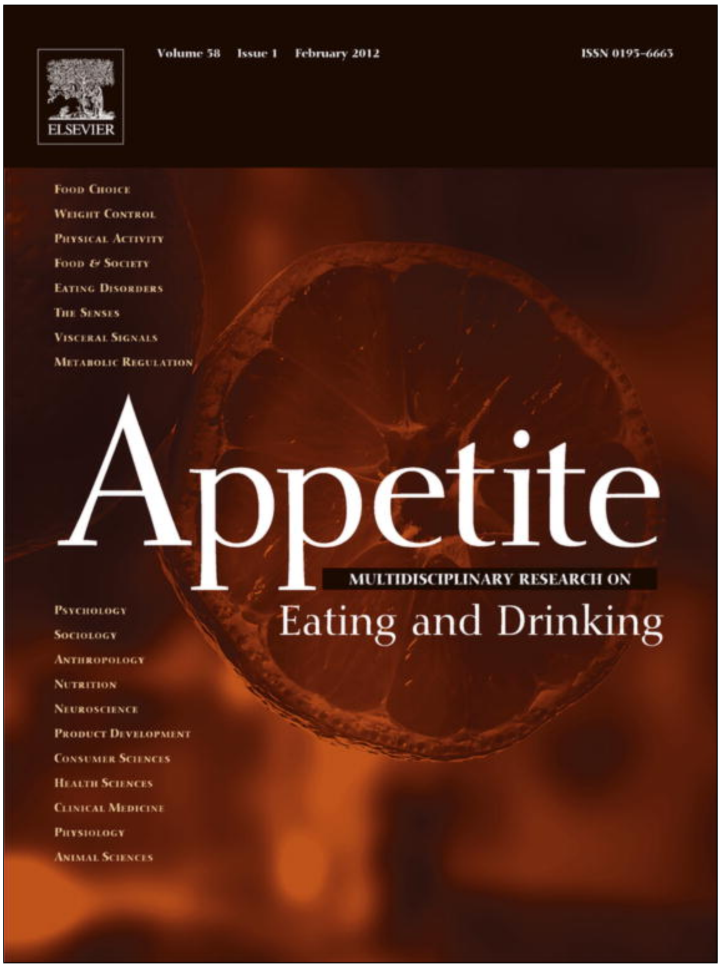

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Research report

Self-reported dieting success is associated with cardiac autonomic regulation in current dieters

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ABSTRACT

Restrained eating, eating disorders and obesity have been associated with cardiac autonomic dysregulation. The current study investigated cardiac autonomic regulation in current dieters. Female students ($N = 50$) indicated if they were currently trying to control their weight and completed the *Perceived Self-Regulatory Success in Dieting Scale* (PSRS). Heart beat intervals were recorded during two 10 min relaxation periods from which parameters of vagal-cardiac control (high frequency power in normalized units, HF n.u.) and sympathovagal balance (ratio of low and high frequency power, LF/HF) were calculated. In current dieters, self-reported dieting success was positively associated with HF and negatively associated with LF/HF. These associations were independent of current body-mass and food deprivation (i.e. hours since the last meal). We conclude that vagal-cardiac control reflects self-regulatory strength, rather than nutritional status, in current dieters.

Introduction

Heart rate variability (HRV) refers to the variation of heart beat intervals and is influenced by sympathetic and parasympathetic input to the sino-atrial node of the heart. Increased high-frequent parasympathetically (or vagally) mediated modulations increase HRV while increased low-frequent sympathetic activation decreases HRV (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Accordingly, time domain measures of HRV are positively correlated with indices of vagal-cardiac control (high frequency power) and negatively correlated with the ratio between low frequency and high frequency power (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). A higher vagal-cardiac control or higher HRV, respectively, reflects a higher flexibility of the cardiovascular system. This enables an organism to quickly adapt to changing environmental requirements (Thayer & Lane, 2009). Although HRV is considered as a stable trait when measured at rest, short-term day-to-day variations (Pinna et al., 2007; Sandercock, 2007) may occur due to a variety of acute circumstances and long-term physical conditions like overall health status, age, exercise, smoking, alcohol, sleep patterns, or body weight (Bonnet & Arand, 1998; Britton & Hemingway, 2004).

