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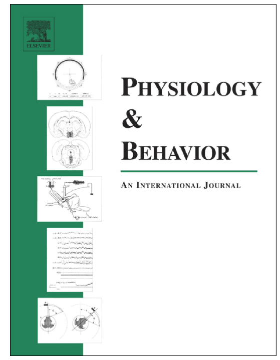

Heart rate variability and emotion regulation among individuals with obesity and loss of control eating

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Running head: LOSS OF CONTROL EATING AND HRV

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ABSTRACT

Autonomic nervous system functioning, measured with heart rate variability (HRV), is associated with emotion regulation and likely contributes to binge eating. This study examined the link between HRV and binge eating severity and analyzed changes in HRV as a marker of emotion regulation in individuals with binge eating. Participants (n=28) with obesity and loss of control eating reported overeating and loss of control episodes and completed an HRV assessment at rest and during a mental stressor. At rest, lower time-domain HRV was linked to more severe loss of control (SDNN B=-0.18, p=0.03). Frequency-domain HRV was associated with more severe overeating (LFn B=14.92, p=0.03; HFn B=-14.81, p=0.04). Frequency-domain HRV differed between resting and stressed conditions (p's<0.001). Findings contribute to understanding emotion regulation in binge eating and guide future research and novel intervention development.

Keywords: loss of control, overeating, binge eating, obesity, emotion regulation, heart rate variability

1. Introduction

Binge eating (BE) comprises two distinct components: eating an unusually large amount of food, known as overeating (OE), and feeling unable to stop oneself or resist eating, called loss of control (LOC) eating [1, 2]. Several theoretical models of BE, including escape theory [3], affect regulation theory [4], and emotional arousal theory [5], note a central role of negative affective states in triggering BE episodes. Laboratory and naturalistic studies support these models, providing evidence that poor regulation of negative affect is linked to BE and can trigger OE and LOC episodes [6-9]. Despite decades of research examining the role of emotion regulation in LOC and OE, the physiological mechanisms of this association remain elusive. Understanding the physiological correlates is not only essential to understanding the momentary factors that contribute to LOC and OE and but also holds promise for developing novel intervention approaches.

Negative affect and emotion regulation have characteristic patterns of physiological arousal. A key system involved in the generation and regulation of this physiological arousal is the automatic nervous system (ANS) [10]. The ANS has two branches, an excitatory sympathetic nervous system (SNS) and an inhibitory parasympathetic nervous system (PNS). During an episode of psychological stress, the SNS produces a cascade of physiological arousal that helps an individual respond to the stressor (e.g., increased heart rate (HR), alterations in blood flow). The PNS, in contrast, reduces psychological arousal and maintains low arousal during periods of safety and security. The activity of the SNS and PNS are thought to reflect the organism's ability to respond to and recover from stress and can be quantified by measuring changes in heart rate [11, 12].

Heart rate variability (HRV) is a commonly used measure of ANS activity that can be derived from data collected by HR monitors. HRV can be measured with both time- and frequency- domains. Time-domain measures are calculated by examining the segments between heartbeats or normal-to-normal (NN) intervals measured in milliseconds (ms).

Mathematical manipulations of the NN variable produce numerous HRV variables, such as the standard deviation of NN intervals (SDNN) and root mean square of successive differences between NN intervals (RMSSD). Spectral analysis of changes in HR yield frequency-domain HRV variables. These frequency-domain HRV variables include power in the very low frequency range (VLF; ≤ 0.04 Hz), low frequency range (LF; 0.04-0.15 Hz) and high frequency range (HF; 0.15-0.4 Hz) measured in ms^2. Power in the LF range is generally thought to reflect SNS and some PNS activity, whereas power in the HF range is thought to reflect primarily PNS activity [13], though debate exists about this distinction [14]. The mechanism underlying VLF is not well-understood. Mathematical manipulations of these frequency-domain measures, such as the LF/HF ratio, are also used, with higher LF/HF ratios putatively reflecting relatively higher SNS activity. Low frequency norm (LFn) and high frequency norm (HFn) values minimize the effect of changes in the VLF and, since they also represent LF and HF activity as relative proportions of total power, may be more suitable than the raw LF and HF values for measuring SNS and PNS activity across subjects [15].

