

**Predictive Cross-Lagged Relationship Between Negative Affect and Alcohol Craving in
Alcohol Dependent People Undergoing Treatment During 100 Days of Ecological
Momentary Assessment**

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Abstract

Background: Alcohol Use Disorder (AUD) poses significant public health challenges, underlined by the interaction of negative affect (NA) and craving, contributing to the cycle of relapse in AUD patients seeking treatment. This study explores the bidirectional predictive relationship between NA and craving and moderating factors over an extended period using Ecological Momentary Assessment, focusing also on idiosyncratic patterns.

Methods: An Intensive Repeated and Continuous Measures in Naturalistic Settings Case-study design was conducted. Ten participants recruited from an addiction care facility in the Netherlands completed eight questionnaires per day over the course of 100 days, providing self-reported measures of craving, affect, and lapses. Fixed-effect and linear mixed models were used to investigate the cross-lagged predictive relationship of affect and craving, using 3-hour lags, including moderators of time passed since the beginning of the study and different weekly lapse frequencies observed, on a group and individual level.

Results: Affect did not significantly predict craving, nor did craving significantly predict affect across all participants. Individual analyses indicated a bidirectional predictive effect only for one participant. Time and weekly lapse frequency did not moderate the affect-craving relationship at a group level. At an individual level, a minority of participants exhibited significant positive and negative moderation effects of time and weekly lapse frequency.

Conclusion: This study highlights the interindividual variability and complexity of the relationships between affect and craving in AUD treatment. While no consistent predictive relationships were identified at the group level, individual trajectories varied, underscoring the necessity of future research investigating the individual trajectories further for personalised treatment approaches to effectively manage the cycle of relapse in AUD.

Predictive Cross-Lagged Relationship Between Negative Affect and Alcohol Craving in Alcohol Dependent People Undergoing Treatment During 100 Days of Ecological Momentary Assessment

In the landscape of public health challenges, Alcohol Use Disorder (AUD) emerges as a formidable risk. Harmful alcohol use is responsible for 5.3% of all deaths globally, amounting to three million fatalities each year (World Health Organization, 2022). Beyond obvious health implications, AUD also causes significant economic and social losses and treatment is often accompanied by a relentless cycle of relapse (Kirshenbaum et al., 2009). Central to understanding and interrupting this cycle are the concepts of craving and negative affect (NA). Craving, defined as the subjective experience of wanting to use a drug (Tiffany & Wray, 2012), has shown mixed results regarding its relationship with relapse, some finding a strong association, some finding none at all (Ferguson & Shiffman, 2009; Paliwal, 2008; Walton et al., 2003). Still, it remains a significant obstacle on the way to recovery (Lowman et al., 2000) and therefore should be a factor that is taken into account when researching AUD.

When it comes to NA, consensus among researchers points to its substantial link with alcohol use and craving. Bresin et al. (2018) discovered a positive correlation between NA and alcohol craving and consumption in their meta-analysis of AUD laboratory studies. Other studies support this association, highlighting that heightened NA can increase craving which in turn relates to drinking behaviour (Waddell et al., 2021; Witkiewitz & Villaruel, 2009; Zywiak et al., 2006). An explanation for the association between NA, craving, and drinking is the notion that drinking offers individuals with alcohol dependence a means to escape from their negative emotions (de Castro et al., 2007). Behavioural-learning theories suggest that once dependent individuals learn that alcohol can alleviate their NA, negative emotions start to trigger the urge for alcohol (Stasiewicz & Maisto, 1993). This urge, in the absence of alcohol, is experienced as craving (McKay, 2011). Witkiewitz et al. (2011) further support this by showing that learning to manage cravings induced by NA reduces heavy drinking and lowers NA levels post-treatment. The authors concluded that addressing cravings that arise from negative emotional states may aid in lowering the likelihood of relapse.

Both craving and NA are highly dynamic phenomena (Drummond et al., 2000; Schoevers et al., 2021). But capturing the temporal dynamics and fluctuations of experiences such as craving and NA presents a methodological challenge. Traditional, cross-sectional approaches cannot capture the moment-to-moment experiences of individuals and can be vulnerable to retrospective biases. A more recent approach is Ecological Momentary

Assessment (EMA), where participants provide multiple self-reports throughout the day, often via their smartphones. This results in data that is collected in real-time and within the participant's natural environment, leading to high ecological validity (Myin-Germeys & Kuppens, 2022). Shiffman (2009) deems EMA to be highly effective for examining substance use behaviours, which are often sporadic and occur in distinct episodes.

The Relationship of Negative Affect and Craving

Recent EMA studies have sought to deepen the understanding of the relationship between NA and craving, with partially limited results. Serre et al. (2015) found that most studies included in their meta-analysis reported a positive correlation between NA and craving. Similarly, in their review of longitudinal AUD studies, Votaw et al. (2022) reported that increased NA is typically followed by a heightened urge to drink in the subsequent moment. However, through their review, it becomes clear that most included studies using NA as a predictor investigate the effect it has on relapse, rather than on craving. Furthermore, the review also sheds light on the short study duration and few daily assessment points of most of these studies investigating NA and craving. Zhao et al. (2023) pointed towards the necessity of longer EMA studies, as they found the relationship between NA, craving, and abstinence to vary over time and expressed concern that significantly shorter EMA studies, might fall short of discovering such dynamics.

Another less researched avenue in AUD is bidirectionality. If NA causes craving, craving might also heighten NA, starting a vicious cycle in which the patient craves alcohol due to their low mood and suffers from a decreased mood caused by the relentless craving for the substance. With this notion in mind, Waters et al. (2020) explored NA and the temptation to drink, a variable similar to craving, finding NA predicted temptations to drink but not vice versa. They suggested their lack of evidence for a bidirectional relationship might be related to the utilised lag-interval of 5 hours, proposing future studies with shorter assessment intervals. Additionally, it remains unclear if focusing on craving specifically rather than temptation to drink would alter their results. Importantly, bidirectionality warrants further research, as its relevance has already been established in addiction research. For instance, a study on smoking has found a bidirectional relationship between withdrawal symptoms (including NA and craving) and smoking relapse (Robinson et al., 2019).

Interindividual differences also play a crucial role in the investigation of NA and craving. Cleveland et al. (2023) demonstrated that patients with stronger NA-craving associations had longer periods of abstinence post-treatment, suggesting variability in NA-craving links. Similarly, research on NA in substance use disorder treatment outcomes has

revealed more consistent associations within individuals over time compared to between individuals (Votaw et al., 2022). This suggests that while one person's experience of NA might predict their craving levels at a given moment, this is not necessarily a universal predictor for all individuals in treatment for AUD.

Rationale

Collectively, these studies underline the necessity of extending EMA research on NA and craving beyond traditional timeframes (Serre et al., 2015; Votaw et al., 2022; Zhao et al., 2023). Moreover, recovery paths in AUD are notably diverse, highlighting the importance of individualised approaches (Cleveland et al., 2023; Zheng et al., 2015). Alcohol models that instead rely on aggregated data fail to capture how individuals experience NA or craving over time and may mask interindividual differences (Fisher et al., 2018), making it challenging to develop effective personalised treatment strategies.

Additionally, AUD treatment may affect the NA-craving relationship. Cognitive-behavioural therapy techniques aid individuals in identifying triggers, enhancing coping strategies, and altering maladaptive thought patterns, which may influence the NA-craving relationship (Sudhir, 2018). Thus, time spent undergoing treatment could weaken the relationship between NA and craving. However, since the timing in treatment response varies among individuals, another influencing factor could be the number of lapses an individual has, with fewer lapses indicating more effective treatment. Abstinence, a common measure of intervention effectiveness, is associated with reduced craving, further weakening the predictive effect of NA (Hallgren et al., 2018).