The model of neurovisceral integration (Thayer & Lane, 2009) provides a theoretical framework for the empirical observation of an association between HRV and physical conditions and introduces HRV as a measure of self-regulatory strength. This model is based on a link between prefrontal and subcortical brain structures and the autonomic regulation of cardiac activity (*central autonomic network* (CAN)). The output of the CAN is directly linked to HRV, and particularly high-frequent, parasympathetically mediated tonic HRV has been shown to covary with the activity of the prefrontal cortex (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). Accordingly, HRV is associated with processes that are involved in self-regulation, e.g. emotion regulation and executive functioning (Appelhans & Luecken, 2006; Thayer et al., 2009). For example, positive associations have been found between resting levels of vagally mediated HRV and performance in working memory tasks and the continuous performance test (Hansen, Johnsen, & Thayer, 2003), performance in the P300 brain–computer interface (BCI; Kaufmann, Vögele, Sütterlin, Lukito, & Kübler, 2012) or longer persistence in an unsolvable anagram task (Reynard, Gevirtz, Berlow, Brown, & Boutelle, 2011; Segerstrom & Nes, 2007).

If high self-regulatory capacity in general is reflected in high HRV, then this should also apply to successful self-regulation of food intake. Support for this hypothesis comes from clinical studies which show parasympathetic dominance and decreased

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sympathetic modulation in anorectic patients (Mazurak, Enck, Muth, Teufel, & Zipfel, 2011) while the opposite is true for obese patients (e.g. Karason, Molgaard, Wikstrand, & Sjostrom, 1999; Latchman, Mathur, Bartels, Axtell, & De Meersman, 2011). Nevertheless, these differences in cardiac autonomic regulation may reflect physiological changes and differences in body mass due to malnourishment and lifestyle factors rather than variations in self-regulatory capacity.

Few studies have investigated tonic cardiac autonomic regulation in relation to eating behavior by taking such differences in body mass into account. In a sample of patients with bulimia nervosa (BN), only fasting women showed increased parasympathetic modulations compared to controls whereas non-fasting subjects displayed sympathetic dominance without differing in body mass (Coles, Vögele, Hilbert, & Tuschen-Caffier, 2005; Vögele, Hilbert, & Tuschen-Caffier, 2009). These results support the hypothesis that it is rather the effort and success in controlling food intake (i.e. fasting) than BMI *per se*, which is associated with HRV. Another study compared cardiac autonomic regulation between obese patients with and without binge eating disorder (BED; Friederich et al., 2006). Although there was no baseline difference in cardiac autonomic regulation between groups, an augmented reduction of vagal-cardiac control was observed in obese binge eaters as a result of mental challenge and this change was linked to binge eating frequency (Friederich et al., 2006). Similarly, binge eating-related symptomatology moderated the association between cardiac autonomic regulation and stress reactivity in BN (Hilbert, Vögele, Tuschen-Caffier, & Hartmann, 2011). Therefore, it can be concluded that "in cases of BN and obese BED, HRV cannot be explained only by the amount of digested and absorbed food, nor by body weight and fat. Behavior [...] itself is considered to affect HRV" (Kikuchi et al., 2011, p. 854).

Only two studies have investigated tonic cardiac autonomic regulation in relation to eating behavior in non-clinical samples. Rodríguez-Ruiz et al. (2009) found that eating disorder symptoms were associated with low HRV in trait chocolate cravers, but not in non-cravers while groups did not differ in body mass. They interpreted their results such that low vagally mediated HRV was a marker of inadequate emotion regulation that was associated with food cravings and uncontrolled eating behavior. Most recently, we found cardiac autonomic dysregulation in unsuccessful restrained eaters compared to unrestrained eaters after controlling for differences in body mass (Meule, Vögele, & Kübler, 2012).

In the current study, we investigated if tonic cardiac autonomic regulation is associated with perceived self-regulatory success in individuals who try to control their weight. The current study extends our previous study (Meule, Vögele, et al., 2012) as we (1) differentiated between successful and unsuccessful dieters and non-dieters and (2) measured heart beat intervals on two different occasions thereby reducing the effects of day-to-day variations in cardiac autonomic regulation. Based on our previous findings, we expected successful dieting to be associated with increased vagal-cardiac control and sympathovagal balance whereas unsuccessful dieting should be associated with decreased vagal-cardiac control and sympathovagal imbalance. These relationships were expected to be independent of physical and physiological influences like current body-mass-index (BMI) or food deprivation.

