Eating and Weight Disorders - Studies on Anorexia, Bulimia and Obesity
https://doi.org/10.1007/s40519-020-01079-z

ORIGINAL ARTICLE

Eating expectancies and reinforcement learning: a state-based test of affect regulation and expectancy models in the natural environment

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Received: 10 April 2020 / Accepted: 19 November 2020

Abstract

Purpose Affect regulation and expectancy-based models suggest that improvement in affect following binge-eating (BE) episodes contributes to increased eating expectancies, which then promote BE maintenance.

Methods The current pilot study utilized ecological momentary assessment to examine the prospective independent and interactive effects of eating reinforcement experiences [operationalized as reductions in negative affect (NA) following BE episodes] and eating expectancies on subsequent BE behavior among 17 women with recurrent BE.

Results Greater reductions in momentary NA following a BE episode (i.e., greater reinforcement) predicted higher levels of eating expectancies on the following day. Further, current eating expectancies interacted with proximal reinforcement history to predict future BE episodes. Participants were more likely to report BE episodes on days that were characterized by higher eating expectancies and preceded immediately by a day during which they experienced greater reinforcement from BE.

Conclusion These preliminary results are consistent with affect regulation and expectancy-based models of BE, suggesting a dynamic and potentially modifiable process of reward-based learning associated with BE behavior.

Level of evidence Level IV, multiple time series.

Keywords Binge eating · Eating expectancy · Affect · Reward · EMA

Introduction

Binge eating (BE), which is characterized by overeating accompanied by a sense of having lost control over one's eating, is a transdiagnostic symptom of bulimic-spectrum disorders including binge-eating disorder, bulimia nervosa, and anorexia nervosa-binge/purge subtype [1]. As such, BE is associated with increased mortality, psychosocial impairment, and risk for medical and psychiatric comorbidity [1–3]. BE is also common among individuals with obesity [4], contributing to weight gain and difficulties achieving weight loss [5–7]. Importantly, interventions for BE disorders demonstrate only moderate success [8]. Given this, additional research is needed to identify key maintaining factors, which may be meaningfully targeted in novel intervention approaches.

A large body of research indicates that eating disorders, including those characterized by BE, are associated with broad deficits in emotion regulation, including difficulties tolerating negative affective states and utilizing adaptive emotion regulation strategies to effectively manage emotional experiences [9]. In the absence of adaptive emotion regulation skills, individuals with eating disorders may seek out alternative means by which to modulate or escape from unpleasant affective states. Consistent with this premise, affect regulation models of eating disorder symptom maintenance posit that BE serves to reduce experiences of negative affect (NA), ultimately promoting continuation of the behavior through a process of negative reinforcement

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[10]. Ecological momentary assessment (EMA) [11], which involves the repeated assessment of one's experiences and behaviors in the natural environment, provides a particularly powerful tool for examining affect regulation models of BE, as this technique allows researchers to examine the temporal relationships between affect and BE. In support of affect regulation hypotheses, numerous EMA studies have demonstrated that, on average, the trajectory of NA following BE episodes declines [12–15]. Importantly, however, we are unaware of any studies that have utilized EMA to examine the other core tenet of affect regulation models, namely that experiences of affect improvement following BE predict future engagement in the behavior. That is, although it is clear that improvements in affect tend to follow BE episodes, it has not yet been demonstrated that experiences of affect improvement serve to maintain the BE behavior. This represents an important gap in the literature as many ED intervention approaches are premised on the expectation that targeting affect in treatment will result in symptom reduction.

Notably, affect regulation models offer a relatively strict behaviorist account of the proposed association between post-binge affective improvement and continued BE. In other words, from a reinforcement learning perspective, these models suggest a simple response–outcome relationship in which the degree of affective improvement following a given BE episode exclusively determines the likelihood of a subsequent BE episode. However, it is also possible (and, indeed, likely) that other factors intercede on, or influence this relationship.