Moreover, the potential bidirectional relationship between NA and craving adds a new dimension to AUD research. Robinson et al. (2019) suggested that addiction research should consider a network of interrelated symptoms and behaviours rather than simple one-way causation. This perspective is crucial, as it acknowledges the dynamic interplay and mutual influence of various factors in addiction.

Current Study

Seeing as there is no conclusive evidence on the potential bidirectional relationship of NA and craving for patients undergoing AUD treatment, the primary aim of the current study is to explore the predictive strength of NA on subsequent craving for alcohol, as well as the predictive strength of craving on subsequent NA, using an EMA design. Shortcomings of previous studies, especially regarding the study-duration, will be accounted for by analysing the data of AUD patients seeking treatment, collected over 100 days. Furthermore, a time lag regarding the effect on subsequent NA or subsequent craving shorter than 5 hours will be

explored, as suggested by Waters et al. (2020). Additionally, as a secondary aim, possible influencing factors such as treatment over time and the number of lapses will be considered. Participants will be examined collectively to determine the potential overarching effect of one variable on another. Concurrently, an additional exploration of each participant will be conducted to identify and capture individual trajectories. By gaining a better understanding of the relationship between NA and craving, its dynamics during the course of treatment and afterwards, and by also mapping personal patterns of experiences, the current study could inform clinical practices and personalised interventions to help break the cycle of relapse.

Therefore, this research will aim to answer the following research question: “*What is the predictive strength of negative affect on subsequent craving three hours later, and the predictive strength of craving on subsequent negative affect three hours later, during a 100-day observation period in patients seeking treatment for alcohol use disorder?*”

A second research question will aim to go more into depth regarding individuals by answering: “*What are individual participant trajectories of negative affect and craving during a 100-day observation period in patients seeking treatment for alcohol use disorder?*”

Since the current study combined negative and positive affect into a bidirectional affect variable, the term *affect* will be used from here on onwards instead of NA. Based on previous literature within the field of addiction and the subsequent expectations, the following hypotheses are proposed for both research questions:

H1: Affect is a negative predictor of subsequent craving.

H2: Craving is a negative predictor of subsequent affect.

H3: Affect is a stronger predictor of craving than craving is of affect.

H4: The impact of affect on subsequent craving is attenuated over time.

H5: The impact of craving on subsequent affect is attenuated over time.

H6: The impact of affect on subsequent craving is positively moderated by lapse frequency.

H7: The impact of craving on subsequent affect is positively moderated by lapse frequency.

Methods

Design

In order to test the cross-lagged predictive strength of affect on craving and of craving on affect, as well as potential moderators, an ESM study was conducted using an Intensive Repeated and Continuous Measures in Naturalistic Settings Case-study design (Moskowitz et

al., 2009). The secondary data usage of this study was approved by the Ethical Committee of the University of Twente (request number: 240050).

Participants

The participants recruited were undergoing treatment for AUD at an addiction care facility in the Netherlands. Recruitment occurred from September 2016 to March 2017. Upon beginning treatment, patients were evaluated using the Substance Abuse Module of the Composite International Diagnostic Interview (Compton et al., 1996) to determine the type and severity of their substance use disorder. Participation in the study started approximately six weeks into treatment, coinciding with patients establishing their primary treatment goal (to achieve abstinence or reduce drinking). Craving was anticipated to become more pronounced once a clear goal of abstinence was set, marking drinking episodes as lapses. Inclusion prior to this six-week threshold was anticipated to yield lower or non-existent craving levels and non-representative drinking episodes since patients were not yet committed to abstaining. Participants provided informed consent before joining the study. The final sample consisted of ten participants, including six men and four women with an average age of 40 years (SD = 11). Next to having established a treatment goal, the inclusion criteria specified all participants to be older than 18 years, have a moderate or severe use disorder (DSM-V), be in treatment, and own a smartphone. Subjects who were diagnosed with other diseases, used other substances except nicotine, or were pregnant were excluded from participation in the study.

Materials

During the study, self-reported lapses, self-reported craving, as well as affect, stress, and contextual information were measured and documented. For the current study, only self-reported craving, affect, and the number of recorded lapses were of relevance.

Craving and affect were both reported through the EMA questionnaires. Craving was assessed using a single-item measure. The question was formulated the following way: “*how strong is your craving currently?*” and was measured using a 10-point Likert scale. Although it is not common to evaluate craving using a single item in clinical practice (Flannery et al., 1999; Martinotti et al., 2013; Ooteman et al., 2006), using a single-item measure specifically for an EMA study is not unreasonable. The primary intention of assessing craving with a single item is its time-efficiency and the reduction of participant burden (Eisele et al., 2022). Furthermore, Ooteman et al. (2006) claim that when concentrating on immediate states, such as craving, single-item measures exhibit a strong correlation with more comprehensive measures. Affect was assessed through a valence-arousal scale. Using this two-dimensional

scale, participants could self-report the valence of their emotion on the x-axis, ranging from negative to positive, and their arousal on the y-axis, ranging from low to high energy levels. This resulted in a bipolar affect variable with a positive and negative anchor. Lapses were assessed outside of the EMA questionnaires by participants indicating that drinking occurred since the last lapse assessment, using a dichotomous response option (yes/no).

Procedure

The study started with an initial meeting in which participants' demographic data were collected. Participants reported data by completing questionnaires on their mobile phones at the start and end of each day and by EMA prompts throughout the day. The first questionnaire of the day was used to record data on possible lapses from the previous day. Participants had to indicate whether a lapse occurred or not. Throughout the day, participants received eight prompts to answer the self-report questionnaire inquiring, among other variables, for affect and the level of craving. This assessment frequency is common in EMA studies (Dejonckheere & Erbas, 2022). A time-contingent design with a fixed sampling scheme was employed to gather data points. Participants received a small monetary incentive of max €1 a day for each completed questionnaire, a method shown to foster high compliance (Musthag et al., 2011). The questionnaire triggered in the evening provided another possibility to record a lapse that occurred during the day. See Table 1 for an overview of when each type of questionnaire was prompted. The study period lasted for 100 days, aligning with research indicating that the likelihood of relapse significantly decreases after this period (Kirshenbaum et al., 2009). It concluded with an evaluative interview.

Table 1*Schedule of the Assessment Prompts*

Type of Assessment	Information assessed	Triggered
		04:00
		07:00
		10:00
EMA Questionnaire	Self-reported affect, self-reported craving	13:00
		16:00
		19:00
		22:00
		01:00
Lapse Registration	Self-reported lapses	Possibility to record at the end and beginning of each day

Note. EMA = Ecological Momentary Assessment. Each EMA Questionnaire expired after 59 minutes.

Data Analysis

All analyses were performed using R Statistical Software (v4.3.0; R Core Team, 2023). Given the 24-hour measurement schedule and the understanding that participants might not respond to every query, especially at night, the compliance rate was adjusted to be more realistic. Five out of eight responses daily were determined to be more reasonable, aiming for a total of 500 possible responses over 100 days. Still, compliance in EMA studies is an issue, and a response rate below 80% could impact the representativeness of the data, particularly if the missing data is not random (Stone & Shiffman, 2002; Viechtbauer, 2022a). Other EMA studies have used lower cut-off points from 50% to 33% (Kraiss et al., 2023; Viechtbauer, 2022a). Due to the extensive length of the study and the consequent challenge of adhering to it, a cut-off point of 40% of the 500 expected responses was utilised. This equates to a required minimum of 200 data points per individual. Participants below this cut-off point were removed and not included in the analyses.