Method

Participants

Female participants were recruited among students at the University of Würzburg. Advertisements were posted on campus and using a mailing list of a student council. Women who responded to the advertisements were contacted by phone ($N = 82$) and screened for exclusion criteria. Participants were excluded if they reported to have a current diagnosis of mental disorder or were currently using psychoactive medication, if they were under- and overweight (BMI <17.5 or >25 kg/m^2), and if they were <18 or >40 years of age. A total of $n = 50$ participants were included and took part in the study. Participants either received course credits or €20 for participation.

Materials

Dieting status

Current dieting status (yes/no) was assessed with a single question ["Are you currently restricting your food intake to control your weight (e.g. by eating less or avoiding certain foods)?"].

Perceived Self-Regulatory Success in Dieting Scale (PSRS)

The PSRS (Fishbach, Friedman, & Kruglanski, 2003) was used to assess dieting success. In this three-item questionnaire, participants have to rate on seven-point scales how successful they are in watching their weight, in losing weight, and how difficult it is for them to stay in shape. Internal consistency of the German version is $\alpha > .70$ (Meule, Papies, & Kübler, 2012) and was $\alpha = .79$ in the current study.

Control variables

Participants reported their age, frequency of weekly exercise (ranging from *zero* to *five or more times*), smoking status (yes/no), and if they regularly consumed alcohol (yes/no). They also reported the number of hours of sleep during the night before testing and the number of hours that elapsed since their last meal (i.e. food deprivation). Current hunger was assessed with the corresponding subscale of the *Food Cravings Questionnaire – State* (FCQ-S; Cepeda-Benito, Gleaves, Williams, & Erath, 2000; Meule, Lutz, Vögele, & Kübler, 2012). Participants' height and weight was measured and used for calculation of BMI (kg/m^2). Depressive symptoms were assessed with the *Center for Epidemiologic Studies Depression Scale* (CES-D; Hautzinger, 1988; Radloff, 1977) which had an internal consistency of $\alpha = .90$ in the current study. Impulsivity was assessed with the short form of the *Barratt Impulsiveness Scale* (BIS-15; Meule, Vögele, & Kübler, 2011; Spinella, 2007) which had an internal consistency of $\alpha = .79$ in the current study.

Heart rate recording

Heart rate was recorded with the Polar watch RS800CX (Polar Electro Oy, Kempele, Finland), using a sampling rate of 1000 Hz.

Procedure

The reported data were part of a study that consisted of three weekly testing sessions that also involved several behavioral tasks, which are reported elsewhere (cf. Meule, Lutz, Vögele, & Kübler, submitted for publication). All participants were asked not to consume food, caffeine, nicotine, or alcohol at least 3 h before testing. Participants were told that the aim of the study was to investigate the relationship between the regulation of the heart rate and the regulation of behavior. No further specifications were given, e.g. that we were particularly interested in eating behavior. Participants then signed informed consent and heart rate was monitored at the beginning of the first session. After attaching the chest strap, participants were seated in a quiet room. Subsequently, the experimenter instructed participants to close their eyes and relax and left the room for 10 min. After physiological measurement, participants performed a Go/No-go-task which included pictorial food and neutral stimuli. Finally, participants indicated their hours of sleep, levels of hunger and hours since the last consumption of food, caffeine, nicotine and alcohol (all participants reported to have adhered to the instructions). The identical procedure was repeated in the second session. In the third session, participants completed the rest of the questionnaires, and participants' height and weight was measured.

Data analysis

R-R-recordings were analyzed using Kubios HRV 2.0 software (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2009). Interbeat interval series were corrected for artifacts with the default settings of the program. Trend components were removed with the smoothness priors detrending method ($\lambda = 500$). The last 5 min of the 10-min recording session was chosen for HRV analysis to ensure that data reflected resting conditions. Spectral power was obtained for high frequency (HF: 0.15–0.4 Hz) and low frequency (LF: 0.04–0.15 Hz) components by autoregressive modeling. HF power, expressed in normalized units (HF n.u. = HF ms^2/(total power ms^2 – very low frequency ms^2)) is an index of vagal-cardiac control and LF/HF power ratio a marker of sympathovagal balance (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Vagal-cardiac control (HF n.u.), sympathovagal balance (LF/HF), hours of sleep, food deprivation, and hunger were averaged across measurements.[1] LF/HF was log-transformed due to skewed distribution.