Low HRV is observed in numerous psychological and physical health concerns and has been proposed as a biomarker of lower capacity for self-regulation of physiological, emotional, and cognitive responding and of less effective adaptation to environmental stress and demands, including exposure to food cues [10, 11, 16, 17]. In studies of HRV at rest, higher values in HF HRV and time-domain HRV variables (SDNN, RMSSD) have been related to better individual emotion regulation skills, whereas studies of intraindividual phasic changes in HRV have found lower values in these HRV variables in response to stress [18]. HRV is also appealing to examine as a physiological measure of emotion regulation because commercially available HR monitors worn on the chest or hand provide the potential for mobile psychophysiological assessment.

Very few studies to date have examined ANS activity in BE, and previous research has produced inconsistent results. Compared to obese individuals without BE individuals with binge eating disorder (BED) demonstrated greater reduction in HF activity [19] in one study, whereas another study found stable HF activity and an increase in LF activity [20]. Comparisons to non-obese controls did not reveal any HF or LF differences during or in recovery from a stressor [21]. Therefore, research has not yet identified consistent patterns of ANS activity at baseline (trait-level) and in response to stress that are unique to BED. Studies correlating ANS activity with BE severity within those with BED have also shown inconclusive findings [19, 21]. The inconsistency in the literature may be due to several factors, such as methodological differences in the stress task used or the limited duration of HRV recording.

In addition to concerns with the stress induction protocols, previous research is limited in other ways. By comparing diagnostic groups with and without BED, researchers have not studied the full spectrum of individuals with obesity and LOC. Studying only individuals meeting full BED criteria is problematic for several reasons. Evidence supports that individuals with sub-threshold BED have high levels of impairment, such as emotional distress and suicidality [22]. Emotion regulation may be a challenge for some individuals with obesity [23] and individuals with LOC [24]. Efforts to prevent, treat, and maintain treatment effects for BE may benefit most from elucidating the physiological mechanisms of emotion regulation across the range of individuals with obesity and LOC rather than focusing exclusively on individuals who currently meet BED diagnostic criteria. Determining whether HRV can be used as a marker of emotion regulation in this population requires examining changes in HRV within individuals with LOC rather than comparing diagnostic groups with and without BED. Advancing this area of research may also come from naturalistically examining correlates of poor emotion regulation as triggers for BE. Only one published study to date has used ecological momentary assessment and ambulatory physiological assessment to study HRV as a momentary psychophysiological risk factor preceding LOC episodes [25]. However, that study and others in the literature have also been limited by only examining the association of HRV and BE in samples of women.

Given the limitations of prior studies on the relationship between HRV and BE more research is needed. To fill these gaps in the literature, the current study of women and men with obesity and LOC aimed: 1) to examine whether lab-based time- and frequency-domain HRV at rest and during a mental math stressor is related to BE severity; and 2) to consider if changes in time- and frequency-domain HRV from resting to stressed conditions can be used as a marker of emotion regulation in women and men with obesity and LOC. We hypothesized that more severe BE would be associated with lower time-domain HRV, lower HF and higher LF at rest and when stressed, signifying more SNS activity and less ANS flexibility. For Aim 2, we hypothesized that time- and frequency-domain variables would be significantly different under resting and stressed conditions.

2. Methods

2.1. Participants

Participants were recruited through internet and community advertising from September 2015 to April 2016. Potential participants were screened over the phone to ensure they met the inclusion criteria: 18-69 years; BMI of > 30 kg/m^2; at phone screening, reporting at least 4 episodes of LOC or OE eating for the previous four weeks; and at least one rating of 2 or higher on the 4-item Cohen Perceived Stress Scale (PSS) [26, 27] to indicate the presence of some stress. Participants were excluded for serious or unstable medical conditions, psychiatric illness, or psychosocial instability, current recreational drug use or high risk for substance use disorder, or pharmacotherapy for obesity (e.g., Orlistat or Meridia) or bariatric surgery within the past 6 months, current use of beta-blocker medications or tobacco. Participants were also excluded for medical conditions that might impact ANS function (e.g., cardiovascular disease, cardiopulmonary problems, endocrine disorders, and autoimmune disorders) and for having sleep apnea or being at high risk of sleep apnea without current treatment. Participants provided written informed consent and were given compensation, based on their level of participation. The study received approval from the University of California, San Diego Human Research

Protections Program (Institutional Review Board). Thirty-three participants were consented and completed the study tasks, but 5 were excluded from analysis because the interview assessment revealed that they did not have any LOC episodes in the 4 weeks prior to the lab visit.