Descriptive statistics were obtained. Person-mean centered scores of craving and affect were calculated and standardised to include in the models. The person-mean score of affect/craving was obtained by calculating the average of the variable for each participant across all observations. For each participant, this average score was then subtracted from each

individual momentary observation, resulting in person-mean centered scores. This approach disaggregates within-person effects by centering scores around each participant's mean and therefore focusing on how variables change within a person, independent of differences between individuals (Kraiss et al., 2023; van de Pol & Wright, 2009; Wang & Maxwell, 2015). Person-mean centered scores were standardised by subtracting the mean of each participant's person-mean centered scores from it and dividing it by the standard deviation. This standardisation allows for the comparison of effects across participants by ensuring that the scores have a consistent scale. The variables of crave and affect were also lagged forward (t+1) to be able to assess the cross-lagged predictive association between and affect and craving. The variables were only lagged for datapoints three hours apart. If a questionnaire prompt was missed by a participant, leading to a gap larger than three hours from one recorded data point to the subsequent one, no lag was applied.

To test the first two hypotheses, two linear mixed models (LMM) were run using the “nlme” package (Pinheiro & Bates, 2000; Pinheiro et al., 2023). Mixed-effect models were suitable for the current study due to their capability to handle repeated measures and account for dependencies within individual measurements (Myien-Germeys, et al., 2018; Viechtbauer, 2022b). The first mixed-effects model included person-mean centered, standardised affect as the independent variables and craving (t+1) as the dependent variable (H1). The second model included person-mean centered, standardised craving as the independent variable and affect (t+1) as the dependent variable (H2). For both models, participants were specified as a random effect, utilising a random intercept model. The model was further specified using a variance-covariance structure of autoregressive (1) (Borckardt et al., 2008). An AR(1) structure posits that observations closer in time are more highly correlated than those further apart (Kincaid, 2005). These specifications allow assessment of the bidirectional prediction of affect and craving while controlling for dependencies within individuals (Borckardt et al., 2008). The third hypothesis was tested by visually comparing the output of both LMMs.

To test the fourth to seventh hypotheses, the LMMs for each direction were expanded by adding an interaction effect of the respective independent variable and time (H4 & H5) or an interaction effect of the respective independent variable and weekly lapse frequency (H6 & H7). Time and weekly lapse frequency were both coded as discrete variables. The moderation effects were also explored visually by plotting regression lines of the relationship under certain conditions of the moderation variable. Sensitivity analyses were conducted to determine the impact of including participants with lower response rates, assessing the

robustness of the models. This was done by rerunning the models and including all ten participants who participated in the study.

All group-level analyses were repeated using simple linear models for each participant to investigate individual effects and trajectories. To account for autocorrelation in these simple linear models as well, a covariate representing the non-lagged value of the respective dependent variable was added. In all analyses conducted, findings with a p-value less than .05 were deemed statistically significant.

Results

Descriptive statistics about participant's compliance rates and craving moments can be found in Table 2. For the analysis, participants numbered 1, 2, and 5 were excluded because they completed less than 40% of the questionnaires. After excluding these participants, the average compliance rate was 65.6%. Compliance was highest for prompts delivered at 13, 16, and 19 o'clock, and lowest for prompts delivered at 1, 4, and 7 o'clock (see Appendix A, Table A1).

Table 2

Descriptive Statistics of Compliance Rates, Mean Craving, Mean Affect per Individual, and Number of Lapses

Participant	Compliance (% of 500 registrations)	Mean Craving	Mean Affect	Lapses
1 ^a	141 (28.2%)	1.51	6.25	0
2 ^a	79 (15.8%)	0.51	2.34	0
3	315 (63%)	1.5	13.9	3
4	282 (56.4%)	0.37	35.7	6
5 ^a	106 (21.2)	3.89	31.7	20
6	228 (45.6%)	2.83	3.70	0
7	435 (87%)	1.16	20.4	26
8	303 (60.6%)	0.88	27.1	16
9	405 (81%)	0.47	38.6	0
10	327 (65.4%)	1.15	1.50	28

^a Participant removed for analysis due to low compliance.

Hypothesis 1: Affect is a Negative Predictor of Subsequent Craving

At the group level, results from the LMM showed no significant fixed effect of affect on subsequent craving when controlling for autocorrelation, $b = -0.116$, $p = .058$ (Table 3). Analyses of single individuals showed a significant negative effect of affect on subsequent craving when controlling for autocorrelation only for participant 4, $b = -0.046$, $p = .001$ (see Appendix C, Table C1).

Hypothesis 2: Craving is a Negative Predictor of Subsequent Affect

At the group, level no significant fixed effect was found for craving on subsequent affect when controlling for autocorrelation, $b = -0.818$, $p = .132$ (Table 3). Analyses of single individuals showed a significant effect of craving on subsequent affect when controlling for autocorrelation only for participant 4, $b = -1.558$, $p = <.001$, and for participant 9, $b = 2.342$, $p = .005$ (see Appendix C, Table C2). Only the effect for participant 4 was negative, while the effect for participant 9 was positive, against expectations. Regression lines for the effect in both directions for each individual can be seen in Figure 1.

Table 3

Linear Mixed Model Coefficients: Affect on Subsequent Craving and Craving on Subsequent Affect

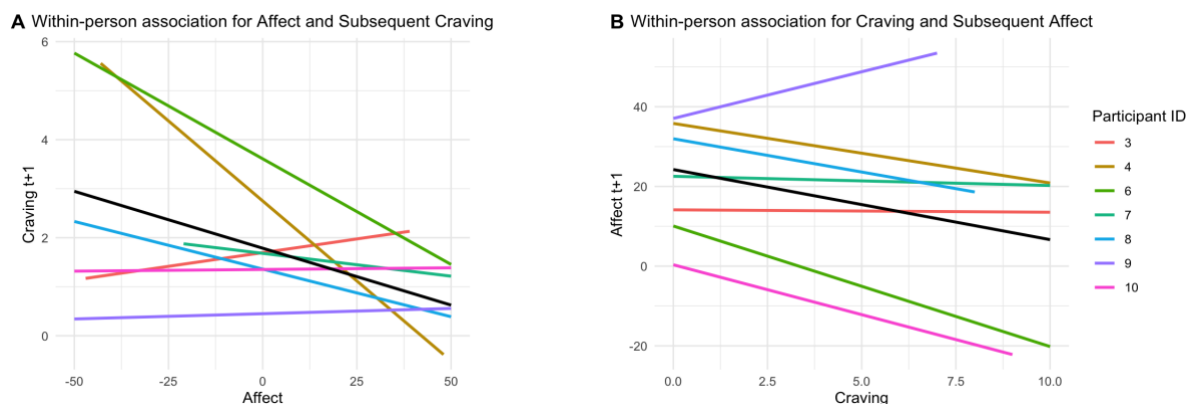
Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.402	.376	1403	.665	2.139	< .001
Affect	- 0.116	.061	1403	- 0.235	.004	.058
Craving on subsequent affect ^a						
Intercept	20.088	6.025	1395	8.269	31.908	< .001
Craving	- 0.818	.543	1395	- 0.883	.247	.132

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^a $N = 7$.

Figure 1

Within-person Associations for Affect and Subsequent Craving and for Craving on Subsequent Affect per Individual



Note. Associations are not corrected for autocorrelation. Only associations for participant 4 (A & B) and participant 9 (B) were significant. Affect scores range from 50 (Positive Affect, PA) to -50 (Negative Affect, NA). The black regression line represents the group-level effect.