Group differences between dieters ($n = 18$) and non-dieters ($n = 32$) were investigated separately for each variable using χ^2- and *t*-tests. Associations between control variables with self-reported dieting success and cardiac autonomic regulation were investigated using Pearson and biserial correlations. Finally, regression analyses were run separately with vagal-cardiac control and sympathovagal balance as dependent variables. Dieting status, self-reported dieting success, the interaction dieting status × self-reported dieting success and control variables were chosen as *z*-standardized predictors. All *p*-values are reported two-tailed.

Results

Participant characteristics

Participants had a mean age of $M = 22.32$ years ($SD = 3.03$) and a mean BMI of $M = 21.45$ kg/m^2 ($SD = 2.67$). Of all participants, $n = 18$ indicated that they were currently trying to control their weight (i.e. dieters). There were no group differences between dieters and non-dieters in age, BMI, self-reported dieting success, depressive symptoms, impulsivity, food deprivation, hunger, exercise, smoking status, alcohol consumption, hours of sleep, vagal-cardiac control or sympathovagal balance (Table 1).

Correlations with control variables

Self-reported dieting success was inversely correlated with BMI ($r = -.67$, $p < .001$) and smoking status ($r_b = -.50$, $p < .05$), indicating lower BMI and a smaller number of smokers with increasing self-reported dieting success. No other control variable was correlated with self-reported dieting success. Vagal-cardiac control was positively correlated with exercise ($r = .29$, $p < .05$) and inversely correlated with alcohol consumption ($r_b = -.46$, $p < .05$), indicating more frequent exercise and less alcohol consumption with increasing vagal-cardiac control. Similarly, sympathovagal balance was inversely correlated with exercise ($r = -.29$, $p < .05$) and positively correlated with alcohol consumption ($r_b = .46$, $p < .05$), indicating less frequent exercise and more regular alcohol consumption with sympathovagal imbalance. No other control variable was correlated with cardiac autonomic regulation.

Regression analyses

The overall model using dieting status, self-reported dieting success, and its interaction as predictors of vagal-cardiac control was significant ($F_{(3,46)} = 3.19$, $p < .05$, adj. $R^2 = .12$). The interaction dieting status × self-reported dieting success was the only significant predictor in this model (Table 2). Vagal-cardiac control was positively predicted by self-reported dieting success but only in current dieters (Fig. 1). Control variables (i.e. BMI, smoking status, alcohol consumption, exercise) that were correlated with either self-reported dieting success or cardiac autonomic regulation were added to the regression in step 2. In this model ($F_{(7,42)} = 2.38$, $p < .05$, adj. $R^2 = .16$), the interaction dieting status × self-reported dieting success remained significant (Table 2).

The overall model using dieting status, self-reported dieting success, and its interaction as predictors of sympathovagal balance was marginally significant ($F_{(3,46)} = 2.78$, $p < .06$, adj. $R^2 = .10$). The interaction dieting status × self-reported dieting success was the only significant predictor in this model (Table 3). Sympathovagal balance was predicted by self-reported dieting success such that higher values (i.e. sympathovagal imbalance) were associated with lower self-reported dieting success, but only in current dieters. After inclusion of control variables in this model ($F_{(7,42)} = 2.33$, $p < .05$, adj. $R^2 = .16$), the interaction dieting status × self-reported dieting success was marginally significant (Table 3).

Discussion

In the current study, we found that self-reported dieting success was associated with vagal-cardiac control and sympathovagal balance in current dieters, indicating increased parasympathetic cardiac modulation with increasing self-reported dieting success, even after controlling for the effects of BMI, smoking status, alcohol consumption, and exercise.