2.2. Procedures

Eligible participants attended a lab visit to provide informed consent and enroll in the study. Participants were asked to refrain from eating, drinking alcohol or caffeinated beverages, and exercising 2 hours before the lab visit to minimize the impact of digestion, sedation, and stimulation on the HRV assessment [19, 20, 28]. Participants were seated upright in a comfortable chair within the assessment room. The HRV assessment protocol consisted of 5 minutes each of 1) rest while subjects were asked to sit quietly, move minimally, breathe normally, and keep their eyes open to stay awake; 2) self-relaxation where participants imagined being at a relaxing place and were prompted to notice their five senses in this location, 3) paced breathing (metronome breathing to 6 breaths per minute); 4) a mental math stressor (serial 7 task); and 5) recovery. In order to maintain task consistency between participants, the mental math stressor was performed in the presence of the researcher who recorded responses but did not provide corrections [29]. Mental math is the most commonly used mental stressor for inducing physiological stress and studying physiological reactivity and produces similar physiological responses to other tasks [30]. It has some advantages over other methods for inducing stress in the lab, such as its short duration, consistent delivery across participants, and use without the need for confederates, deception, or specialized equipment. The five segments were separated by 30-45 seconds, during which instructions for the next segment were given. The protocol was developed from and analyzed using recommended and previously used procedures [13, 28, 30, 31]. All segments were included to examine HRV during other conditions such as induced relaxation and intentional breathing but are not the focus of the current manuscript. Subjects were fitted with the chest-worn HR monitor, Hidalgo Equivital™

LifeMonitor. This continuous monitoring system records the physiological activity of the myocardium via ECG leads embedded in an elastic fabric chest strap that continuously encrypts and stores participant data on a compact flash memory card within a plastic device snapped on the chest strap. Cardiac data are sampled at 200 Hz and analyzed with Vivonoetics, a proprietary PC-based software. This program decrypts the data, images the continuous stream of cardiac autonomic output over time, and exports processed data in ASCII format. HRV data from the LifeMonitor has demonstrated sufficient reliability and validity [32]. After the HRV assessment, participants completed self-reported questionnaires.

2.3. Measures

2.3.1. HRV

HRV data from the chest-worn HR monitor were processed using Vivonoetics VivoSense software (version 2.9), and automatic artifact detection was used to determine the presence of noise or artifacts. Segments with more than one marked artifact, excluded data point, or interpolated data point in one minute were considered poor quality and were excluded from analysis. A visual inspection of the data examined to confirm that the software's automatic Q wave, R wave, and S wave (QRS complex) detection had occurred properly. HRV measures were generated per standard recommendations [13]. Time-domain HRV measures derived from the data included SDNN and RMSSD. Frequency-domain measures derived from raw data were mathematical manipulations of LF and HF: LFn, HFn, and LF/HF ratio.

2.3.2. BE severity, anthropometric assessment, and self-report measures

The BED module of the Eating Disorder Examination Interview (EDE) [33, 34] 16th edition assessed BE severity with the frequency of LOC and OE episodes in the four weeks prior to the lab visit and determined BED diagnostic status according to DSM-5 criteria as a means of characterizing the sample. The EDE has demonstrated adequate test-retest reliability of binge eating episodes and long term recall and discriminant and convergent validity [35]. Participants' height and weight were measured with clothing on and shoes off (Scale-Tronix

5002 Stand-On Scale). Self-reported eating disorder symptoms were assessed in order to describe the sample. The Dutch Eating Behavior Questionnaire (DEBQ; 34) and the Binge Eating Scale (BES; 35) assessed eating disorder symptoms. Both measures have demonstrated good psychometric properties [38, 39] with high internal consistency within the current sample (BES Cronbach's alpha = 0.85, DEBQ restrained eating Cronbach's alpha = 0.89, DEBQ emotional eating Cronbach's alpha = 0.97, DEBQ external eating Cronbach's alpha = 0.81). Potential covariates were measured with self-report questionnaires of demographic information, medications, medical conditions, self-reported stress in the past month from the PSS 10 item scale [26, 27], and physical activity levels from the International Physical Activity Questionnaire [40].

