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Dynamic associations between anxiety, stress, physical activity, and eating regulation over the course of a behavioral weight loss intervention

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Abstract

Negative emotional experiences are associated with dysregulated eating behaviors that impede weight management. While weight loss interventions promote physical activity and self-regulation of eating, no studies have examined how physical activity may directly influence eating by attenuating associations between negative emotions and eating.

Objective: The current study examined how momentary negative emotions (stress and anxiety), moderate-to-vigorous intensity physical activity (MVPA), and their interactions predict eating

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dysregulation (i.e., intensity of eating temptations, inability to resist eating tempting foods, overeating), as well as how these associations change during a weight loss intervention.

Methods: Women with overweight/obesity (N=55) completed 14-day ecological momentary assessment (EMA) protocols with objective measurement of physical activity (i.e., bout-related MVPA time) before and after a three-month internet-based weight loss program.

Results: Three-way interactions emerged predicting overeating and eating tempting foods. When women experienced higher than usual levels of momentary anxiety or stress at end-of-treatment, they were less likely to subsequently overeat or eat tempting foods when they had recently engaged in more MVPA (relative to their usual level). No significant associations were found for ratings of temptation intensity.

Conclusions: Findings suggest MVPA may exert direct effects on eating regulation. Specifically, MVPA appears to increasingly buffer the effect of negative emotional states on dysregulated eating behavior over the course of a weight loss intervention. Future work is needed to develop ways of communicating to patients how activity can have both indirect and direct effects on body weight, and examine whether such knowledge improves outcomes.

Keywords

ecological momentary assessment; physical activity; obesity; eating; weight loss

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Obesity is associated with elevated risk of chronic disease and early mortality (e.g., Cecchini et al., 2010). Of critical concern, obesity rates have increased in the last several decades, now affecting over 40% of adults in the U.S. (Hales, Carroll, Fryar, & Ogden, 2020). However, outcomes of existing weight management approaches are sub-optimal and are associated with variability in long-term weight loss maintenance, which highlights the need to identify and target factors that impede successful weight regulation (Elfhag & Rössner, 2005; Franz et al., 2007). Stress-related and emotional eating (i.e., eating in response to negative emotions) are key factors related to excess caloric intake and poor weight outcomes (Frayn & Knäuper, 2018), though behavioral weight loss programs often fail to address emotional factors (e.g., Webber et al., 2016). As such, identifying factors that attenuate associations between negative emotional experiences and dysregulated eating may ultimately help to improve weight loss interventions.

Considerable research has shown that negative emotional states can lead to dysregulated eating (e.g., binge eating; Haedt-Matt & Keel, 2011) and altered appetitive motivations (e.g., increased food craving; Hepworth et al., 2010). Such associations may be related to underlying emotion regulation difficulties as well as acute effects of negative affect on self-regulatory functions (Leehr et al., 2015; Loth et al., 2016). Consistent with the resource depletion model, experiencing and attempting to regulate momentary negative affect reduces self-control resources, which in turn can impede subsequent attempts to control one’s behavior, including eating (Loth et al., 2016). Furthermore, a recent meta-analysis showed the effects of momentary negative affect on increased eating were more pronounced among restrained eaters (Evers et al., 2018). In line with Loth and colleagues’ conceptual model (2016), individuals who are trying to lose weight may have depleted self-regulatory capacity through engaging in dietary restraint and dieting behaviors. Thus, their ability to regulate and control their eating may be particularly susceptible to the momentary influences of negative affect. As such, identifying factors that facilitate self-control over eating when experiencing momentary negative emotional states is particularly relevant in the context of weight loss interventions.

Besides having a direct effect on weight management via energy balance, physical activity may exert beneficial effects on eating regulation, which may be due in part to effects on affective processes. That is, physical activity is known to have anxiolytic effects, and higher physical activity levels are consistently related to better emotional functioning (e.g., lower depression, anxiety, and emotion regulation difficulties; Bernstein & McNally, 2017; Rebar et al., 2015). Relatedly, ecological momentary assessment (EMA) studies have shown that physical activity predicts higher positive affect, as well as lower stress and negative affect in the few hours following exercise (Liao, Shonkoff, & Dunton, 2015; Schultchen et al., 2019).

Moreover, several studies have shown that higher physical activity is associated with better eating regulation, including improved appetite control, reduced food cue responsivity, and less binge eating (Andrade et al., 2010; Elfhag & Rössner, 2005; Luo, O'Connor, Belcher, & Page, 2018). For example, acute bouts of activity have been shown to attenuate appetite, urges to consume palatable food, and energy intake in controlled experiments (e.g., Maraki et al., 2005; Taylor & Oliver, 2009). Prior naturalistic (i.e., EMA) research among adults with overweight or obesity also found that dietary lapses and temptations were less likely to occur after exercising (Carels, Douglass, Cacciapaglia, & O'Brien, 2004) or following periods of elevated physical activity (Crochiere et al., 2020).

Taken together, physical activity may directly influence eating behaviors and appetitive motivations, as well as attenuate associations between momentary negative affect and dysregulated eating behaviors and motivations. That is, it is plausible that by improving affect and emotion regulation capacity, bouts of physical activity could buffer the adverse effects of momentary negative affect on subsequent eating dysregulation. While previous EMA studies have examined independent effects of negative affect and physical activity on eating-related outcomes, no EMA studies have assessed their interactive effects across a range of variables associated with eating regulation.

Moreover, despite the relevance of emotional eating in the context of weight management, no studies have examined how associations between negative affect, physical activity, and eating regulation may change over the course of weight loss interventions that specifically promote physical activity. This is important to examine given that weight loss and uptake of physical activity may alter mechanisms that influence eating dysregulation, potentially via the improvement of emotional and cognitive functioning, appetite control, and/or self-efficacy (e.g., Beaulieu et al., 2018; Tomporowski et al., 2003; Warziski et al., 2008). It is also important to consider the multidimensional nature of negative emotional experiences. Stress and other negative emotional states (e.g., anxiety) are distinct constructs that show differential associations with eating behaviors in daily life (Reichenberger et al., 2018), which is further evidenced by research showing only modest correlations between trait-level tendencies to eat in response to stress and other emotional states (Meule, Reichenberger, & Blechert, 2018). In addition, given that individuals could have initial difficulty breaking habitual patterns of eating in response to negative emotions, the potential beneficial effects of physical activity may be lower at the start of weight loss interventions given the presence of more robust negative emotion-eating associations, in addition to the possibility that at baseline individuals may not yet engage in sufficient levels of physical activity duration or intensity to experience beneficial effects on mood or eating regulation. Elucidating these associations could therefore be used to harness physical activity interventions to target a wider array of constructs contributing to weight regulation (e.g., affect regulation and emotional eating).