These results are in line with previous findings of low HRV in chocolate cravers with symptoms of eating disorders (Rodríguez-Ruiz et al., 2009) or low vagal-cardiac control in restrained eaters (Meule, Vögele, et al., 2012). Although our findings indicate that there are important physiological moderators of cardiac autonomic regulation that are related to eating behavior (e.g. BMI, exercise, substance use), they also imply that there are other behavioral influences as has recently been suggested (Kikuchi et al., 2011). In line with a neurovisceral integration perspective on self and emotion regulation (Thayer & Lane, 2009; Thayer et al., 2009), increased vagal-cardiac control in successful dieters could be a physiological endophenotype of successful eating-related self-regulation.

Several limitations of our study have to be noted. Firstly, only 18 participants reported to be currently on a diet (i.e. at the time of taking part in the study). The present results, therefore, need to be replicated in larger samples of current dieters. Secondly, dieting success and control variables were assessed by self-report, which is subject to potential self-report bias. However, we have demonstrated the validity of the PSRS previously (Meule, Papies, et al., 2012). Accordingly, construct validity of the PSRS was supported by a negative correlation with BMI in the current study. An important issue that remains when dieting success is assessed with the PSRS is that items may not be equally applicable to individuals who have never been on a weight control diet compared

[1] All variables were moderately or highly correlated between measurements (HF n.u.: $r = .65$, $p < .001$; LF/HF: $r = .57$, $p < .001$; hours of sleep: $r = .48$, $p < .001$; food deprivation: $r = .61$, $p < .001$; hunger: $r = .41$, $p < .01$).

Table 1
Means and standard deviations of all variables in current dieters and non-dieters.

	Dieters (n = 18)	Non-dieters (n = 32)	Test statistic
Age (years)	21.89 (3.82)	22.56 (2.53)	$t_{(48)}$ = .75, *ns*
Body-mass-index (kg/m^2)	22.26 (2.50)	21.00 (2.70)	$t_{(48)}$ = −1.63, *ns*
Perceived Self-Regulatory Success in Dieting Scale	10.83 (3.02)	12.94 (4.45)	$t_{(48)}$ = 1.79, *ns*
Center for Epidemiologic Studies Depression Scale	16.22 (9.24)	15.72 (9.27)	$t_{(48)}$ = −.19, *ns*
Barratt Impulsiveness Scale – Short Form	32.83 (6.60)	30.41 (4.53)	$t_{(48)}$ = −1.54, *ns*
Food deprivation (h)	5.54 (2.65)	5.08 (3.02)	$t_{(48)}$ = −.54, *ns*
Hunger subscale of the Food Cravings Questionnaire – State	11.22 (1.65)	10.70 (2.28)	$t_{(48)}$ = −.85, *ns*
Regular exercise	1.39 (.98)	.94 (.67)	$t_{(48)}$ = −1.74, *ns*
Regular smoking (yes/no)	3/15	2/30	χ^2 = 1.39, *ns*
Regular alcohol consumption (yes/no)	9/9	9/23	χ^2 = 2.39, *ns*
Sleep (h)	7.08 (1.13)	7.18 (1.02)	$t_{(48)}$ = .31, *ns*
Vagal-cardiac control (HF n.u.)	49.33 (20.49)	50.36 (20.74)	$t_{(48)}$ = .17, *ns*
Sympathovagal balance (ln(LF/HF))	.07 (.96)	.10 (1.00)	$t_{(48)}$ = .11, *ns*

Table 2
Regression analysis predicting vagal-cardiac control (HF n.u.) as a function of dieting status, self-reported dieting success, and control variables.

	β	t	p
Step 1			
Dieting status	.11	.78	*ns*
Self-reported dieting success	.25	1.69	<.10
Dieting status × self-reported dieting success	.44	3.03	<.01
Step 2			
Dieting status	.10	.61	*ns*
Self-reported dieting success	.14	.70	*ns*
Dieting status × self-reported dieting success	.34	2.19	<.05
BMI	−.06	−.31	*ns*
Smoking status	.08	.50	*ns*
Alcohol consumption	−.33	−2.20	<.05
Exercise	.15	.96	*ns*

Table 3
Regression analysis predicting sympathovagal balance (LF/HF) as a function of dieting status, self-reported dieting success, and control variables.