Hypothesis 3: Affect is a Stronger Predictor of Craving than Craving is of Affect

Given the group level results, affect and craving show no significant cross-lagged predictive association. Therefore, visual comparison of the model output yields no evidence that affect is a stronger predictor of subsequent craving than craving is of subsequent effect. Comparing the individual results for H1 and H2, participant 4 is the only participant showing a significant cross-lagged predictive association. However, for this participant the effect of affect on subsequent craving is weaker ($b = -0.046$) than the effect of craving on subsequent affect ($b = -1.558$), indicating that craving is a stronger predictor of affect than affect is of craving. Furthermore, participant 9 only showed a significant effect of craving on subsequent affect, indicating that also for this participant craving is a stronger predictor of affect than affect is of craving.

Hypothesis 4: The Impact of Affect on Subsequent Craving is Attenuated over Time

At the group level, the LMM revealed that time did not significantly moderate the relationship between affect and subsequent craving $b = .003, p = .109$ (see Table 4). However, when accounting for the interaction with time, affect emerged as a significant predictor of subsequent craving, $b = -0.255, p = .01$ (see Table 4), unlike in the models not including the interaction effect. The lack of a significant interaction effect suggests that the moderating condition of time may not be uniformly distributed across the study period or may not follow a simple linear progression, while the significant main effect of affect on subsequent craving points towards time still being a relevant variable in the relationship between affect and

subsequent craving. Exploratively plotting the relationship between affect and subsequent craving for three different time periods shows that the relationship strength does seem to fluctuate (Figure 2). During the very first week of the study, affect and subsequent craving seem to show a weak to moderate negative relationship, which is increased in strength by the middle week. Then a shift seems to happen as the last week exhibits a weak to moderate positive relationship between affect and subsequent craving. Analysis of individuals yielded no significant moderation effect of time on the relationship of affect on subsequent craving for any participant (see Appendix C, Table C3).

Hypothesis 5: The Impact of Craving on Subsequent Affect is Attenuated over Time

At the group level, the LMM assessing the moderating effect of time on the relationship from craving to subsequent affect yielded no significant results, $b = -0.024$, $p = .188$ (see Table 4). Analysis of individuals showed time to significantly attenuate the relationship of craving on subsequent affect only for participant 10, $b = -0.251$, $p < .001$ (see Appendix C, Table C4). This indicates that for this participant, as time passed, the predictive effect of craving on affect became weaker.

Table 4

Linear Mixed Model Coefficients: Affect on Subsequent Craving and Craving on Subsequent Affect with an Interaction Effect of Time and Affect/Craving

Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.797	.387	1401	1.038	2.556	< .001
Affect	- 0.255	.099	1401	- 0.448	- 0.062	.01*
Affect * Time	.003	.002	1401	< - 0.001	.007	.109
Craving on subsequent affect ^a						
Intercept	24.787	6.266	1393	12.496	37.078	< .001
Craving	- 0.429	.830	1393	- 2.057	1.199	.605
Craving * Time	- 0.024	.018	1393	- 0.059	.012	.188

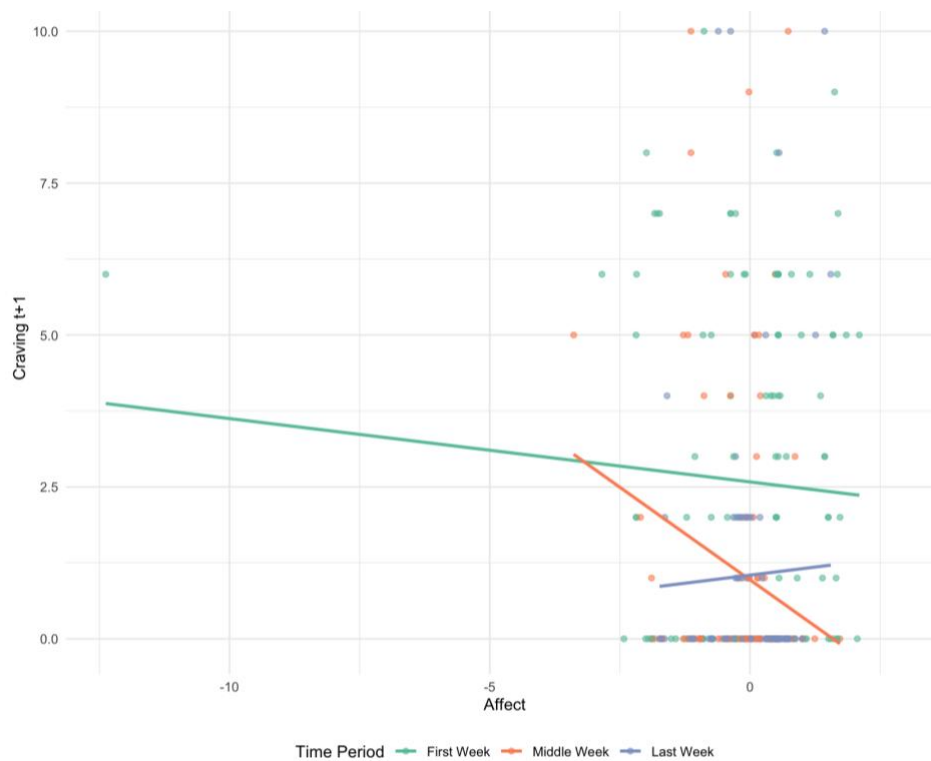
Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^a $N = 7$.

* $p < .05$.

Figure 2

Regression Lines of Affect on Subsequent Craving for Three Different Weeks



Note. Affect scores are person-mean centered and standardised and craving scores are raw, in line with the LMM testing this relationship.

Hypothesis 6: The Impact of Affect on Subsequent Craving is Positively Moderated by Lapse Frequency

At the group level, no significant moderation of weekly lapse frequency on the impact of affect on subsequent craving was revealed, $b = .041$, $p = .432$ (see Table 5). Here, when accounting for the interaction with lapse frequency, affect also emerged as a significant predictor of subsequent craving, $b = -0.14$, $p = .047$ (see Table 5), similar to the effect for affect on craving with a moderation of time. This suggests that the inclusion of lapse frequency reveals a more nuanced relationship, where affect's role as a predictor of craving becomes apparent under specific conditions that may relate to the lapse context. Figure 3 shows the relationship between affect and subsequent craving for the different lapse frequencies observed. Data recorded in weeks where either no lapses occurred or only one or two, showed a clear downward trend for the relationship between affect and subsequent craving. In weeks with three or four lapses, the relationship between affect and subsequent craving seems to be positive. Lastly, the relationship for weeks with five lapses is again slightly negative. Analysis of individuals showed that only for participant 4 the relationship

between affect and subsequent craving was significantly moderated by weekly lapse frequency $b = -0.07$, $p = .022$, (see Appendix C, Table C5). The effect is, against expectations, negative. It indicates that for this participant, with decreasing lapses, the predictive effect of affect on craving became stronger.

Hypothesis 7: The Impact of Craving on Subsequent Affect is Positively Moderated by Lapse Frequency

At the group level, no significant moderation of weekly lapse frequency was found on the impact of craving on subsequent affect, $b = -0.388$, $p = .326$ (see Table 5). Analysis of individuals showed that weekly lapse frequency significantly moderated the relationship between craving and subsequent affect for participants 4 ($b = 1.375$, $p = .022$) and 10 ($b = 3.541$, $p < .001$; see Appendix C, Table C6). This indicates that, as lapses decreased, the predictive effect of craving on affect became weaker for these participants.