The current study sought to address these gaps using a multimethod approach that combined EMA with objectively measured physical activity before and after a weight loss intervention. Specifically, we examined how momentary negative emotional experiences (i.e., stress and anxiety), physical activity (i.e., bout-related moderate-to-vigorous physical activity [MVPA]), and their interactions predict eating regulation (i.e., intensity of temptations to eat, overeating episodes, and the ability to resist eating tempting foods), as well as the extent to which these micro-temporal (i.e., momentary) associations may change between the beginning and end of the intervention. The current study focused on stress and anxiety, which have shown to predict disordered eating and appetitive motivations at the momentary level (e.g., Huh et al., 2015; Mason et al., 2018).

It was hypothesized that when individuals reported elevated negative emotional states (relative to their usual level), they would report less subsequent eating regulation (i.e., increased temptations to eat, increased likelihood of overeating, and decreased likelihood of resisting tempting foods). In addition, it was expected that higher momentary bout-related MVPA time would moderate these associations, such that heightened stress and anxiety would be less likely to result in eating dysregulation when individuals had engaged in more bout-related MVPA over recent hours (relative to their usual level). Last, it was hypothesized that the momentary associations between stress/anxiety and eating dysregulation may be stronger at baseline compared to end-of-treatment.

Method

Participants

Fifty-five women with overweight or obesity (86% Caucasian; mean body mass index [BMI]: 31.6±4.4 kg/m^2, mean age: 48.2±9.3 years) were recruited as part of a 12-week, internet based weight loss intervention (see description below for more details). To be eligible for the study, participants needed to be female, aged 18–55, have a BMI of 25 to <40 kg/m^2, own a smartphone, and be willing to receive and respond to text message prompts for 14 days at baseline and 14 days after the weight loss program. Exclusionary criteria included: recent weight loss or current enrollment in a weight loss program, women who were pregnant, those with any medical condition that would contraindicate weight loss or participation in physical activity, or an inability to walk without an assisted device. Participants with a previous history of heart disease or diabetes were required to provide physician consent prior to participating in this study. Further, participants with <80% compliance to the EMA monitoring at baseline or those who wore the activity monitor for <10 hours/day on 5 or more days were excluded.

Procedures

At baseline, participants completed a study visit that included the informed consent process, measurement of height, weight, and demographic information, as well as training on the EMA protocol. Participants completed a 14-day EMA protocol prior to the weight loss intervention and following the weight loss intervention (3 months). During each 14-day monitoring period, participants responded to five semi-random prompts per day on their smartphones and answered questions related to stress, affect, and eating (measures described in detail below). Participants were instructed to respond to the survey as soon as possible upon receiving the text message, but they had 45 minutes to respond before it was considered a missed survey. They were also provided with an objective physical activity monitor (Sensewear Armand; Body Media, Pittsburgh, PA, USA) to wear during all waking hours throughout the entire EMA monitoring period. At the post-intervention assessment visit, body weight was assessed and participants were compensated for completion of study procedures. Participants received $20 for completing the three-month, in-person visit, $0.50 for each EMA prompt responded to within 45 minutes during the three-month assessment period, and a completer's bonus of $45 if they have >80% compliance to EMA monitoring and wore the armband for at least nine days for ≥10 hours/day. Study procedures were approved by the Miriam Hospital Institutional Review Board (Providence, RI, USA).

Weight loss intervention

All participants received a 12-week, internet-delivered behavioral weight loss program (Leahey et al., 2015; Unick et al., 2015). Prior to the program participants were provided with a brief tutorial in which they were familiarized with all aspects of the study website and taught how to self-monitor calorie intake. As part of the program, they were given a weight loss goal of 1–2 pounds/week, were prescribed a daily calorie and fat gram goal based upon their starting weight (<200 lbs: 1200 kcal/day and 40 grams of fat; 200–250 lbs: 1500 kcal/day and 50 grams of fat; ≥250 lbs (1800 kcals/day and 60 grams of fat), and were given a physical activity goal (gradually increase to 200 min/week of moderate-intensity exercise). Participants were instructed to count their calories daily and to track and record their weight, calorie, fat grams, and physical activity minutes daily via the study website. Based upon these self-report data, participants received weekly automated feedback related to their progress. In addition, participants were instructed to view a weekly, 10–15 minute multimedia lesson modeled after intervention lessons from the Look AHEAD Trial (Pi-Sunyer et al., 2007). The website also provided weekly recipes as well as useful tip sheets related to meal plans, prepackaged foods, negative thoughts, and safe exercise.

Measures

Anthropomorphic measures.—Height and weight were measured in person at each study visit and used to calculated BMI (kg/m^2) and total percent weight loss. Percent weight loss was calculated as ([end-of-treatment weight – baseline weight])/baseline weight*100), such that more negative values indicate greater percent weight loss.

Anxiety and Stress.—Negative emotional states included stress and anxiety, which have shown to predict disordered eating and appetitive motivations at the momentary level (e.g., Huh et al., 2015; Mason et al., 2018). At each EMA recording, participants were asked to rate their current anxiety in response to the prompt *Right now, I feel…* using a four-point Likert-type scale ranging from *not at all* (1) to *very much so* (4). Anxiety states were derived from the State-Trait Anxiety Inventory State Anxiety (STAI) scale, which has shown excellent reliability and validity (Ross & Pourtois, 2012; Spielberger et al., 1983). Specifically, the present study used items from the 10-item Anxiety-Present STAI subscale: *tense, strained, upset, worried, frightened, nervous, jittery, indecisive, worried about possible misfortunes,* and *confused*. This measure demonstrated excellent reliability at the within- and between-person level (ω=.87 and .98, respectively). The mean rating of items was calculated at each EMA recording to derive a composite score of anxiety at each signal. Participants also reported their current level of stress at each EMA recording by responding the item, *Right now, I feel stressed*. Responses were rated on a seven-point Likert-type scale ranging from *not at all* (1) to *very much so* (7).