	β	t	p
Step 1			
Dieting status	−.14	−.99	*ns*
Self-reported dieting success	−.24	−1.59	*ns*
Dieting status × self-reported dieting success	−.42	−2.82	<.01
Step 2			
Dieting status	−.13	−.79	*ns*
Self-reported dieting success	−.11	−.57	*ns*
Dieting status × self-reported dieting success	−.31	−1.98	<.06
BMI	.08	.41	*ns*
Smoking status	−.11	−.66	*ns*
Alcohol consumption	.35	2.34	<.05
Exercise	−.17	−1.05	*ns*

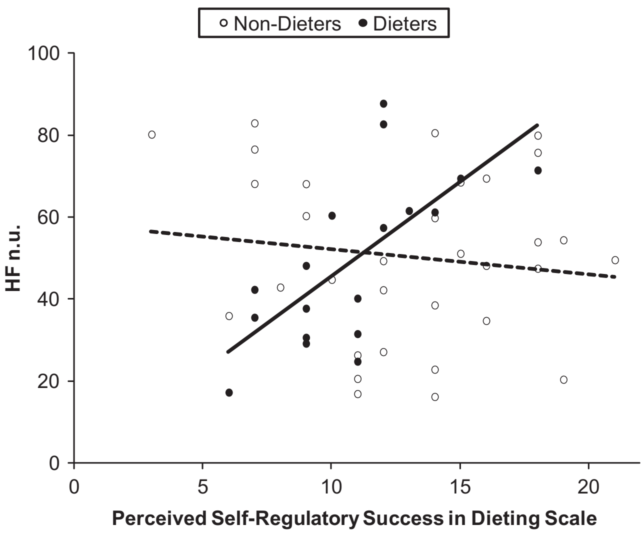

Fig. 1. Association between self-reported dieting success and vagal-cardiac control as a function of dieting status. A linear relationship between variables exists in dieters (continuous line, r = .68, p < .01), but not in non-dieters (dashed line, r = −.13, *ns*). HF n.u. = high frequency power in normalized units.

with those who are currently dieting. An implication of the current study is that future investigations using this scale should consider that the PSRS might be useful only in combination with further questions that identify those who report going on diets to control their weight in the past. With regard to physical activity, we would argue that validity of our one-item measure is provided by its positive correlation with vagal-cardiac control in the present study. Thirdly, although we included several possible physiological moderators of cardiac autonomic regulation, we did not measure actual nutritional status. Previous studies using blood sampling showed that current fasting affects cardiac autonomic regulation (e.g. Vögele et al., 2009). Furthermore, it has been shown that vagal activity is associated with feelings of hunger after short term food deprivation (Herbert et al., 2012). However, it is unlikely that current nutritional deficits in successful dieters contributed to higher vagal-cardiac control because hours that elapsed since the last meal and hunger were not associated with self-reported dieting success or cardiac autonomic regulation and did not differ between dieters and non-dieters. Moreover, we measured heart beat intervals on two occasions, thereby providing a more stable indicator of cardiac autonomic regulation and minimizing bias by current food deprivation. Finally, we did not measure respiration which could potentially have influenced cardiac autonomic regulation. Correcting HRV for respiration, however, is a heavily debated issue and it has also been noted that controlling for respiration effects in HRV indices may not be necessary or even unfavorable because mechanisms of the respiratory and cardiovascular system are tightly intertwined (Thayer, Loerbroks, & Sternberg, 2011).

Bearing these limitations in mind, a practical implication of our findings is that increasing vagal-cardiac control and balancing sympathovagal interactions might influence eating behavior positively. A useful technique to train cardiac autonomic regulation is HRV-biofeedback (Lehrer, Vaschillo, & Vaschillo, 2000). This method has already been found to reduce psychopathological symptoms in several psychiatric diseases, such as depression or post-traumatic stress disorder (Wheat & Larkin, 2010). In a pilot study, we found that HRV-biofeedback training reduced self-reported food cravings and eating and weight concerns in food cravers (Meule, Freund, Skirde, Vögele, & Kübler, in press). Although these results are preliminary and the exact mediating effects need to be further investigated, Rodríguez-Ruiz et al. (2009) have suggested that HRV-biofeedback might help individuals to learn self- and emotion regulation skills. Future studies should investigate whether HRV-biofeedback training can be used as an adjunct therapy in patients with eating disorders to reduce binge eating or in patients with obesity to enhance weight loss.

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