Table 5

Linear Mixed Model Coefficients: Affect on Subsequent Craving and Craving on Subsequent Affect with an Interaction Effect of Weekly Lapse Frequency and Affect/Craving

Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.269	.396	1401	.492	1.269	.001
Affect	- 0.140	.070	1401	- 0.278	- 0.002	.047*
Affect * Lapse Frequency	.041	.052	1401	- 0.061	.142	.432
Craving on subsequent affect ^a						
Intercept	20.403	6.010	1393	8.613	32.192	< .001
Craving	- 0.402	.666	1393	- 1.709	.905	.546
Craving * Lapse Frequency	- 0.388	.396	1393	- 1.165	.388	.326

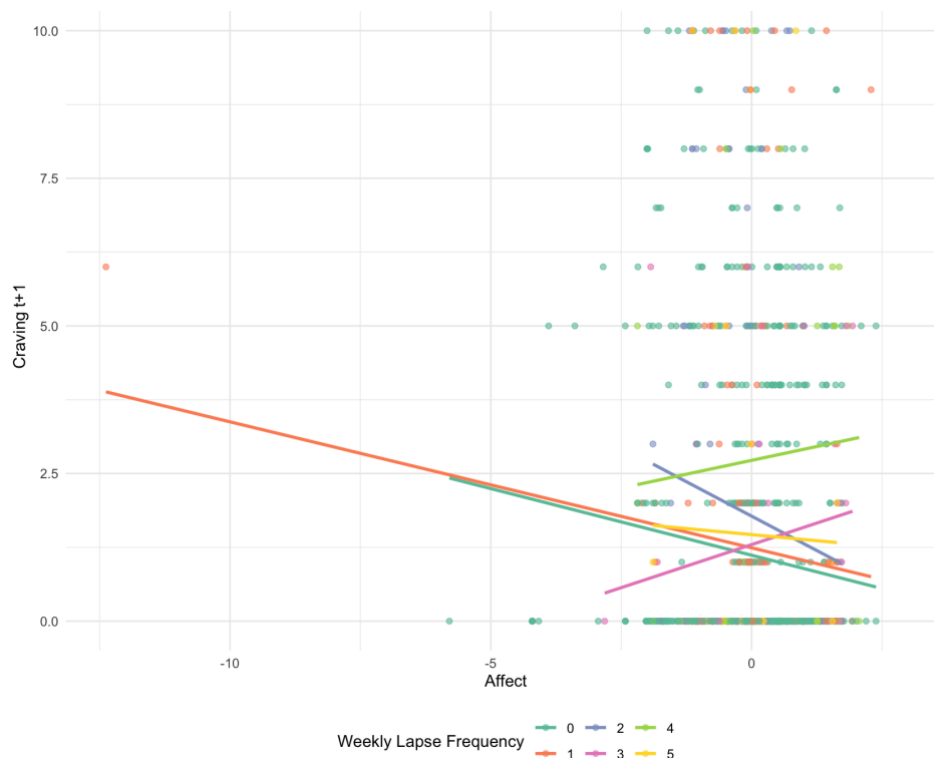
Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^a $N = 7$.

* $p < .05$.

Figure 3

Regression Lines of Affect on Subsequent Craving for Different Weekly Lapse Frequencies



Note. Affect scores are person-mean centered and standardised and craving scores are raw, in line with the linear mixed model testing this relationship. Weekly Lapse Frequency was grouped by the number of lapses that occurred in a week. Five lapses were the highest frequency of lapses recorded in a week.

Sensitivity Analyses

The sensitivity analyses conducted for group-level analyses, which included participants with a response rate below 40%, yielded similar results compared to the primary group level analyses (see Appendix B). This indicates that the findings remain robust when including all participants. One exception was observed for the effect of affect on subsequent craving when including lapse frequency in the model. While the primary analysis indicated that affect was a significant predictor, the sensitivity analysis did not replicate this significance, $b = -0.114$, $p = .087$, suggesting that this result may be contingent on the sample composition (see Appendix B, Table B3).

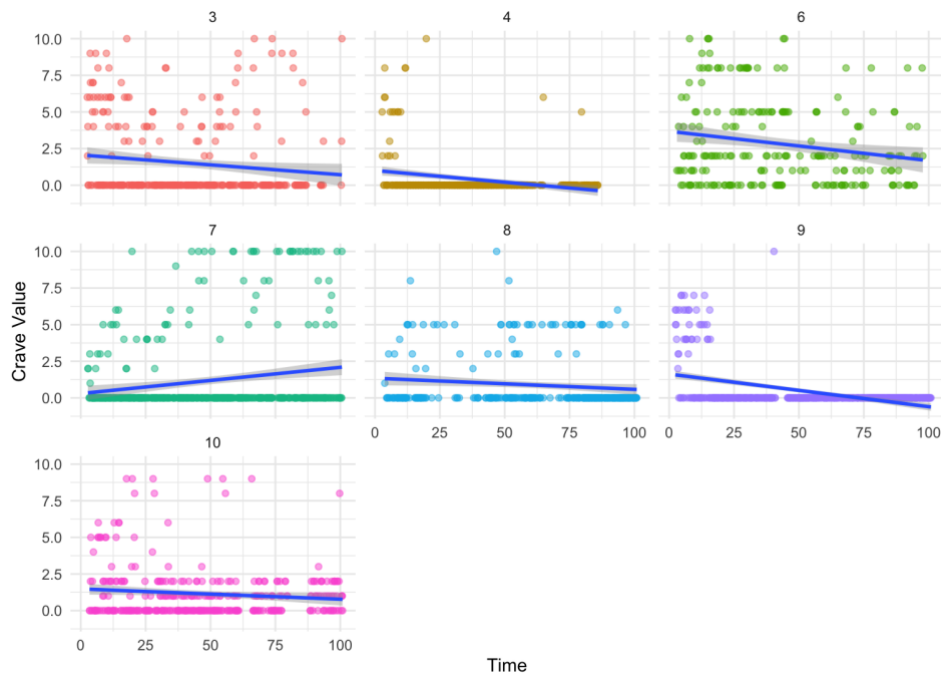
Individual Patterns

During the course of the study, craving decreased for most participants (Figure 4), while both upward and downward trends over time can be seen in the affect variable (Figure

5). Five out of the seven participants lapsed and all recorded lapses over the course of the study can be found in Figure 6.

Figure 4

Scatterplot of the Level of Craving and Mean Craving over Time by Participant

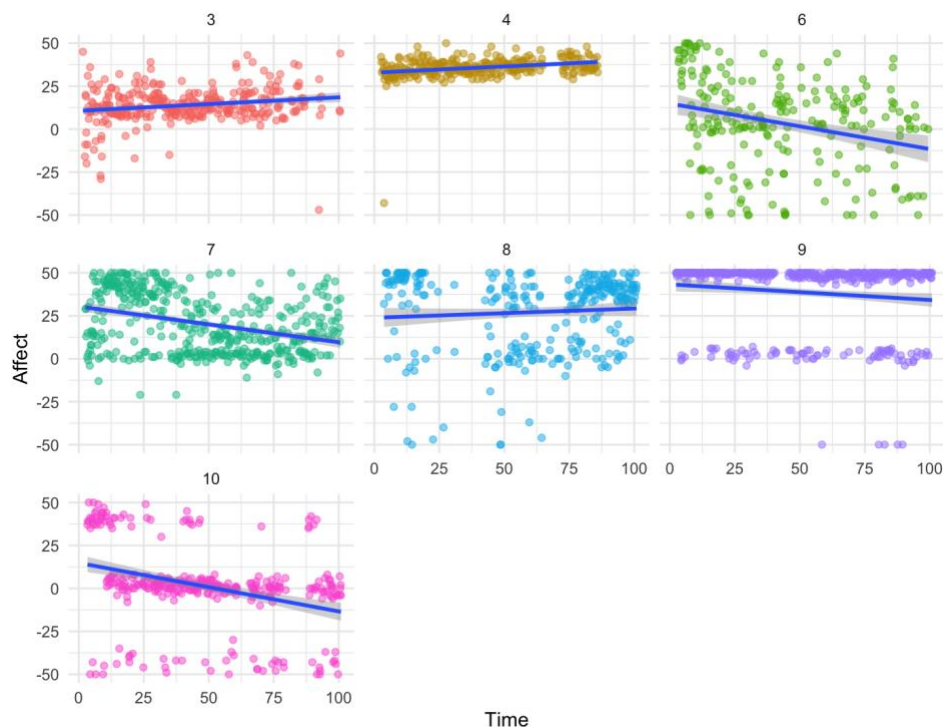


Note. Raw craving scores. Time measured in days. Regression line represents the mean. Standard error is shaded around the regression line.