Outcome expectancy theory [16, 17] suggests one plausible mechanism by which experiences of affective improvement following BE may contribute to BE maintenance. Broadly, outcome expectancy theory suggests that an individual's learning and reinforcement history relating specific actions to specific consequences become summarized cognitively as outcome expectancies, or if–then contingencies relating a given behavior to its anticipated consequence. When behaviors consistently result in a rewarding outcome, positive outcome expectancies (i.e., the expectation that the behavior will continue to elicit a rewarding consequence) are hypothesized to develop, and ultimately to contribute to behavior maintenance. [16, 17]. Outcome expectancy theory has been successfully applied in the substance abuse field to explain the onset and continuation of problematic substance use behaviors [18]. In the context of eating pathology, outcome expectancy theory suggests that individuals who experience greater reinforcement from previous eating episodes learn to expect greater reinforcement from future food consumption (i.e., develop more positive eating expectancies), which then increases risk for, or serves to maintain BE behavior. Prior research provides strong support for the proposed relationship between eating expectancies and future BE. For example, longitudinal research indicates that baseline levels of eating expectancies (e.g., the belief that eating helps to improve NA) among middle school girls is predictive of increases in and onset of BE 3 years later [19]. More recently, EMA studies have demonstrated that eating expectancies may fluctuate over time (which is consistent with outcome expectancy theory hypotheses suggesting that expectancies are fluid and responsive to changes in learning history) and may interact with other momentary states (e.g., momentary affect) to predict subsequent engagement in BE [20]. Notably, however, we are not aware of any studies that have utilized EMA to examine the proposition that a history of reinforcement from BE predicts increased eating expectancies. Consistent with affect regulation and outcome expectancy models, it is possible that greater reductions in NA following BE episodes may lead to stronger expectancies that eating reduces negative affective states, which may each increase risk for future BE episodes. Clearly, research is needed to test this hypothesis.

In sum, while research provides support for important elements of affect regulation models (i.e., that BE is followed by reductions in NA) and outcome expectancy theory (i.e., that expectancies of reinforcement from eating predict BE), key hypotheses from these models remain largely untested. Specifically, we are not aware of any prior studies examining the assertion that a history of reinforcement from BE prospectively predicts increased eating expectancies and BE symptoms. Therefore, the current pilot study aimed to examine the prospective independent and interactive effects of eating-related reinforcement experiences and eating expectancies among individuals with recurrent BE in the natural environment using EMA. Consistent with affect regulation and outcome expectancy models, it was hypothesized that greater reductions in momentary NA following a BE episode would predict (a) higher levels of eating expectancies reported on the following day, and (b) higher BE symptoms also reported on the following day, which would be moderated by eating expectancies on that day.

Method

Participants and procedure

The study recruited 40 women who reported recurrent BE (i.e., ≥ once/week over the past month) from clinical and community settings ($M_{\mathrm{BMI}} = 34.30 \pm 9.84$ kg/m^2; $M_{\mathrm{age}} = 34.70 \pm 15.59$). Study inclusion criteria were: endorsement of regular BE (i.e., ≥ once/week over the past month) as determined by the Structured Clinical Interview for DSM-5, Research Version (SCID-5-RV) [21], female gender, age 18–65 years. Exclusion criteria were: inability to read/speak English, current psychosis, current mania, acute suicidality, medical instability, severe cognitive impairment or intellectual disability, current pregnant or breastfeeding, inpatient or partial hospitalization in the past 4 weeks, changes to ED treatment in the past 4 weeks, history of bariatric surgery, and body mass index (BMI) < 18.0 kg/m^2. Study participants were diagnosed with binge-eating disorder (n = 29), bulimia nervosa (n = 9), anorexia nervosa binge-eating/purging type (n = 1), and Other Specified Feeding or Eating Disorder (n = 1). Following a phone screen, participants attended a study visit that included the informed consent process, baseline assessments, and training on the EMA protocol, which was administered on Samsung Galaxy tablets provided by the researchers. Following one practice day, participants competed a 10-day EMA protocol, during which they received five semi-random signal-contingent prompts per day (distributed around anchor points between 8:30 a.m. and 9:00 p.m.). Participants also initiated event-contingent recordings after eating episodes, although eating episodes that participants did not report could also be entered at the next signal-contingent recording. All procedures were approved by the Institutional Review Board of Sanford Research.

EMA measures

Negative affect

Momentary NA was measured using six items from the Positive and Negative Affect Schedule (PANAS) [22] rated on a Likert-type scale ranging from 1 (*not at all*) to 5 (*very much*). Ratings were summed to create a composite NA score at each EMA signal. Internal consistency was good ($\alpha = 0.88$).

