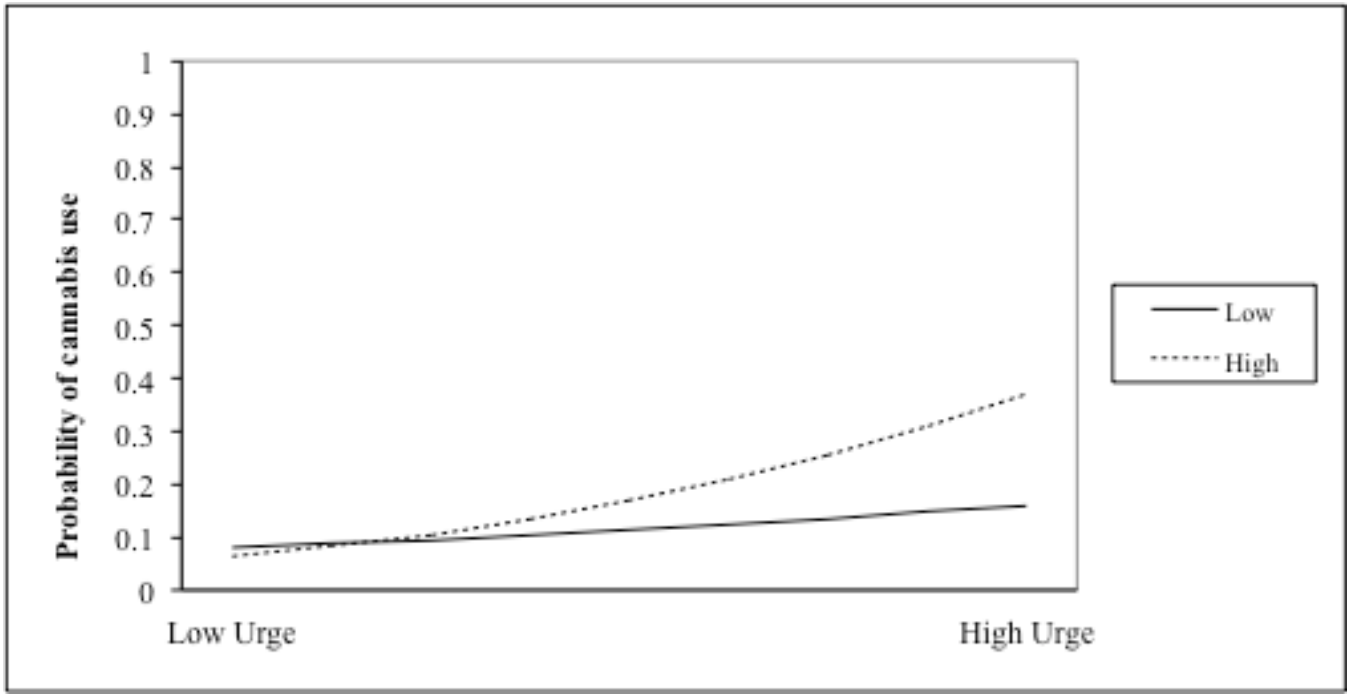
Note. The two lines represent different levels of baseline self-distraction. The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on self-distraction. The dotted line represents the predicted probability for participants 1 SD above the mean.

Figure 7. Acting with awareness moderates the association between momentary urges and cannabis use.