Combining these data visualisations and individual model results, only the most notable findings for specific participants will be described. Participant 4 presents a remarkable case, being the only participant with significant cross-lagged predictive associations of affect and craving (see Appendix C, Tables C1 and C2). Furthermore, this participant reported consistently high affect and a marked decline in craving levels as the study progressed (see Figures 4 and 5). Similarly, the participant only reported lapses at the beginning of the study (see Figure 6). Although their number of reported lapses was lower compared to other participants (6 lapses in total), weekly lapse frequency was a significant moderator for cross-lagged predictive associations of affect and craving. Interestingly, the moderator had differing effects on the affect-craving association: the relationship between affect and subsequent craving was significantly attenuated by weekly lapse frequency, meaning that with fewer lapses, this relationship strengthened (see Appendix C, Table C5). Conversely, lapse frequency positively moderated the relationship between craving and subsequent affect, indicating that as lapses decreased, this craving-affect relationship weakened (see Appendix C, Table C6).

Figure 5

Scatterplot of the Level of Affect and Mean Affect over Time by Participant



Note. Raw affect scores. Affect scores range from 50 (Positive Affect, PA) to -50 (Negative Affect, NA). Time measured in days. Regression line represents the mean. Standard error is shaded around the regression line.

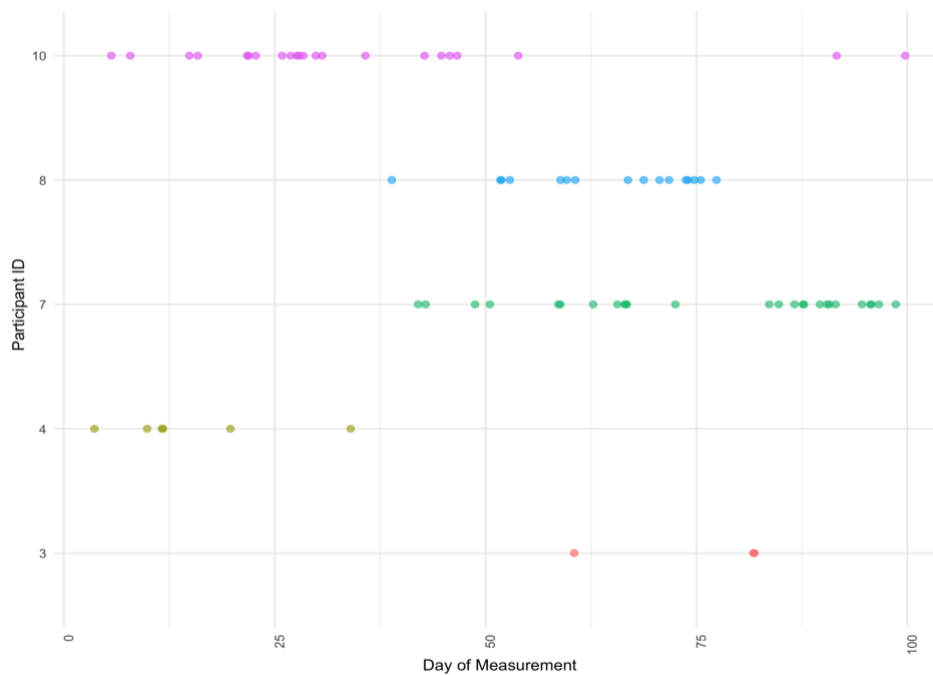
Participant 9 also exhibited an unexpected pattern by showing no significant associations except the significant positive effect of craving on subsequent affect (Appendix C, Table C5). This is in contrast with the expectation that craving would be a negative predictor of subsequent affect. This participant experienced increased craving episodes primarily at the study's onset, which tapered off rather rapidly (see Figure 4) and recorded no lapses.

Participant 10's data revealed two significant moderation effects on the relationship of craving and subsequent affect: an attenuation by time, indicating that as the study continued, the influence of craving on affect diminished (see Appendix C, Table C4). And additionally, a positive moderation by lapse frequency on the same relationship, suggesting that weeks of higher lapse frequencies were associated with stronger connections between craving and subsequent affect (see Appendix C, Table C6). This is especially interesting, since participant 10 had the highest number of recorded lapses (28 lapses in total), which predominantly occurred in the first half of the study (see Figure 6).

For all other participants, no effects on any of the models were found, indicating no effect of affect on subsequent craving or of craving on subsequent affect, and no moderation effect of time or lapse frequency on both directions.

Figure 6

Time Series Plot of Recorded Lapses over Time by Participant



Note. Time measured in days. Participants 6 and 9 are not included since they had no recorded lapses.

Discussion

This study examined the bidirectional interplay between affect and alcohol craving over a 100-day period using EMA, focusing on 10 individuals undergoing treatment for AUD. The primary objective was to understand how affect and craving predict each other over time. Additionally, it was sought to determine whether treatment progress is reflected in changes of the relationship between affect and craving. Moderators of time and weekly lapse frequency were observed for this. The study aimed to evaluate both collective trends across participants and unique patterns within each individual's experience, providing insights into both general and personal dynamics of AUD.

Hypothesis 1: Affect is a Negative Predictor of Subsequent Craving

The findings indicated that affect did not reliably predict subsequent craving across the group. While the effect was approaching significance (see Table 3), this outcome still contrasts with some of the literature. In a review of longitudinal studies, Votaw et al. (2022) reported that decreased affect typically follows a heightened urge to drink. Despite this, the

current results align more closely with those of Serre et al. (2018), who reported a lack of a significant predictive relationship between these factors. The discrepancy between these findings and that of Votaw et al. (2022) could partly be explained by the group-level analysis potentially masking individual differences (Fisher et al., 2018; Votaw et al., 2022). However, individual results for affect predicting subsequent craving in this study also stand in contrast to the literature. For merely one participant was affect a negative predictor of subsequent craving, all others showed no association between the two factors. Given the extended duration of this study, the lack of an effect might highlight how shorter studies in this field, which are most commonly conducted (Votaw et al., 2022), could have overestimated these effects. This 100-day period allowed for a more nuanced observation of the prediction of affect on craving, suggesting that factors previously believed to be significantly predictive in shorter studies may not hold the same influence over extended timeframes.

Hypothesis 2: Craving is a Negative Predictor of Subsequent Affect

The findings also showed that craving did not reliably predict subsequent affect across the group. While bidirectionality of effects within the context of substance use disorders has been investigated and encouraged (Robinson et al., 2019), these results support the findings of Waters et al. (2020), who found no bidirectional effect between affect and the temptation to drink. These findings were obtained even after shortening the lag interval between the variables to 3 hours, as proposed by Waters et al. (2020). Individual analyses revealed two participants for whom craving had an effect on subsequent affect. For one of these, the effect was negative as expected, but for the other, a positive effect was found, indicating that increased craving led to higher affect in the subsequent moment. This participant recorded no lapses and experienced a downward trend in craving over the study period, possibly pointing to effective coping strategies that, when dealing with cravings, could boost affect. Increased craving might test their coping skills, and each successful resistance could reinforce a sense of self-efficacy, initiating a positive emotional response (Bodin & Martinsen, 2004).