2.4. Data analysis

Overall, about 12% of the HRV data collected at the lab visit with the chest-worn HR monitor did not meet data quality standards to be included in the analyses. These data quality issues were due to abnormalities in participants' QRS complex or HR monitor technical issues such as large amounts of artifact, excluded data, data interpolation, or the monitor turning off during the assessment. HRV data from the rest portion of the assessment were valid for 26 of the 28 participants (2 participants excluded for QRS complex abnormalities), and HRV data from the mental math stressor were valid for 25 participants (2 participants excluded for QRS complex abnormalities, 1 participant excluded for excessive artifact).

Multiple linear regression models examined if frequency of OE and LOC episodes during the four weeks before the lab visit (response variable) was related to HRV variables (explanatory variable) at rest and during the mental math stressor (aim 1). Repeated-measures Analysis of Variance (ANOVA) was used to examine within-participant changes in HRV variables from resting to the mental math stressor (aim 2). Sex, BMI, age, use of psychotropic medications (e.g., antidepressants), self-reported stress, and physical activity levels were considered as potential covariates in the models. Significant sex differences were found for LFn, HFn, and LF/HF ratio. Therefore, sex was included as a covariate in HRV models with LFn, HFn, and LF/HF ratio for all aims. BMI was not a significant covariate, possibly due to the limited variability of BMI in our sample of participants all with BMIs in the obese range. Distributions of all variables were examined to examine skew and determine if outliers were present or if transformations were necessary. Only LF/HF at rest was substantially skewed (positively) due to an extreme value from one participant. Sensitivity analyses revealed no change in findings when excluding this participant from the models at rest so results are presented with untransformed data including all participants. An alpha of .05 was used for all models. Statistical analyses were conducted using SPSS 23 (IBM).

3. Results

3.1. Participants and descriptives

The demographic characteristics for the sample (N= 28) are presented in Table 1. The sample was mostly female, non-Hispanic/Latino white or African American, single, with either some college or a Bachelor's degree, and was evenly distributed in terms of the household income. Eating and physiological characteristics by diagnostic group are presented here for descriptive purposes (Table 2). On average, participants reported that over the four weeks prior to the lab visit they had 7 OE episodes and 12 loss of control episodes. Mean scores on the BES were above suggested cutoff score (non-binge eaters ≤17) previously used by other authors [41]. Participants in this study scored higher on all subscales of the DEBQ (restrained, emotional, and external eating) compared to a sample of individuals with obesity [36].

Figure 1 displays the time- and frequency-domain HRV variables, excluding LF/HF ratio, across the sections of the physiological assessment protocol. These data are included here for descriptive purposes only as the aims and hypotheses of the study pertain only to HRV assessed at rest and during the mental math stressor. It should be noted that frequency-domain HRV variables from the paced breathing section have not been adjusted to account for changes in respiration frequency, a method that others have used to correct spectral analysis in slowed breathing protocols [42]. In previous studies, correcting for respiration did result in increased HF during paced breathing trials [42].

3.2. HRV and BE severity

Table 3 displays results of linear regression models of HRV and BE for the 4 weeks prior to the lab visit. Regression analyses of previous four weeks BE behaviors and HRV demonstrated statistically significant associations between resting SDNN and LOC, $B = -0.18$, $t(25) = -2.39$, $p = 0.025$, $sr^2 = 0.19$, resting LFn and OE, $B = 14.92$, $t(25) = 2.39$, $p = 0.026$, $sr^2 = 0.18$, and resting HFn and OE, $B = -14.81$, $t(25) = 2.39$, $p = 0.037$, $sr^2 = 0.16$. The relationship between resting RMSSD and LOC was nearly statistically significant, $B = -0.17$, $t(25) = -2.05$, $p = 0.052$, $sr^2 = 0.15$. No significant associations were found between HRV during the mental math stressor and OE or LOC.