Eating expectancy

Momentary expectancy of affective benefit from eating was assessed at EMA signals by the item: *Eating would make me feel better right now*, which was adapted from the well-established Eating Expectancy Inventory [23]. Prior EMA research using a similar item demonstrates a positive association with binge eating, suggesting convergent validity [24]. The item was rated on a Likert-type scale ranging from 1 (*not at all*) to 5 (*very much*).

Binge eating

For each eating episode, questions assessed participants' degree of loss of control eating (*While you were eating, to what extent did you: feel a sense of loss of control?; feel that you could not stop eating once you started?; feel disconnected [e.g., numb, zoned out, on auto-pilot]?*) and overeating (*To what extent do you: feel that you overate?; think that others would consider what you ate to be an usual or excessive amount of food?*) using a Likert-type scale ranging from 1 (*not at all*) to 5 (*extremely*). Scores on the loss of control and overeating items were averaged to create composite scores; the episode was categorized as a BE episode (yes/no) if the composite ratings were each ≥ 3. Internal consistencies were excellent (loss of control composite: $\alpha = 0.90$; overeating composite: $\alpha = 0.94$).

Statistical analyses

We first calculated post-binge slope components for each participant, which reflected the rate of change in NA after a BE episode on a given day. Generalized estimating equations (GEEs) then examined whether the post-binge NA slope component (1) predicted eating expectancies on the next day and (2) interacted with eating expectancies to predict BE episodes on the next day.

Post-binge NA slope

The trajectories of NA in the 4 h leading up to and following BE episodes for each individual were calculated using a GEE analogous to prior studies by our group [25]. Given the limited number of data points (i.e., five signals per day), quadratic and cubic terms were excluded. The GEEs employed an autoregressive covariance structure (AR1) to account for serial correlations between EMA ratings, and analyses were limited to the first BE episode of the day to prevent possible confounding relationships between affect ratings. The slope parameter estimate reflecting post-binge change in NA was extracted for each individual, with lower post-binge slope values indicating a greater rate of improvement (i.e., decrease) in NA following BE episodes.

Post-binge NA slope as a predictor of eating expectancies and BE

Next, a GEE was conducted to assess post-binge NA slope as a predictor of eating expectancies on the next day. The GEE employed an AR1 covariance structure and included both within- and between-person effects of the post-binge NA slope component. The within-person effect was person-mean centered, reflecting the degree to which a participant's post-binge NA slope on a given day differs from that individual's average post-binge NA slope. The between-person effect was grand-mean centered, indicating the degree to which an individual's average level of post-binge NA slope (i.e., aggregated across the EMA protocol) differed from the total sample mean. The within-person component was lagged from the previous day to examine the temporal relationship with subsequent eating expectancy, which was the primary effect of interest. A gamma link function was applied to account for skewed distribution of the dependent variable (i.e., eating expectancies). Age and BMI were also entered in the model as covariates (grand-mean centered).

A second GEE assessed whether the post-binge NA slope (measured on day 1) interacted with eating expectancies (measured on day 2) to predict BE likelihood on day 2. A binary logistic function was applied due to the dichotomous nature of the dependent variable. Similar to the slope components, the main effects of eating expectancies were separated into within- and between-person components. Given that eating expectancies were examined multiple times per day, these ratings were aggregated and centered within day; thus, the within-person component was interpreted as the degree to which a participant's level of eating expectancies on given day differed from the participant's average level. In addition to the main effects of the within- and between-person components of post-binge NA slope and eating expectancies, the GEE included the two-way interaction between the within-person components of post-binge NA slope and eating expectancies. Specifically, the momentary within-person effects were the primary effects of interest. Age and BMI were modeled as covariates.

Results

There was excellent compliance (90.3%) to EMA signals in the total sample. However, the majority of BE episodes were reported late in the day (i.e., > 50% of episodes after 5:00 pm), which limited the number of BE episodes with sufficient post-binge NA ratings to calculate the post-binge slope components, resulting in a subsample of 17 participants for final analyses ($M_{\mathrm{BMI}} = 34.65 \pm 7.50$ kg/m^2; $M_{\mathrm{age}} = 42.55 \pm 17.92$). The GEE results are displayed in Table 1. The GEE examining post-binge NA slope as a predictor of next day eating expectancies revealed significant effects for both the within- and between-person slope components, albeit in opposite directions. Between-person results indicated that participants with *higher* post-binge slope values, reflecting lower rates of decline in NA (i.e., less reinforcement relative to other participants in the sample), reported greater overall eating expectancies ($B = 0.03$, $SE = 0.01$, $p = 0.004$). However, within-person analyses revealed that days during which participants evidenced *lower* post-binge slope values, reflecting greater rates of decline in NA or more reinforcement relative to their average level of post-binge slopes, were associated with higher eating expectancies on the next day ($B = -- 4.14$, $SE = 1.32$, $p = 0.002$). The final GEE examining eating expectancy as a moderator of the relationship between BE reinforcement and subsequent BE behavior revealed a significant interaction