Temptation intensity.—At every EMA recording, participants were asked to indicate whether they were tempted to overeat, had a sudden urge to eat a tempting or forbidden food, and/or were exposed to tempting foods or beverages since the last EMA prompt. If they endorsed any of these options, they were asked to rate the intensity of their temptation on a 10-point Likert-type scale ranging from *not strong at all* (1) to *extremely strong* (10).

Ability to resist eating tempting foods.—In addition, if participants reported they were tempted to overeat, had a sudden urge to eat a tempting or forbidden food, and/or were exposed to tempting foods or beverages, they were asked whether they ate the tempting food. Resisting tempting foods was defined as occurrences during which participants reported (*a*) temptation to overeat, having an urge to eat a tempting/forbidden foods, and/or exposure to tempting foods/beverages, and (*b*) reported they did *not* eat the tempting foods (vs. eating the tempting foods when experiencing temptation). In analyses this variable was coded as 1=ate the tempting food (reflecting decreased self-control) and 0=did not eat the tempting food (reflecting exertion of self-control).

Overeating.—At each EMA recording, participants were asked whether they ate since the last prompt. If they responded yes, they were asked to indicate whether they (1) ate past the point of being full; (2) ate more than usual; and/or (3) had unplanned eating (i.e., defined for participants as consuming food when they did not usually eat and were not making up for a missed meal). Similar to prior EMA research (Thomas et al., 2011), if at least one of these items was endorsed, the eating episode was defined as an overeating episode (vs. an eating episode without overeating present).

Physical activity.—Given that engaging in MVPA in bouts lasting at least ten minutes has been associated with improved weight outcomes (e.g., Jakicic et al., 2014), physical activity was operationalized as time spent in MVPA accumulated in bouts of ten minutes or more. Bout-related MVPA time (minutes) during the 14-day EMA monitoring period was assessed using the Sensewear Armband, which is a device worn on the back of the upper arm and has been previously validated in adults (Jakicic et al., 2004). Each device was programmed with the participant's age, height, weight, and gender. Data from a unique combination of sensors (heat flux, galvanic skin response, skin temperature, and near body temperature) and a bi-axial accelerometer are integrated into proprietary equations to provide minute-by-minute estimates of energy expenditure, assigning a metabolic equivalent (MET) value to each minute the monitor is worn. Completed EMA recordings and MVPA data were merged based on time stamps. In the present study, MVPA time was defined as the total time (minutes) spent engaged in MVPA (>3.0 METs) bouts of at least 10 minutes between EMA prompts. When multiple MVPA bouts occurred between EMA prompts, these were added together to calculate total bout-related MVPA minutes between prompts.

Statistical Analyses

Generalized linear mixed models (GLMMs) were used to examine the extent to which momentary negative emotional states (i.e., anxiety or stress), total bout-related MVPA minutes since the last EMA prompt, and their interactions predicted subsequent EMA-measured overeating, temptation intensity, and resisting tempting foods. Three levels were specified, with days nested within persons and observations (i.e., EMA prompts) nested within day. In order to examine changes in the degree to which momentary negative emotional states and MVPA minutes predict eating regulation over the course of the intervention, assessment time (i.e., baseline vs. end-of-treatment) was added to models as a main effect, as well as the two- and three-way interactions of assessment time, emotional state, and MVPA minutes. In each GLMM, the effects of anxiety, stress, and MVPA minutes were separated into within-person (i.e., person-mean centered) and between-person (i.e., grand-mean centered) components. That is, within-person associations indicate the degree to which changes in the independent variable, relative to an individual’s own mean, are related to the dependent variable, whereas between-person associations reflect the degree to which an individual’s average level of an independent variable across EMA ratings, relative to other individuals, is associated with the dependent variable. Variables were centered based on person-means and grand-means within each EMA wave (i.e., baseline and end-of-treatment). In order to assess temporal effects of momentary emotional states on eating regulation, the within-person effects of anxiety or stress were lagged from the previous completed EMA recording (*t*-1) but not lagged across days.

Thus, each GLMM included the following fixed effects: main effect of assessment time (i.e., baseline vs. end-of-treatment), within- and between-person main effects of momentary emotional states (anxiety or stress) and MVPA minutes, and the two- and three-way interactions of assessment time, within-person anxiety/stress, and within-person MVPA minutes. In addition, random effects of person and day were included to model variability in outcomes across persons and days. Between-person interactions were not examined given the research question focused on how physical activity moderates momentary (i.e., within-person) associations between emotional states and eating regulation. Age, baseline BMI, total percent weight loss, and time elapsed since the last EMA recording were included as covariates in each model. All GLMMs specified an AR1 serial autocorrelation to account for dependencies within the nested data. GLMMs predicting overeating and self-control over eating used a binary logistic function given the dichotomous nature of these variables, and GLMMs predicting temptation intensity used a linear function. Analyses were conducted using SPSS version 25.

Results

Descriptive Information and Preliminary Analyses

Table 1 displays descriptive statistics for variables across each EMA monitoring wave. Across the sample, the mean percent weight loss over 12 weeks was −3.8±3.9% (range: −13.1–4.4%). Overall, EMA compliance was high, as defined by the proportion of completed vs. delivered EMA prompts (baseline: 86.1%; three-month end-of-treatment: 82.4%), and daily Sensewear Armband wear time was greater than 11 hours per day for all participants. The mean time lapse between consecutive EMA prompts occurring on the same day was approximately 3.3 hours (M=197.10±90.54 minutes). Of the 55 participants who completed the baseline EMA protocol, 41 (74.5%) completed the three-month end-of-treatment EMA protocol. Independent *t*-tests indicated participants who completed the three-month EMA protocol did not differ from those who dropped out in terms of baseline EMA compliance, average daily Sensewear Armband wear time, BMI, average MVPA minutes between EMA prompts, stress, or any dependent variable (ps>.05). However, completers tended to be older (p=.007) and reported lower overall anxiety (p=.048). Among those who completed the protocol, the average daily bout-related MVPA time at end-of-treatment tended to be higher at end-of-treatment compared to baseline, with a small-to-medium effect size (Cohen's d=.29), though this increase was not statistically significant (p=.075).