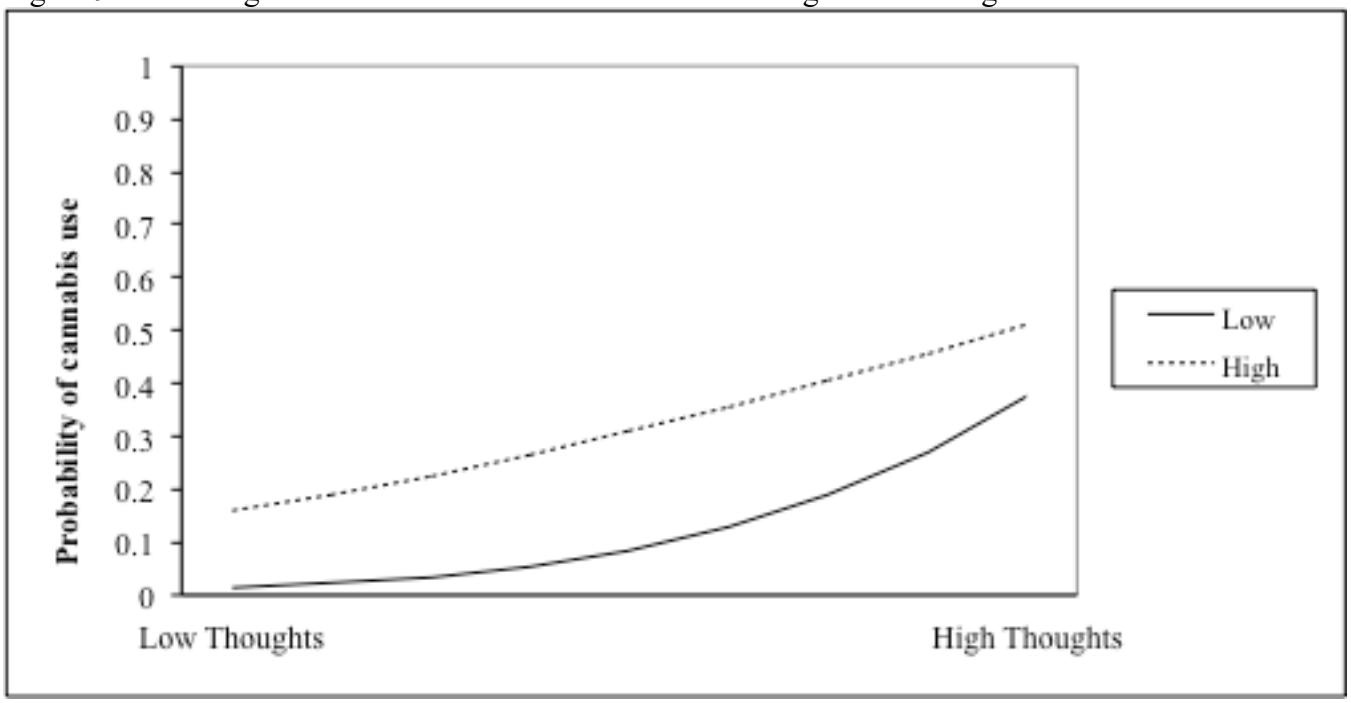
Note. The two lines represent different levels of baseline acting with awareness. The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on acting with awareness. The dotted line represents the predicted probability for participants 1 SD above the mean.

Figure 8. Implicit marijuana identity moderated the association between person-mean urges and cannabis use.



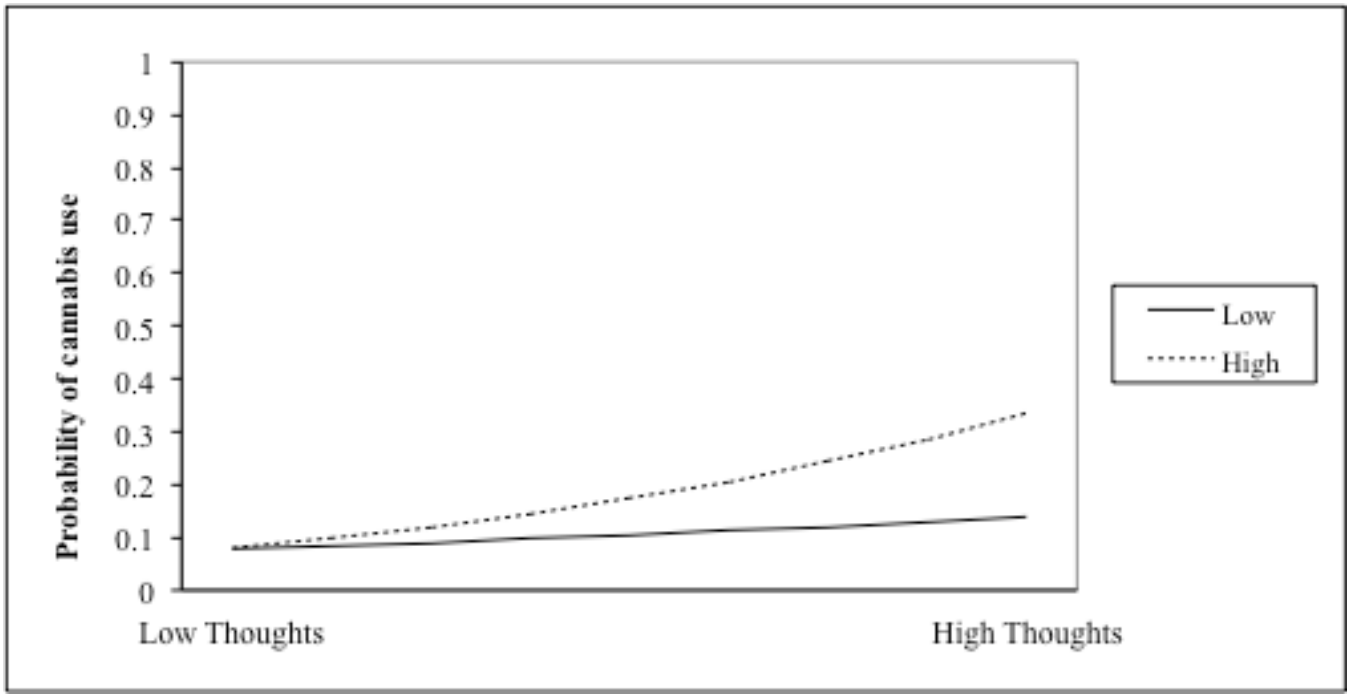
Note. The two lines represent different levels of baseline implicit marijuana identity (IMI). The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on IMI. The dotted line represents the predicted probability for participants 1 SD above the mean.