3.3. HRV as a marker of emotion regulation

Table 4 displays descriptives of the HRV variables at resting and during the mental math stressor and results of repeated-measures ANOVA analysis. Within-subject effects showed significantly lower HFn, $F(1, 23) = 56.9$, $p < 0.001$, during the mental math stressor compared to rest. LFn, $F(1, 23) = 38.0$, $p < 0.001$ and LF/HF ratio, $F(1, 23) = 17.6$, $p < 0.001$, were both significantly higher during the mental math stressor, relative to rest. The lower RMSSD value during mental math stressor was nearly statistically significant, $F(1, 24) = 4.0$, $p = 0.056$. SDNN did not demonstrate a statistically significant difference between rest and mental math conditions.

4. Discussion

This study assessed 28 participants with obesity and LOC to examine if laboratory assessed time- and frequency-domain HRV at rest and during a mental math stressor is related BE severity. At rest, individuals with lower time-domain HRV (SDNN) had higher severity of LOC. This association suggests that higher severity of LOC is related to lower ANS flexibility. Individuals with higher severity of OE in the four weeks prior to the lab visit had lower HFn and higher LFn. Broadly, the interpretation of these associations is that higher severity of LOC and OE are related to lower ANS flexibility.

Our findings are in line with our hypothesis and with research demonstrating that resting HRV is related to individual variation in emotion regulation [16, 43]. Interestingly, LOC and OE were uniquely related to different HRV variables in our small sample. Although researching these potentially unique relationships in a larger study is necessary, these preliminary findings could be in line with emerging research suggesting OE and LOC have subtle differences in their correspondence with specific emotion regulation skills with OE associated with lack of emotional clarity whereas LOC is linked to non-acceptance of emotions [24]. Further exploring the potentially unique physiological aspects of LOC and OE may be a promising area for continued research.

Another aim of this study was to analyze if changes in time- and frequency-domain HRV from rest to stressed conditions can be used as a marker of emotion regulation in individuals with obesity and LOC. From rest to stressed conditions, participants demonstrated increases in LFn and decreases in HFn. These significant changes suggest that these frequency-domain HRV variables may have potential to detect changes in momentary emotion regulation capacity in individuals with obesity and LOC. Reductions in HFn under stressed conditions has been found in some studies of HRV in BE [19] but not in others [20]. The finding that LFn increased during the mental math stressor is consistent with one study that found LF increased in response to the lab stressor in individuals with BED [20]. Given that the current study and another study of a mental stressor in BED [20] both found increases in LF during a mental stressor, this HRV measure should continue to be studied as a possible marker of momentary emotion regulation capacity in this population. Consistent with recent research supporting the link between momentary low time-domain HRV and LOC eating episodes [25], RMSSD was nearly significantly lower during the lab stressor, suggesting that this variable has promise as a marker of momentary capacity for emotion regulation. Further determination of the links among

RMSSD, emotion regulation, BE requires a study with a larger sample size and, ideally, naturalistic ambulatory assessment. Although more work is needed to provide further evidence and resolve the inconsistencies in the literature, our results contribute more evidence to the growing body of research studying ANS activity as a physiological correlate of emotion regulation in BE.

Evidence was not found for the hypothesized relationship between measures of HRV during the lab stressor and LOC or OE. Research in BED samples has found mixed evidence on the link between BE severity and HRV during a stressor [19, 21] so it may be that HRV when stressed is truly not linked to BE severity. Notably, these studies correlated BE severity with changes in HRV variables from rest to stressed conditions, which makes it difficult to know if the findings were partially influenced by HRV values at rest. In this study, the effect sizes for the relationships between BE severity and HRV when stressed were slightly smaller than the effect sizes for HRV at rest, despite having associations of similar direction and magnitude to the resting models. Therefore, the current study may be under-powered to detect associations between HRV when stressed and frequency of LOC and OE, which should be examined in larger samples in the future to better understand these relationships .