Associations between Anxiety, Stress, Bout-related MVPA, and Eating Regulation

Table 2 displays results of GLMMs. In all GLMMs the random effects of person were significant (ps<.01), indicating substantial between-person variability in outcome variables. In addition, the random effects of day were significant (ps<.001) in all models except for those predicting temptation intensity, suggesting significant day-to-day variability (within persons) with respect to overeating and the ability to resist eating tempting foods. Regarding covariates, age, BMI, and PWL did not show significant effects for any outcome. However, time since the last EMA prompt was related to both overeating and resisting eating tempting foods, such that longer time lapses since the last prompt were associated with increased likelihood of overeating and eating tempting foods at the next prompt. While not the focus of the current study, between-person effects of MVPA, stress, or anxiety did not emerge as significant predictors of any outcome.

Temptation intensity.—There were no main effects or interactions of assessment time, within-person MVPA minutes, stress, or anxiety predicting temptation intensity.

Ability to resist eating tempting foods.—A three-way interaction emerged between assessment time (i.e., baseline vs. three-month end-of-treatment), within-person anxiety, and within-person MVPA minutes predicting the likelihood of eating tempting foods (p=.041). Similarly, there was a three-way interaction between assessment time (i.e., baseline vs. end-of-treatment), within-person stress, and within-person MVPA minutes predicting the likelihood of eating tempting foods (p=.045). Figures 1–2 display these interactive effects. At baseline, there was not a strong association between momentary anxiety and the likelihood of eating tempting foods, irrespective of MVPA levels prior to the EMA prompt.

The patterns of associations were markedly different at end-of-treatment, yet generally similar across anxiety and stress GLMMs. That is, when individuals engaged in *more* MVPA prior to EMA recordings (relative to their average levels), the association between anxiety/stress and eating tempting foods was negative, such that they were *less* likely to eat tempting foods when experiencing higher anxiety/stress. However, when individuals engaged in *less* MVPA prior to EMA recordings, they were *more* likely to eat tempting foods when experiencing higher anxiety/stress.

Overeating.—There were also significant three-way interactions in both anxiety and stress GLMMs predicting the likelihood of overeating (*p*s=.016 and .028, respectively), which were generally in line with the above findings. At baseline there were minimal associations between anxiety/stress and overeating, though lower levels of MPVA were related to greater likelihood of overeating (which were also reflected by significant within-person main effects of MVPA in both models). At end-of-treatment, when individuals engaged in more MVPA than their usual level, they were less likely to overeat when they reported higher levels of anxiety, though this association was reversed at lower levels of MVPA (Figure 3). Similarly, when individuals engaged in more MVPA than usual, they were less likely to overeat when they reported higher stress; however, there was not a strong association between stress and overeating at lower MVPA levels (Figure 4).

Discussion

The present study is the first to examine how physical activity may impact micro-temporal associations between momentary negative emotional states (i.e., anxiety and stress), and eating regulation, as well as how these dynamics change over course of a weight loss intervention. Contrary to hypotheses, associations between negative emotional states and eating variables were minimal at baseline. However, interactive effects also emerged that were partially consistent with hypotheses, and which were independent of women’s BMI, degree of weight loss, and age. These interactive effects were only observed at end-of-treatment, and emerged even with modest, albeit not statistically significant, overall changes in MVPA. That is, three months after starting the intervention, higher bout-related MVPA time moderated associations between momentary anxiety and stress levels and the likelihood of overeating and eating tempting foods. In other words, when individuals were experiencing higher than usual levels of momentary anxiety or stress at end-of-treatment, they were less likely to subsequently overeat or eat tempting foods when they had recently engaged in more bout-related MVPA (relative to their usual level). The observed effects were also specific to eating *behaviors (e.g., overeating or eating tempting foods)*, as no significant associations were found for ratings of temptation intensity. Taken together, this pattern of moderating effects indicates that greater time spent engaged in bout-related MVPA may exert a buffering effect on momentary associations between negative emotional states and aspects of eating self-regulation that can affect weight loss.

In addition, when individuals engaged in more bout-related MVPA than their usual level at baseline, they were less likely to report subsequent overeating or eating tempting food, though the effect for eating tempting food was attenuated at higher levels of momentary stress (Figure 2).. These findings are generally in line with previous EMA research showing that higher levels of physical activity were related to reduced likelihood of dietary lapses among individuals with overweight or obesity (Crochiere et al., 2020). Such results are also supported by research demonstrating that acute bouts of physical activity decrease ghrelin (i.e., an appetite-stimulating hormone) and increase appetite-suppressing hormones such as peptide YY (PYY), pancreatic polypeptide (PP) and glucagon-like peptide 1 (GLP-1; Schubert et al., 2014), which may contribute to reduced likelihood of overeating after bout-related MVPA. Nevertheless, the attenuation of the effect for eating tempting food at high stress levels is notable. Consistent with our hypothesis and the resource depletion model, the presence of high stress may have an adverse impact on self-control in the face of palatable, tempting food cues. At baseline, it may be that when individuals had engaged in physical activity but also felt stressed, they were more likely to reward themselves with food. It could also be that exercising increased hunger, and when individuals felt stressed at baseline it was more difficult to resist food when hungry than in less stressful situations.