Table 1 Generalized estimating equation results

	B	SE	95% confidence interval		Wald χ^2	p
			Lower	Upper		
Dependent variable: Next day eating expectancy						
Intercept	0.71	0.05	0.61	0.81	200.90	< 0.001
Age	– 0.01	0.00	– 0.01	0.00	2.11	0.146
BMI	0.00	0.01	– 0.02	0.02	0.00	0.945
NA slope (between)	**0.03**	**0.01**	**0.01**	**0.05**	**8.26**	**0.004**
NA slope (within)	**– 4.14**	**1.32**	**– 6.73**	**– 1.54**	**9.75**	**0.002**
Dependent variable: Next day binge eating						
Intercept	– 1.34	0.26	– 1.84	– 0.83	26.77	< 0.001
Age	– 0.01	0.02	– 0.04	0.02	0.27	0.606
BMI	0.06	0.04	– 0.01	0.14	2.81	0.094
NA slope (between)	0.14	0.16	– 0.18	0.47	0.77	0.381
NA slope (within)	– 2.29	15.40	– 32.47	27.90	0.02	0.882
EE (between)	0.81	0.74	– 0.64	2.25	1.20	0.274
EE (within)	0.11	0.11	– 0.10	0.32	1.03	0.309
NA slope (within) X EE (within)	**– 3.30**	**1.32**	**– 5.89**	**– 0.70**	**6.19**	**0.013**

Bold values indicates predictors that were significant at $p < .05$

BMI body mass index, *NA* negative affect, *EE* eating expectancy, *between* grand-mean centered variable (i.e., individual difference), *within* person-mean centered variable. Within-person NA slope variables were lagged from the previous day

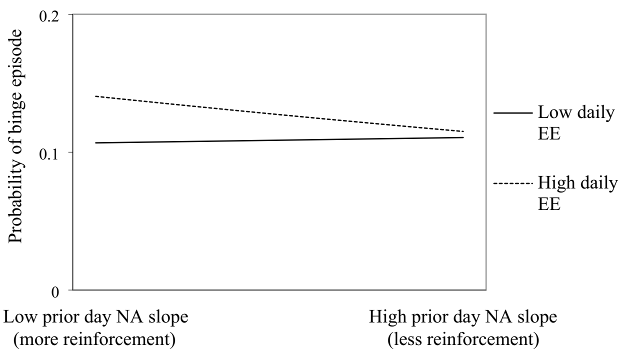

Fig. 1 Two-way interaction between daily eating expectancies (EE) and previous day post-binge negative affect (NA) slope predicting probability of binge eating

between post-binge NA slope on day 1 and daily eating expectancies on day 2 predicting BE on day 2 ($B = -3.30$, $SE = 1.32$, $p = 0.013$), though no main effects were significant. As shown in Fig. 1, participants were most likely to binge on days that were (1) characterized by higher eating expectancies, and (2) preceded by days during which they evidenced lower post-binge NA slopes (i.e., greater affective reinforcement).

Discussion

The current study utilized EMA to examine the prospective momentary relationships between reinforcement history, eating expectancies, and BE among individuals with recurrent BE, and to test key hypotheses from affect regulation and outcome expectancy models of BE maintenance. Consistent with outcome expectancy theory [16, 17], within-person effects indicated that greater affective improvement following BE episodes on 1 day (i.e., greater reinforcement), predicted greater eating expectancies (i.e., increased expectation that future food consumption will be rewarding) on the following day. This finding suggests a dynamic process of reward-based learning associated with BE behavior. That is, eating expectancies, or one's cognitive appraisal of the reward value of food, appear to be flexible and potentially malleable, fluctuating across time and within an individual in response to one's recent reinforcement history.