Findings from this study may have clinical implications for innovative intervention development, such as just-in-time adaptive interventions (JITAIs), which deliver interventions through a smartphone application in high risk moments (e.g., when individuals' capacity for emotion regulation is low) [44, 45]. JITAIs may be limited if they rely solely on self-reported measures of stress, coping, and other risk factors which can be biased or difficult to assess as individuals habituate to continuous prompts. Identifying means to passively collect data on an individual's affect and emotion regulation capacity through HRV could reduce the demand on individuals to frequently provide self-report data. Continuing this line of research can inform methods to best incorporate HRV or other psychophysiological data into innovative treatment technologies, such as JITAIs.

4.1. Strengths and limitations

This study has several strengths. The sample of individuals with obesity was comprised of both men and women and a blend of those meeting diagnostic criteria for BED and those who are binge eating at subclinical levels. Thus, external validity and clinical utility might be higher than previous research as this sample likely represents a larger clinical spectrum relative to samples of only individuals, typically women, currently meeting diagnostic criteria for BED.

There were several limitations of this study. Our sample size was relatively small, which may have limited our ability to obtain reliable findings. We had fewer participants than two previously conducted studies of HRV and BE [19, 21], though our sample size was larger than samples in other studies [20]. The small sample size and small male representation also precluded the use of analyses to examine differences between male and female participants. Some caution is advised when interpreting associations with frequency-domain HRV. Early models of ANS activity proposed that LF was linked to SNS activity, HF capturing PNS activity, and the LF/HF ratio measuring the SNS/PNS balance [46-48]. However, this model has been challenged by emerging research suggesting substantially limitations in interpreting HRV variables as directly assessing activity of the ANS branches and urging more research to elucidate the precise physiological underpinnings of SNS and PNS [14, 47-50]. This study did not have a control group so the changes in HRV seen across the assessment protocol in our sample could not be compared to a group with obesity but without LOC or to control participants without obesity and LOC. We believe this limitation does not impact our ability to examine the aims of the study, which were to identify correlates and patterns of HRV among individuals with obesity and LOC, not to find HRV characteristics uniquely associated with this population nor to distinguish HRV in these participants from other groups. The HRV assessment protocol had paced breathing followed by the mental math stressor task. It would have been preferable to have the mental math stressor task before paced breathing, as this section of the protocol induced large changes in HRV. Another limitation is the lack of detailed weight loss history for these participants, which could have been informative in examining weight loss history, current weight suppression, and other variables of interest.

4.2. Conclusions

This study analyzed whether HRV is related to LOC and OE severity and examined if HRV measured in the lab is a marker of emotion regulation in women and men with obesity and LOC. Findings support that ANS activity is associated with LOC and OE, that HRV may be a feasible marker of emotion regulation in this population.

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Table 1. Sample demographics.

		Total sample *N* = 28
Age, *M* (*SD*)		41.1 (16.5)
Sex, *n* (%)	**Female**	22 (78.6)
Ethnicity, *n* (%)	**Hispanic/Latino**	5 (18.5)
Race, *n* (%)	**Asian**	2 (7.1)
	Black or African American	8 (28.6)
	White	11 (39.3)
	Hispanic/Latino	3 (10.7)
	More than one/Mixed	4 (14.3)
Marital status, *n* (%)	**Single, never married**	14 (50.0)
	Married	6 (21.4)
	Divorced	2 (7.1)
	Widowed	2 (7.1)
	Living with partner	4 (14.3)
Highest level of education, *n* (%)	**Some college, no degree**	10 (35.7)
	Technical or vocational school graduate	2 (7.1)
	Bachelor's degree	11 (39.9)
	Graduate or professional degree	5 (17.9)
Household income, *n* (%)	**<$20,000**	3 (10.7)

$20,000 – 29,999	4 (14.3)
$30,000 – 39,999	4 (14.3)
$40,000 – 49,999	3 (10.7)
$50,000 – 59,999	4 (14.3)
$60,000 – 69,999	4 (14.3)
$70,000 – 79,999	3 (10.7)
$80,000 or more	3 (10.7)

Table 2. Eating and physiological characteristics by diagnostic group and for the total sample.