It is also intriguing that there the moderating effects emerged only after the weight loss intervention. Bouts of physical activity bolster short-term cognitive recourses and improve momentary affect (Liao et al., 2015; Tomporowski, et al., 2003), which may independently and interactively support better eating regulation. However, individuals may not be engaging in sufficient levels of bout-related physical activity at the start of an intervention to buffer potential effects of emotions on eating. It is also possible that during treatment individuals become more prone to engage in MVPA rather than eat as a means of coping with momentary anxiety and stress. Relatedly, evidence suggests that individuals who engage in higher levels of physical activity have more sensitive appetite control, whereas excess body weight can adversely influence sensitivity of hunger and satiety signaling, as well as cognitive control (Beaulieu et al., 2018; Veronese et al., 2013). Therefore, as individuals lose weight and engage in more habitual physical activity during weight loss interventions, they may experience improvements in neurocognitive functioning and homeostatic appetite control (Beaulieu et al., 2018; Veronese et al., 2017). Together, this may increase the likelihood that bouts of physical activity will have beneficial momentary effects on eating and appetitive motivations, while mitigating detrimental influences of momentary emotional states.

Moving forward, research is needed to explore individual and contextual factors (e.g., type of stressor, exercise motivations, dietary restraint, inhibitory control) that may lead to increased vs. decreased self-regulation over eating across different levels of MVPA (Manasse et al., 2018). It is also notable that no general relationships were found between emotion and eating variables in the absence of MVPA, and there was a lack of between-person associations observed for predictor variables despite significant random effects (indicating substantial variability between and within persons in outcome variables). As such, it will be important for future research to consider potential sources of inter- and intra-individual variability in these associations. For example, prior EMA research has shown trait-level emotional eating moderated associations between momentary negative emotions and taste- and hunger-driven eating (Reichenberger et al., 2018), and that momentary associations between stress and craving varied as a function of individual differences in the tendency to alter intake in response to stress (Reichenberger et al., 2021).

Limitations

Although the current study has many strengths, including the use of multimethod naturalistic assessment across two time points in the context of behavioral weight loss treatment, there are also limitations to consider. Due to the lack of a control group, it is not possible to determine whether changes in constructs were the result of the intervention or naturalistic variations over time. The sample size was modest with considerable attrition at end-of-treatment, which warrants future replication in larger prospective studies including control groups. The sample was also limited to adult women with overweight/obesity who were mostly Caucasian, and thus findings may not generalize to other demographic groups or individuals of lower weight. Further, participants were required to have >80% EMA compliance to be eligible for the study, which could have resulted in a biased or potentially more motivated sample. Objective caloric intake was not assessed, which would be helpful to elucidate the degree to which physical activity and negative emotional states together influence overall energy balance. The current study also focused on bout-related MVPA, stress, and anxiety, though it would be useful to examine other intensities of physical activity (e.g., total activity, sedentary behavior) as well as additional dimensions of affect and feeling states (e.g., positive affect, boredom) that may be relevant for eating regulation and weight loss. The factor structure and construct validity of the STAI has also been questioned, and some have suggested it would be better conceptualized as a measure of general negative affect (e.g., Balsamo et al., 2013). It is important to note that the SenseWear Armband as well as other activity monitors (e.g., ActiGraph) may overestimate MVPA time compared to indirect calorimetry methods (Bernsten et al., 2010). Finally, the intervention was limited to three months, and therefore it would be important for future research to examine these associations over the course of longer interventions and end-of-treatment periods to capture phases of initial behavioral change as well as maintenance and relapse processes.

Conclusions

Despite these limitations, the current study offers new insights regarding how momentary negative emotional experiences and physical activity together predict eating regulation over the course of a behavioral weight loss intervention. Physical activity appeared to have an increasingly buffering effect on associations between negative emotional experiences and eating regulation over three months, suggesting that early adoption of physical activity behavior may have a critically important transfer effect on dietary adherence and self-control over eating. As such, it will be imperative for future work to examine these effects in larger controlled trials, as well as identify ways of optimizing initial uptake of physical activity behaviors during behavioral weight loss interventions. In addition, examining these associations in specific groups with emotional eating tendencies (e.g., those with binge eating disorder) and/or those who do not respond to treatment may ultimately serve to enhance outcomes via both direct influences on energy balance and indirect support of eating regulation.

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Data Availability:

Data and code are available upon request of the first and senior authors.

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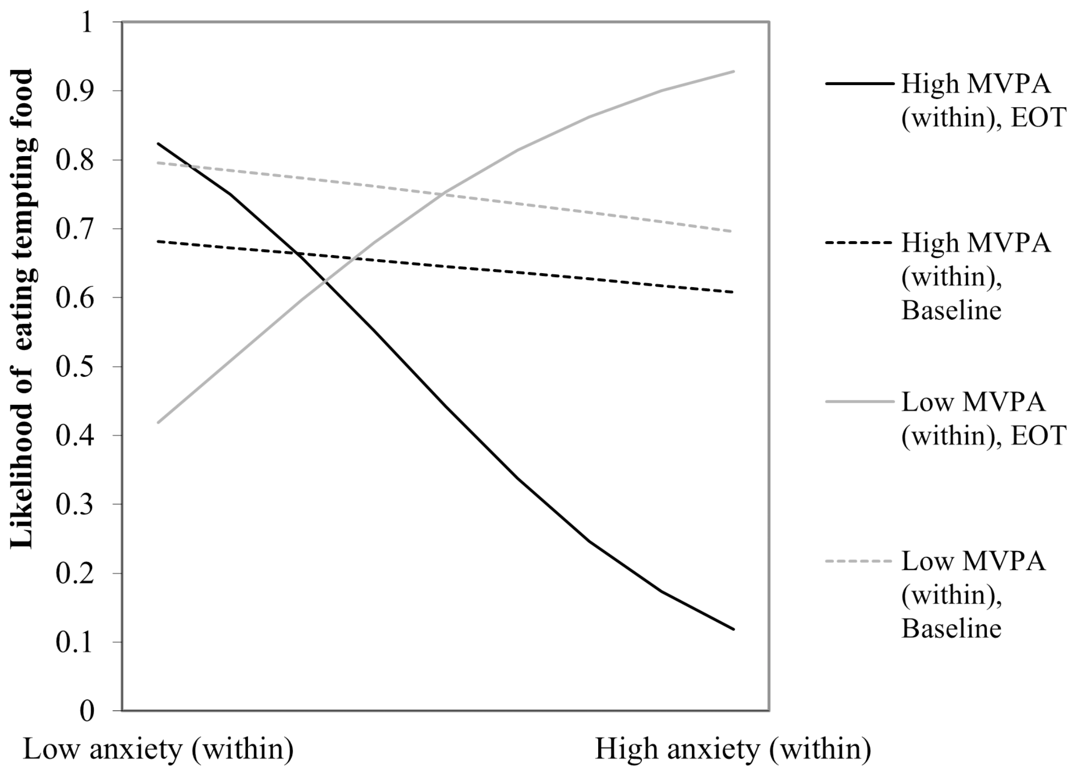