Alternatively, the coping strategy could consist of distracting oneself with a positive activity, potentially inducing positive emotions through the nature of the distraction activity (Waugh et al., 2020).

Hypothesis 3: Affect is a Stronger Predictor of Craving than Craving is of Affect

Considering the non-significant results on the group level, no conclusion about which predictor is stronger can be drawn. It was expected that for this bidirectional predictive association, affect would emerge as the stronger predictor compared to craving, since its effect has been shown more thoroughly compared to the effect of craving on affect (Votaw et

al., 2022). On the individual level, only one participant demonstrated a bidirectional predictive association between affect and craving with the expected valence. Arguably, the investigation into the bidirectionality of the relationship and whether affect is a stronger predictor of craving compared to the reverse direction, is only supported by this single participant and not by any other participants, nor by the whole group. This is in line with Waters et al.'s (2020) findings who found no bidirectional predictive association between affect and the temptation to drink.

Hypotheses 4-7: Time and Weekly Lapse Frequency as Moderators of the Predictive Relationship between Affect and Craving

In evaluating the role of additional factors in the relationship between affect and craving, the study considered the potential moderating effects of time and weekly lapse frequency. Contrary to expectations that treatment, coping strategies, and fewer lapses would weaken the NA-craving relationship (Hallgren et al., 2018; Nadkarni et al., 2023; Sudhir, 2018), no moderation effect was found at the group level.

Interestingly, by including these moderators, affect emerged as a predictor of subsequent craving in both moderation models. This suggests that while the expected moderating influences of time spent in and after treatment and lapse frequency were not supported, they still play a crucial role in revealing the underlying predictive relationship, potentially by refining the model to capture more subtle dynamics between affect and craving. Moreover, the initial analysis without the moderators showed the predictive effect of affect on craving to be nearly significant. Including the moderators slightly altered the model specifications, enough to push this effect into statistical significance. This could indicate that by accounting for the variability in affect and craving across different time points and lapse frequencies, the model more accurately reflects the true nature of their relationship. Including the moderators could have helped remove potential confounding factors that the initial model overlooked.

Individual analyses revealed effects of time or lapse frequency on the predictive relationships between affect and craving for only two participants. For one participant, time attenuated the relationship between craving and subsequent affect, aligning with the expectation that as treatment progresses, craving becomes a less potent predictor of affect. In addition, lapse frequency positively moderated the relationship, which also aligned with expectations; as lapses increased, craving became a stronger predictor of affect. This reflects a stress-response pattern where increased lapses intensify the emotional response to cravings, highlighting a period-sensitive interplay between behavior and emotion (Votaw et al., 2022;

Witkiewitz & Villarroel, 2009). This increase in craving following lapses might also be an emotional reaction to the disappointment and self-criticism that often accompany a lapse. Each time an individual succumbs to craving by lapsing, they might experience negative self-perceptions, subsequently heightening their affect.

Another participant's experience differed. Here, lapse frequency attenuated the relationship between affect and subsequent craving, suggesting that as lapses decreased over the course of the study, affect became more predictive of craving, contrary to what might be anticipated. Tiffany's (1990) cognitive processing model offers a tentative explanation. According to this model, craving emerges strongly when access to alcohol is blocked or when the individual attempts to resist drinking. For this participant, as lapses increased, affect was less predictive of craving. This might suggest that after a lapse—where drinking has occurred—there is a temporary reduction in craving typically associated with affect, perhaps due to a brief period of fulfilment that diminishes the need to drink as a response to negative emotions. The additional finding for this participant that lapse frequency positively moderated the relationship from craving to subsequent affect indicates that experiences of craving were more likely to lead to decreased affect if lapses were frequent. The emotional response to craving is not solely tied to the unavailability of alcohol but may also be related to the psychological impact of the lapses themselves. This effect could reflect heightened emotionality in response to craving during periods of recent lapses. These observations are consistent with Witkiewitz and Villarroel (2009), who established that affect and lapses are linked, where increased drinking behaviour is associated with decreasing affect, possibly due to guilt or shame. These differences suggest that mechanisms may vary between participants, suggesting that individual differences may play a more crucial role than universal mechanisms in understanding the relationship between affect, craving, and lapse frequency.

Implications

In the broader context of this study, the findings are largely inconclusive, with group-level, non-significant results that contrast with certain individual-level outcomes. This highlights a complex and seemingly inconsistent picture of how affect and craving interact at a group and individual level in this sample. It underlines the fact that individuals may follow unique trajectories in their experiences of affect, craving, lapses, and recovery (Cleveland et al., 2023; Zheng et al., 2015). Witkiewitz and Marlatt (2011) advocated for personalised, person-centered approaches in addiction treatment. They argued that interventions tailored to individual characteristics and needs are essential, as what works for one person may not be effective for another. The current results further suggest that the efficacy of such interventions

may also vary over time for the same individual, indicating that strategies effective on one day may not necessarily work later as the individual's circumstances or internal state change. An increase in psychological flexibility may be a universally effective strategy, helping individuals adapt to various challenges in AUD.

Furthermore, the complexity of AUD extends beyond the variables investigated in this study. There are likely additional factors at play that may significantly influence the relationship between affect and craving. Serre et al. (2015) identified factors such as stress, location, coping, and self-efficacy influencing craving levels in their review of craving and substance use. Similarly, Knapp et al. (2021) found that daily negative social exchanges were directly associated with same-day craving and that positive social exchanges could attenuate the link between affect and craving.

Despite the initial goal to inform clinical practices and tailor personalised interventions, the anticipated outcomes did not manifest for most individuals. For those individuals with an affect-craving association, strategies such as mindfulness-based relapse prevention (MBRP) and other acceptance-focused mindfulness-based interventions have shown promise in breaking this association, suggesting that these approaches could be particularly effective for some (Votaw et al., 2022). Additionally, employing distraction techniques can help patients manage cravings by allowing them to observe and accept negative emotions without judgment (Pombo et al., 2016). These techniques help manage immediate responses to negative stimuli and aid in developing long-term resilience against the triggers of craving.

Limitation

A significant limitation concerns the measurement of affect. Affect was assessed using a valence-arousal scale, creating a bipolar affect variable where participants could self-report both positive and negative emotional states. Although this scale effectively measures affect by capturing both NA and positive affect (PA), this was not accounted for in the analysis. This measurement potentially confounds the results, as it does not distinctly separate the effects of PA from those of NA. Furthermore, the majority of participants scored higher on this scale, indicating a prevalence of PA rather than NA. Typically, NA is assessed using the Positive and Negative Affect Schedule (PANAS), which provides a more distinct and reliable measure of PA and NA (Watson et al., 1988). The failure to separate PA from NA in this study's analysis may have obscured specific affective influences on craving, potentially leading to an overestimation of the role of NA or an underestimation of the role of PA.

Similarly, the measurement of lapses presents a limitation. Lapses were self-reported on a binary scale, recorded twice a day and combined into a single daily score, lacking details about the context of the lapse or the amount of alcohol consumed. This aggregated approach may obscure the nuances of how different quantities of alcohol interact with craving and affect. For instance, without knowing the specific amount consumed during a lapse, it is difficult to accurately assess its impact on craving and affect levels. Consequently, this could affect the precision of the moderation analysis for weekly lapse frequency, as the exact relationship between the quantity of alcohol consumed during lapses and subsequent emotional and craving responses remains unclear.

Another limitation concerns the compliance rate. In the current study, a compliance rate of 65.6% was observed, similar to average response rates being reported across several EMA studies (Jones et al., 2019). However, most participants exhibited a non-response rate higher than 20%, a threshold Stone and Shiffman (2002) warned could compromise sampling representativeness. Further complicating this issue is the non-random nature of the missing data, as non-responses predominantly occurred in the early morning hours (see Appendix A, Table A1).