	Met DSM-5 BED criteria ***n* = 15**	**Did not meet DSM-5 BED criteria** ***n* = 13**	**Total sample** ***N* = 28**
EDE Interview, *M* (*SD*)			
Overeating episodes	10.4 (6.8)	3.2 (2.2)	7.1 (6.3)
Loss of control episodes	16.3 (10.7)	8.4 (7.8)	12.6 (10.1)
BES, *M* (*SD*)	24.7 (8.0)	16.8 (6.3)	21.0 (8.1)
DEBQ, *M* (*SD*)			
Restrained eating	2.8 (0.7)	2.9 (0.9)	2.8 (0.8)
Emotional eating	3.9 (0.9)	3.0 (1.2)	3.5 (1.1)
Specific emotional eating	3.8 (1.0)	3.0 (1.3)	3.4 (1.2)
Diffuse emotional eating	4.2 (0.8)	3.2 (1.1)	3.7 (1.1)
External eating	3.8 (0.5)	3.3 (0.5)	3.6 (0.6)
BMI	37.5 (5.1)	39.4 (5.6)	38.4 (5.3)
Resting heart rate	69.1 (10.3)	66.4 (14.3)	67.9 (12.1)

Note. EDE is the Eating Disorder Examination, BES is the Binge Eating Scale, DEBQ is the Dutch Eating Behavior Questionnaire. BMI is body mass index in kg/m^2. Resting heart rate is in beats per minute.

Table 3. Results of linear regression models of HRV and rest and during the mental math stressor (serial 7) and BE for the 4 weeks prior to the lab visit.

	Past 4 weeks OE			**Past 4 weeks LOC**		
Resting HRV	***B***	***p***	***sr***^{2}	***B***	***p***	***sr***^{2}
SDNN	-0.09	0.06	0.14	-0.18	0.03	0.19
RMSSD	-0.10	0.07	0.13	-0.17	0.05	0.15
LFn	14.92	0.03	0.18	14.4	0.19	0.06
HFn	-14.81	0.04	0.16	-20.92	0.07	0.13
LF/HF	1.25	0.18	0.07	1.14	0.45	0.02
Serial 7 HRV						
SDNN	-0.11	0.10	0.12	-0.18	0.11	0.11
RMSSD	-0.09	0.21	0.07	-0.16	0.08	0.13
LFn	8.84	0.25	0.05	-0.89	0.94	<0.01
HFn	-15.62	0.11	0.10	-23.69	0.13	0.09
LF/HF	0.76	0.15	0.08	0.52	0.55	0.02

Note. OE is overeating. LOC is loss of control over eating. SDNN is standard deviation of normal-to-normal (NN) interval in ms. RMSSD is root mean square of successive differences between NN intervals in ms. LFn is the low frequency norm value in nu. HFn is the high frequency norm value in nu. LF/HF is the LF/HF ratio. Models with LFn, HFn, and LF/HF ratio controlled for sex.

Table 4. Within-participant differences across heart rate variability measures between resting and mental math stressor (serial 7) sections of the HRV assessment lab protocol.

	Rest ***M* (*SD*)**	**Serial 7** ***M* (*SD*)**	***F***	***Partial Eta-Squared***
SDNN	48.8 (26.0)	49.5 (19.1)	0.04	<0.01
RMSSD	37.5 (23.1)	32.0 (17.7)	4.04	0.14
LFn	0.5 (0.2)	0.7 (0.2)	38.00***	0.62
HFn	0.5 (0.2)	0.3 (0.1)	56.95***	0.71
LF/HF	1.4 (1.6)	3.4 (2.5)	17.56***	0.43

Note. SDNN is standard deviation of normal-to-normal (NN) interval in ms. RMSSD is root mean square of successive differences between NN intervals in ms. LFn is the low frequency norm value in nu. HFn is the high frequency norm value in nu. LF/HF is the LF/HF ratio. HRV models with LFn, HFn, and LF/HF ratio controlled for sex.