Figure 1.
Three-way interaction of time (baseline vs. 3-month end-of-treatment [EOT]), within-person anxiety, and within-person MVPA time (minutes) predicting subsequent eating of tempting foods at the next EMA signal. High and low values reflect 1 SD above and below individual means, respectively.

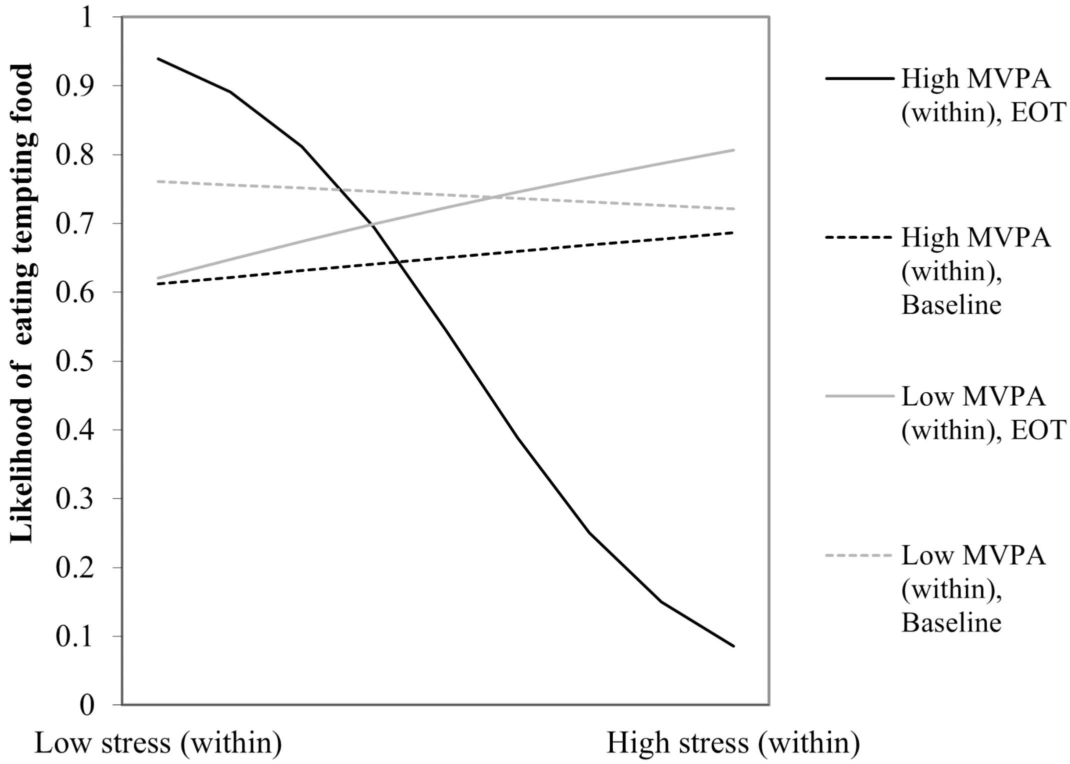

Figure 2.
Three-way interaction of time (baseline vs. 3-month end-of-treatment [EOT]), within-person stress, and within-person MVPA time (minutes) predicting subsequent eating of tempting foods at the next EMA signal. High and low values reflect 1 SD above and below individual means, respectively.

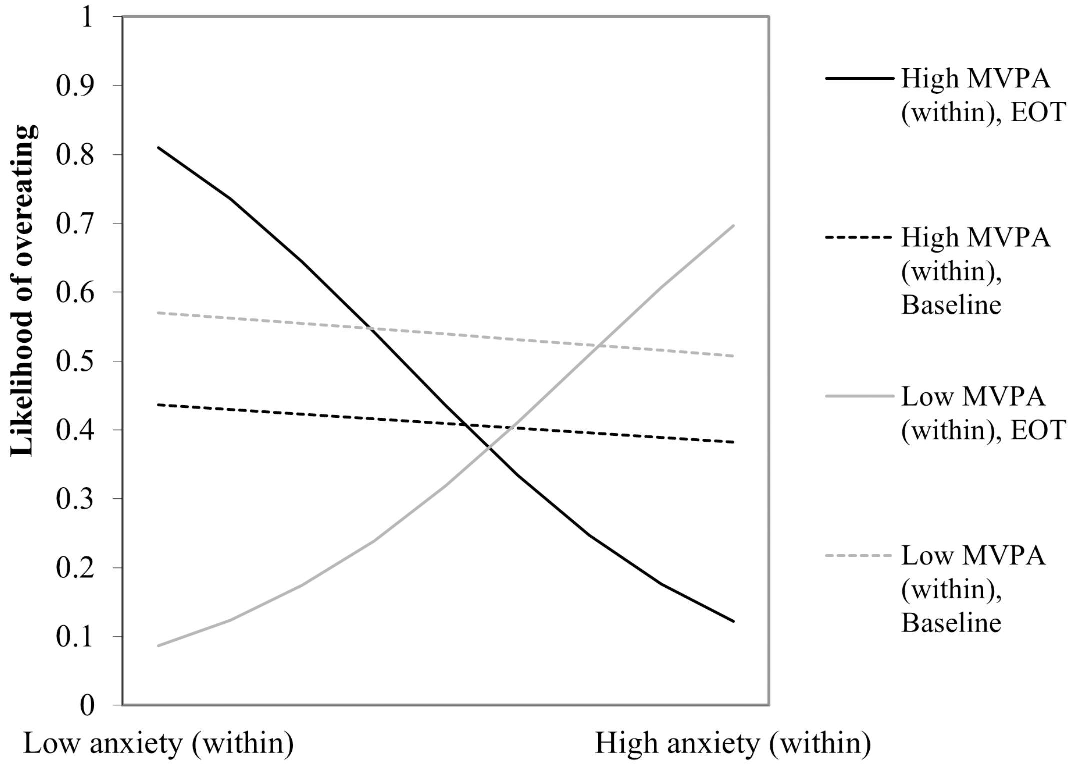

Figure 3.