Further, eating expectancies interacted with reinforcement history to promote BE behavior. More specifically, BE episodes were most likely to occur on days in which participants reported elevated eating expectancies and recent experiences of affective improvement associated with BE. In other words, recent experiences of affective reinforcement from BE episodes appear to promote continued BE behavior, but only when individuals consciously incorporate this new learning into their cognitive appraisal of the reward value of future food consumption. This finding is generally consistent with affect regulation theories [9], which suggest that improvements in affect following BE maintain the behavior. However, the current results provide a slightly more nuanced view of the cognitive-affective process underlying BE maintenance and suggest the importance of incorporating the role of cognitive expectancies within affect regulation models of BE.

Although not the primary focus of the current study, the between-person relationships indicated that individuals who generally experienced lower levels of affective reinforcement from BE throughout the EMA protocol reported greater expectancies of future food reinforcement on average. This finding is consistent with research indicating greater anticipatory reward (i.e., increased activation in reward centers of the brain when anticipating upcoming food consumption), but lower consummatory reward (i.e., decreased reward center when actually ingesting food) among individuals with durable patterns of overeating or BE [26, 27], perhaps due to a downregulation of reward responding to food consumption over time. In other words, as individuals repeat BE behavior, they may come to experience less reward from the BE episode itself while exhibiting increased anticipation or excitement prior to BE episode. Thus, with repetition, BE maintenance may become less strongly linked with the actual experiences of reward, and more strongly linked to the expectation of reward. Although we were not able to examine the moderating role of illness or BE duration in the present study, the opposing between- and within-person effects observed in the current sample suggest the possibility that the higher average levels of eating expectancies reported by individuals who nonetheless generally experience infrequent or blunted reward from BE episodes may be maintained through *occasional* experiences of affective improvement following BE. That is, although BE may not provide consistent regulation of unpleasant affect states for individuals with recurrent BE, the experience of intermittent reward from BE may be sufficient to maintain positive eating expectancies and reward-seeking BE behavior.

The current study possesses a number of important strengths. First, the study aims were guided by well-known theories of maladaptive behavior maintenance (i.e., affect regulation models, outcome expectancy theory). Further, the use of EMA facilitated an ecologically valid examination of the proposed prospective relationships between momentary reward processes and BE. Additional strengths include the use of clinical interviews to confirm the presence of regular BE and the use of previously validated EMA measures of the constructs of interest. Limitations of the current study include the restricted sample size and demographics, suggesting the need for future work testing hypothesized relationships within larger and more diverse samples. In addition, eating expectancy was assessed with a single item.

Although previous research supports the validity of this approach [20, 24], future research may seek to examine the role of distinct eating expectancies (e.g., expectations that eating will reduce negative affect versus increase positive affect) using additional items. Finally, as eating expectancies and BE probability were assessed at the daily level on the same day, the current study is unable to verify the temporal sequencing of these variables, and future work is needed to test the theorized mediating role of eating expectancies.

In sum, the EMA current study is the first we are aware of to test affect regulation hypotheses suggesting that affective improvement following BE episodes promotes continuation of the behavior and outcome expectancy hypotheses suggesting that a history of reinforcement from BE strengthens expectancies of future reinforcement from food. Results from longitudinal within-person analyses indicate that prior experiences of negative reinforcement from BE increase expectancies of future food reinforcement. Further, recent BE reinforcement interacts with eating expectancies to increase risk for future BE episodes. Findings contribute to the growing literature examining altered reward responding among individuals with eating pathology and suggest that both consummatory reward processes (i.e., experienced reductions in NA following BE episodes) and anticipatory reward processes (i.e., beliefs about the reward function of future BE episodes) promote subsequent BE episodes. Future work is needed to examine eating expectancies as a mechanism linking reinforcement history with BE maintenance. If supported, eating expectancies may be an important target for BE treatments.

What is already known on this subject?

Studies indicate that the trajectory of negative affect following binge eating declines. However, it is unclear whether affect improvement following binge eating predicts future binge-eating behavior.

What does this study add?

EMA data indicate that prior experiences of affect improvement from binge eating and expectancies of future food reinforcement interactively increase risk for future binge-eating episodes.

Funding This work was supported by the National Institute of Mental Health (grant number T32 MH082761).

Availability of data and material Supporting de-identified data from this study may be provided upon reasonable request.

Compliance with Ethical Standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethics approval All study procedures were approved by the Institutional Review Board of Sanford Research.

Informed consent All study participants provided informed consent.

Consent for publication All authors contributed to the study/manuscript development and have approved the final version of the manuscript.

Code availability Statistical code may be provided upon request.

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