*p<0.05

**p<0.01

***p<0.001

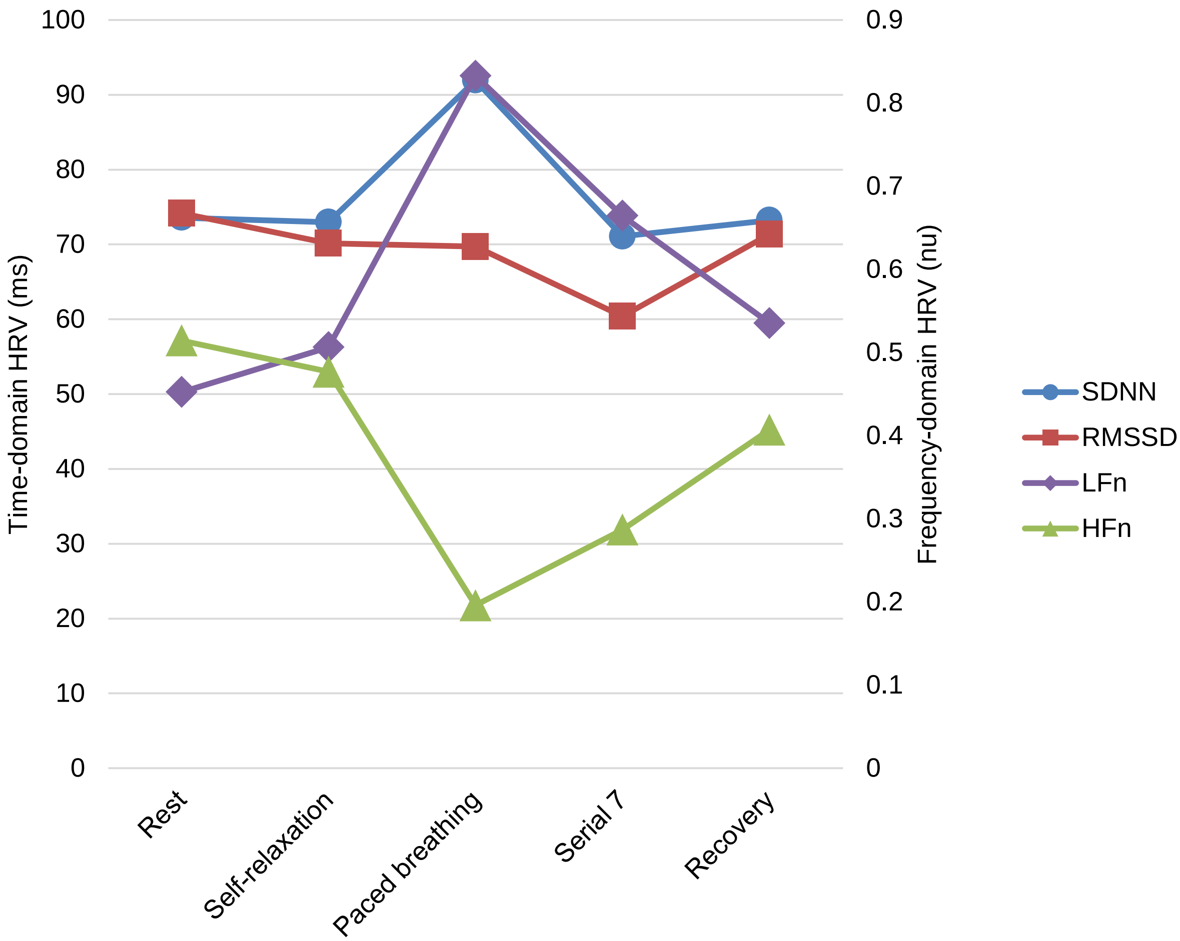

Figure 1. Mean time- and frequency-domain HRV variables across the lab-based HRV assessment protocol.

- Lower autonomic nervous system flexibility is related to higher severity of loss of control eating.
- Lower parasympathetic nervous system activity and higher sympathetic nervous system activity is linked to more severe overeating.
- Frequency-domain heart rate variability may be a marker of changes in momentary emotion regulation capacity in individuals with obesity and loss of control eating.