Three-way interaction of time (baseline vs. 3-month end-of-treatment [EOT]), within-person anxiety, and within-person MVPA time (minutes) predicting subsequent overeating at the next EMA signal. High and low values reflect 1 SD above and below individual means, respectively.

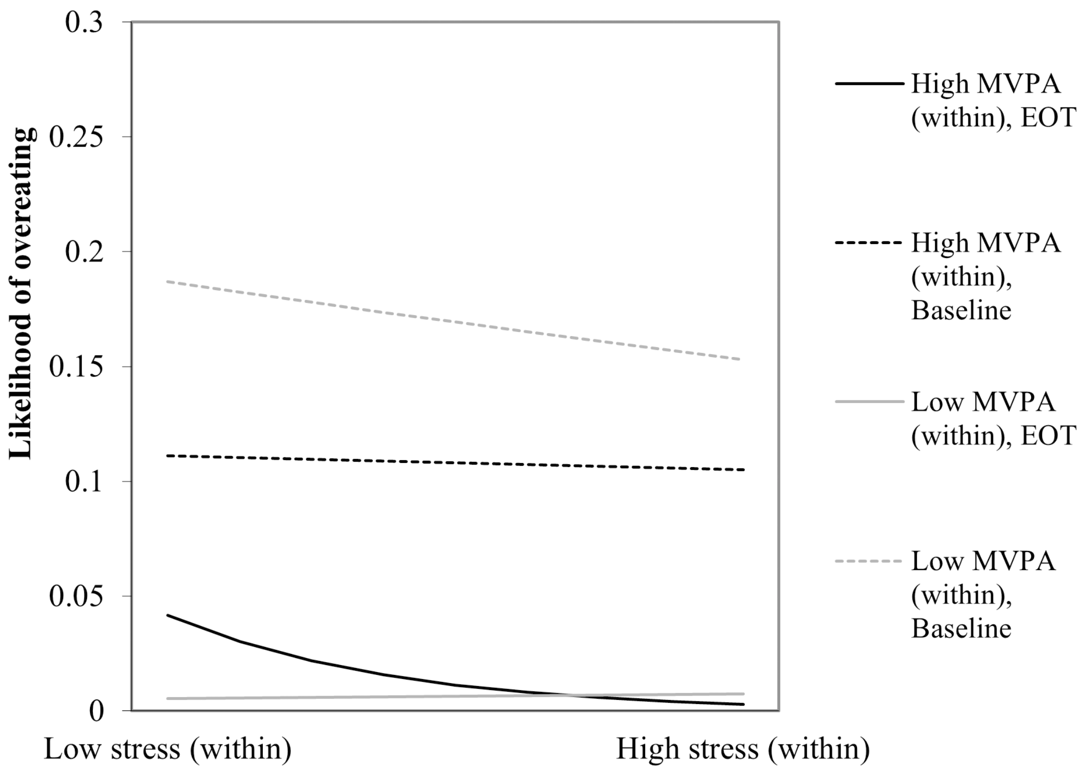

Figure 4.

Three-way interaction of time (baseline vs. 3-month end-of-treatment [EOT]), within-person stress, and within-person MVPA time (minutes) predicting subsequent overeating at the next EMA signal. High and low values reflect 1 SD above and below individual means, respectively.

Table 1.

Descriptive statistics at baseline and 3-month end-of-treatment

	Baseline (*N*=55)				3-month end-of-treatment (*N*=41)			
	M	***SD***	**Minimum**	**Maximum**	***M***	***SD***	**Minimum**	**Maximum**
Daily armband wear time (hours)	14.09	1.64	11.20	19.79	13.94	1.36	11.29	17.62
Daily bout-related MVPA minutes over 14-day	16.89	16.37	0.00	59.03	21.85	18.34	0.00	78.25
monitoring period MVPA minutes between EMA prompts	4.36	4.06	0.00	13.89	5.69	4.61	0.00	17.98
Stress (1–7 scale)	2.19	0.85	1.05	4.80	1.98	0.97	1.00	4.42
Anxiety (1–4 scale)	1.24	0.23	1.01	2.13	1.22	0.36	1.00	2.79
Temptation intensity (1–10 scale)	6.19	1.40	2.57	8.73	6.73	1.48	3.00	9.20
Overeating (number of occurrences)	9.65	6.63	0.00	37.00	4.93	4.53	0.00	15.00
Overeating (% of eating episodes)	25.26	15.91	0.00	92.50	13.82	12.26	0.00	42.42
Resisting temptations (number of occurrences)	9.96	6.27	0.00	27.00	4.88	4.44	0.00	19.00
Resisting temptations (% of temptations)	72.20	21.44	0.00	100.00	74.07	26.36	0.00	100.00

Note. EMA=ecological momentary assessment. Resisting temptations refers to occurrences when participants did not eat tempting foods when temptations were reported. EMA-measured variables were aggregated within each person at each EMA assessment wave.

Table 2.