Additionally, the sample size is a limitation for examining group level-effects. Initially, the study included 10 participants, but due to low compliance rates, only seven were included in the final analysis. This sample size is notably smaller compared to typical longitudinal AUD studies, particularly when examining group-level effects (Votaw et al., 2022). However, the current study also delved into individual trajectories, employing an n-of-1 design (Vieira et al., 2017). While the n-of-1 design offers rich insights into personalised patterns and responses, it presents challenges in generalising findings to the broader AUD population. Since no group-level effects were detected, the small sample might limit statistical power and the ability to detect effects that might be significant in a larger population.

Directions for Future Research

In order to improve validity and generalisability, future research should address the limitations of the current study. Another focus should be developing methods for early identification of AUD patients most likely to benefit from specific interventions, such as MBRP and other acceptance-focused mindfulness-based interventions. Additionally, integrating Time-Varying Effect Modelling (TVEM) could address the temporal complexities of the variables researched here. TVEM models non-linear and non-parametric changes over time, offering a more flexible and precise analysis of how these relationships change throughout an individual's treatment or recovery process (Stull et al., 2023). This could lead to

a better understanding of recovery dynamics, which would help to improve treatment strategies by matching the changing needs of individuals with AUD.

Conclusion

This study aimed to evaluate the bidirectional predictive relationships between affect and craving in individuals undergoing treatment for AUD, alongside assessing the moderating effects of time and weekly lapse frequency. The results indicated no bidirectional predictive relationship between affect and craving at the group level, and only a few individuals displayed significant predictive relationships or moderation effects. This emphasises the variability the affect-craving relationship at an individual level, suggesting that a deeper understanding of these dynamics is still needed to advance the personalisation of interventions. Future research should focus on overcoming the limitations of the current study and consider using more sophisticated statistical models like TVEM.

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Appendix A: Compliance Rate per Prompt

Table A1

Compliance Rate per Prompt

Prompt triggered at	Total number of answered prompts	%
01:00	67	8.36%
04:00	8	1.0%
07:00	187	23.36%
10:00	347	43.36%
13:00	450	56.25%
16:00	438	54.75%
19:00	430	53.75%
22:00	368	46.0%

Note. In total 800 prompts were sent out for one specific hour for the eight participants included in the analysis.

Appendix B: Sensitivity Analyses Results

Table B1

Sensitivity Model Results Affect on Subsequent Craving and Craving on Subsequent Affect

Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.601	0.375	1550	.865	2.337	< .001
Affect	- 0.097	.058	1550	- 0.210	.016	.093
Craving on subsequent affect ^a						
Intercept	18.343	4.995	1541	8.546	28.141	< .001
Craving	- 0.816	.500	1541	- 1.796	.164	.103

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^aN = 10.

Table B2

Sensitivity Model Results Interaction Effect Time with Affect or Craving

Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.914	.382	1548	1.166	2.663	< .001
Affect	- 0.207	.092	1548	- 0.388	- 0.026	.025*
Affect * Time	.002	.002	1548	- 0.001	.006	.178
Craving on subsequent affect ^a						
Intercept	22.275	5.201	1539	12.073	32.477	< .001
Craving	- 0.426	.76	1539	- 1.909	1.056	.573
Craving * Time	- 0.022	.017	1539	- 0.055	.012	.184

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^aN = 10.

* $p < .05$.

Table B3*Sensitivity Model Results Interaction Effect Weekly Lapse Frequency with Affect or Craving*

Effect	Estimate	SE	df	95% CI		p
				LL	UL	
Affect on subsequent craving ^a						
Intercept	1.468	0.373	1548	.736	2.200	< .001
Affect	- 0.114	.066	1548	- 0.244	.017	.087
Affect * Lapse Frequency	.032	.049	1548	- 0.064	.127	.515
Craving on subsequent affect ^a						
Intercept	18.619	5.030	1539	8.753	28.485	< .001
Craving	- 0.321	.603	1539	- 1.504	.862	.595
Craving * Lapse Frequency	- 0.507	.369	1539	- 1.231	.216	.169

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

^a N = 10.

Appendix C: Individual Model Results

Table C1

Individual Linear Mixed Model Results of Affect on Subsequent Craving

Participant	Estimate	SE	df	95% CI		p
				LL	UL	
3	.014	.019	176	- 0.023	.051	.46
4	- 0.046	.014	173	- 0.074	- 0.018	.001**
6	- 0.006	.015	98	- 0.035	.024	.703
7	- 0.11	.010	295	- 0.031	.009	.278
8	- 0.009	.007	176	- 0.023	.004	.182
9	.002	.004	283	- 0.006	- 0.01	.613
10	< .001	< .001	181	- 0.012	.012	.991

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

** $p < .01$.

Table C2

Individual Linear Mixed Model Results for Craving on Subsequent Affect

Participant	Std. Estimate	SE	df	95% CI		p
				LL	UL	
3	- 0.154	.277	177	- 0.7	.393	.579
4	- 1.558	.352	171	- 2.253	- 0.864	< .001***
6	.301	1.139	98	- 1.96	2.561	.792
7	- 0.388	.383	295	- 1.142	.367	.313
8	- 0.941	.878	176	- 2.673	0.792	.285
9	2.342	.818	283	.732	3.952	.005**
10	- 2.502	1.373	182	- 5.212	.0207	.070

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table C3*Interaction Effect of Affect and Time on Subsequent Craving for each Individual*

Participant	Estimate	SE	df	95% CI		p
				LL	UL	
3	< .001	< .001	174	- 0.001	.001	.896
4	< .001	< .001	171	< - 0.001	.002	.227
6	< - 0.001	<.001	96	- 0.002	< .001	.185
7	< .001	<.001	293	< - 0.001	.001	.229
8	< .001	< .001	174	< - 0.001	.001	.142
9	< .001	< .001	281	< - 0.001	< .001	.955
10	< - 0.001	< 0.001	179	- 0.001	< .001	.823

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Table C4*Interaction Effect of Craving and Time on Subsequent Affect for each Individual*

Participant	Estimate	SE	df	95% CI		p
				LL	UL	
3	- 0.004	.01	175	- 0.023	.015	.676
4	.037	.02	169	- 0.002	.076	.066
6	- 0.035	.04	96	- 0.112	.045	.382
7	- 0.011	.013	293	- 0.04	.017	.436
8	.047	.034	174	- 0.02	.113	.167
9	0.004	.193	281	- 0.376	.385	.982
10	- 0.251	.053	179	- 0.356	- 0.147	< .001***

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

*** $p < .001$.

Table C5

Interaction Effect of Affect and Weekly Lapse Frequency on Subsequent Craving for each Individual

Participant	Estimate	SE	df	95% CI		p
				LL	UL	
3	.125	.084	174	.041	.291	.138
4	- 0.070	.030	171	- 0.13	- 0.01	.022*
6			No lapses			
7	.013	.008	293	- 0.003	.03	.116
8	.002	.005	174	- 0.008	.013	.631
9			No lapses			
10	.003	.004	180	- 0.004	.01	.437

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

* $p < .05$.

Table C6

Interaction Effect of Craving and Weekly Lapse Frequency on Subsequent Affect for each Individual

Participant	Estimate	SE	df	95% CI		p
				LL	UL	
3	.835	.845	175	- 0.838	2.508	.326
4	- 1.375	.593	169	.204	2.546	.022*
6			No lapses			
7	- 0.138	.22	293	- 0.57	.295	.532
8	.464	.553	174	- 0.629	1.557	.403
9			No Lapses			
10	3.541	.964	180	1.638	5.443	< .001***

Note. CI = confidence interval; LL = lower limit; UL = upper limit.

* $p < .05$. *** $p < .001$.