Figure 9. Observing moderated the association between craving-related thoughts and cannabis use.



Note. The two lines represent different levels of baseline observing. The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on observing. The dotted line represents the predicted probability for participants 1 SD above the mean.

Figure 10. Implicit marijuana identity moderated the association between person-mean craving-related thoughts and cannabis use.



Note. The two lines represent different levels of baseline implicit marijuana identity (IMI). The solid line represents predicted probability of cannabis use for individuals 1 SD below the mean on IMI. The dotted line represents the predicted probability for participants 1 SD above the mean.

V. General discussion

The present dissertation is comprised of three papers investigating the predictive association between craving and subsequent cannabis use, as well as moderators of this link. The primary aim of the current studies is to increase our understanding of how craving is related to cannabis use behavior among young adults with problematic use who are interested in reducing their use. Therefore, multiple methods and levels of assessment were used to measure craving, use, and factors which have been hypothesized to influence this association. The first paper describes a systematic review of the available literature on the effect of mindfulness on various psychiatric outcomes, including craving and substance use. Evidence indicates a strong negative association between mindfulness training and psychiatric symptoms including symptoms of depression, anxiety, craving, and problematic consumption. The second paper describes the first study from a program of research utilizing intensive longitudinal assessment of craving and cannabis use among college students with problematic use and an interest in reducing use. Results indicated that the momentary assessment of craving was a strong predictor of subsequent cannabis use, while baseline single-assessment craving predictors were not as strongly associated with subsequent cannabis use. The third paper describes a second study from the same program of research, with a focus on investigating factors that influence the association between craving and use. Several variables were associated with subsequent use and moderated the effect of craving on use. The most consistent and robust moderators were non-judgmentalness (a facet of mindfulness) and implicit marijuana identity (an automatic process measured using a response-time task).

Craving and subsequent cannabis use

Craving was measured using two items that assessed unique dimensions of the experience of craving: (1) urges, or the desire to use cannabis, and (2) thoughts about using cannabis. Both urges and thoughts provided unique variance accounted for in the final model that included all predictors. Additionally, a person's average level of urges was strongly associated with subsequent use, although average level of thoughts was not. Only one of the dimensions of craving assessed at baseline using the

Marijuana Craving Questionnaire (MCQ, Heishman, Singleton, & Liguori, 2001) was associated with subsequent use in the final model: purposefulness. In general, the purposefulness items were also present focused, and thus very similar to the items used in the momentary assessment of thoughts and urges, even though they were assessed only once and were therefore time-invariant. While the momentary craving measurements were positively associated with probability of subsequent use at the proximal time point, this was not the case for the distal timepoint – even though it was only a few hours later in most cases.

Mindfulness and the association between urges and use

Based on the literature, mindfulness was hypothesized to be a moderator of the association between craving use, such that higher mindfulness would reduce the strength of the association between craving and use. Results from the current study supported this hypothesis. Specifically, the non-judgmentalness facet of mindfulness reduced the strength of the association between urges and use as hypothesized. While the interaction between non-judgmentalness and thoughts was not observed, there was a negative main effect of non-judgmentalness on probability of cannabis use. Additionally, there was a negative main effect of non-reactivity on subsequent use controlling for momentary urges and momentary thoughts. Although main effects and interactions for the other three facets of mindfulness were not significant, several were nearly significant, and are worthy of further investigation.

Implicit marijuana identity moderates the association between craving and use

The investigation into moderators of the effect of craving on use produced one strong and consistent factor that influenced the effect: implicit marijuana identity (IMI). IMI moderated the association between both average level craving predictors and subsequent use such that as the strength of an individual's IMI increased, the strength of the association between average level of craving and cannabis use was also amplified. For people who strongly identified with marijuana, if they also reported higher average craving their probability of use was high. However, for people who weakly identified with marijuana, their average craving level was less related to use

Conclusions

Findings from the current study provide a framework for future studies investigating hypothesized mechanisms of action in treatments to increase craving management and reduce problematic use among college student cannabis users interested in cutting down. Craving for cannabis appears to be a strong predictor of subsequent use behavior for young adult cannabis users who are interested in reducing or limiting their use. The effect of craving on subsequent use behavior was sensitive to time elapsed between assessment of predictor and outcome. Ecological momentary assessment provided the strongest measure of craving for predicting subsequent use behavior. Non-judgmentalness and IMI influenced the association between craving and use in contradictory ways: non-judgmentalness was protective against the effect of momentary craving, and IMI increased risk of use associated with average level of craving.

While treatments targeting implicit substance using identities have reported mixed results (Lindgren, Wiers, et al., 2015), mindfulness-based interventions have demonstrated some effectiveness at increasing non-judgmentalness (Giannandrea et al., 2018). Future treatment trials may benefit from targeting individuals interested in reducing their cannabis use, with strong IMI, and offer mindfulness training to enhance craving management through increasing non-judgmentalness.

VI. References

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