Generalized linear mixed model (GLMM) results

	Temptation intensity			(In)ability to resist eating tempting foods[2]						Overeating					
Anxiety GLMMs	***B***	***SE***	***P***	***B***	***SE***	***p***	**Exp**	**Lower CI**	**Upper CI**	***B***	***SE***	***p***	**Exp**	**Lower CI**	**Upper CI**
Intercept	5.99	0.24	<0.001	0.86	0.35	0.015	2.36	1.19	4.69	−1.85	0.18	<0.001	0.16	0.11	0.22
Assessment	0.26	0.16	0.114	−0.14	0.30	0.654	0.87	0.48	1.58	**−0.96**	**0.14**	**<0.001**	**0.38**	**0.29**	**0.50**
Age	−0.01	0.02	0.717	−0.02	0.03	0.524	0.98	0.92	1.04	−0.02	0.02	0.257	0.98	0.95	1.01
BMI	−0.08	0.05	0.085	−0.01	0.06	0.824	0.99	0.87	1.12	−0.03	0.03	0.404	0.97	0.91	1.04
PWL	−0.04	0.05	0.351	0.10	0.09	0.240	1.11	0.93	1.31	0.05	0.03	0.164	1.05	0.98	1.12
Time	<0.01	<0.01	0.060	**<0.01**	**<0.01**	**<0.001**	**1.00**	**1.00**	**1.01**	**<0.01**	**<0.01**	**<0.001**	**1.00**	**1.00**	**1.00**
Anxiety (between)	0.41	0.85	0.625	−1.08	1.17	0.357	0.34	0.03	3.40	−0.16	0.56	0.772	0.85	0.28	2.56
Anxiety (within)[1]	0.25	0.23	0.272	**−0.76**	**0.38**	**0.045**	**0.47**	**0.22**	**0.98**	**−0.44**	**0.21**	**0.037**	**0.65**	**0.43**	**0.97**
MVPA (between)	−0.05	0.04	0.191	−0.07	0.06	0.239	0.93	0.83	1.05	−0.04	0.03	0.213	0.96	0.91	1.02
MVPA (within)	<−0.01	0.01	0.973	−0.02	0.01	0.058	0.98	0.96	1.00	**−0.02**	**0.01**	**<0.001**	**0.98**	**0.97**	**0.99**
Assessment X Anxiety (within)	0.03	0.02	0.194	0.01	0.04	0.694	1.01	0.94	1.09	<0.01	0.02	0.926	1.00	0.96	1.04
Assessment X MVPA (within)	<−0.01	0.01	0.814	−0.01	0.02	0.634	0.99	0.95	1.03	0.02	0.01	0.088	1.02	1.00	1.04
Anxiety X MVPA (within)	−0.54	0.54	0.315	0.06	0.97	0.952	1.06	0.16	7.15	0.07	0.43	0.868	1.07	0.46	2.49
Assessment X Anxiety (within) X MVPA (within)	−0.03	0.04	0.451	**−0.16**	**0.08**	**0.041**	**0.85**	**0.73**	**0.99**	**−0.10**	**0.04**	**0.016**	**0.91**	**0.84**	**0.98**
Stress GLMMs															
Intercept	5.99	0.24	<0.001	0.84	0.34	0.016	2.31	1.17	4.53	−1.85	0.18	<0.001	0.16	0.11	0.22
Assessment	0.22	0.17	0.181	−0.07	0.30	0.824	0.93	0.51	1.70	**−0.96**	**0.14**	**<0.001**	**0.38**	**0.29**	**0.50**
Age	−0.01	0.02	0.790	−0.02	0.03	0.603	0.98	0.93	1.04	−0.01	0.02	0.380	0.99	0.96	1.02
BMI	−0.08	0.05	0.084	−0.02	0.06	0.777	0.98	0.87	1.11	−0.03	0.03	0.417	0.97	0.91	1.04
PWL	−0.04	0.05	0.370	0.10	0.09	0.257	1.10	0.93	1.30	0.05	0.03	0.177	1.05	0.98	1.12
Time	<−0.01	<0.01	0.064	**<0.01**	**<0.01**	**<0.001**	**1.00**	**1.00**	**1.01**	**<0.01**	**0.00**	**<0.001**	**1.00**	**1.00**	**1.00**
Stress (between)	0.19	0.20	0.332	−0.16	0.29	0.583	0.85	0.48	1.52	0.07	0.15	0.616	1.08	0.81	1.43
Stress (within)[1]	0.06	0.05	0.303	0.03	0.09	0.786	1.03	0.85	1.23	−0.06	0.05	0.178	0.94	0.86	1.03
MVPA (between)	−0.05	0.04	0.181	−0.06	0.06	0.281	0.94	0.84	1.05	−0.04	0.03	0.220	0.96	0.91	1.02
MVPA (within)	<0.01	0.01	0.945	−0.02	0.01	0.074	0.98	0.96	1.00	**−0.02**	**0.01**	**<0.001**	**0.98**	**0.97**	**0.99**

Anxiety GLMMs	Temptation intensity			(In)ability to resist eating tempting foods[2]						Overeating					
	B	***SE***	***P***	***B***	***SE***	***p***	**Exp**	**Lower CI**	**Upper CI**	***B***	***SE***	***p***	**Exp**	**Lower CI**	**Upper CI**
Assessment X Stress (within)	<0.01	<0.01	0.283	0.01	0.01	0.288	1.01	0.99	1.03	<0.01	<0.01	0.521	1.00	0.99	1.01
Assessment X MVPA (within)	<−0.01	0.01	0.876	<−0.01	0.02	0.901	1.00	0.96	1.04	0.02	0.01	0.089	1.02	1.00	1.03
Stress X MVPA (within)	−0.09	0.13	0.519	−0.30	0.23	0.193	0.74	0.47	1.17	−0.14	0.09	0.132	0.87	0.72	1.04
Assessment X Stress (within) X MVPA (within)	<−0.01	0.01	0.677	**−0.04**	**0.02**	**0.045**	**0.96**	**0.93**	**1.00**	**−0.02**	**0.01**	**0.028**	**0.98**	**0.97**	**1.00**

Note. CI=95% confidence interval; BMI=body mass index (pre-intervention); PWL=percent weight loss; time=time lapsed (minutes) since last EMA recording; MVPA=moderate-to-vigorous physical activity (i.e., bout-related minutes since the last EMA recording). Assessment (baseline vs. end-of-treatment) was coded such that baseline was the reference category.

[1] Within-person effects of anxiety and stress were lagged within day from the previous EMA recording.

[2] Coded as 1=ate tempting food and 0=did not eating tempting food, such that higher *B* values indicate decreased ability to resist eating tempting food.