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High frequency heart rate variability: Evidence for a transdiagnostic association with suicide ideation

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ABSTRACT

Low levels of high frequency heart rate variability (HF-HRV) have been shown to be associated with suicidal ideation and behavior in students and depressed patients. The goal of the present study was to examine associations between suicide ideation and resting HF-HRV as well as HF-HRV reactivity in a diagnostically heterogeneous sample of adult outpatients with or without concurrent suicide ideation. Participants were $N = 85$ outpatients (67.1% female; age: $M = 38.8$, $SD = 13.72$). HF-HRV reactivity was assessed using a sad film induction method. Associations between resting HF-HRV, HF-HRV reactivity and suicide ideation were analyzed using linear regression modeling – controlling for depression, anxiety and stress. HF-HRV reactivity towards the sad film, but not low resting HF-HRV baseline, was predictive of higher scores on suicidal ideation within the whole sample. In women, lower resting as well as perturbed HF-HRV reactivity was associated with higher scores on suicidal ideation. Results suggest that suicide ideators have a reduced capacity to regulate their response to stress.

1. Introduction

High frequency-heart rate variability (HF-HRV) is a marker of vagal tone and has been conceptualized as a transdiagnostic biomarker of self-regulation, cognitive control and psychopathology in general (Beauchaine & Thayer, 2015; Beauchaine, 2015). On a neuronal level, HF-HRV indexes activity within a cortico-limbic control system, enabling the flexible regulation of cardiac output, a mechanism putatively disturbed in psychopathology (Thayer, Hansen, Saus-Rose, & Johnson, 2009). There is evidence that HF-HRV is correlated with prefrontal cortex activity and performance on executive function tasks (Thayer et al., 2009), reflecting its influence on cognitive control capacity. Importantly, low resting HF-HRV (rHF-HRV) and large reductions in HF-HRV in response to emotional stressors, are associated with symptoms of both internalizing and externalizing psychopathology (Beauchaine, 2015; Thayer et al., 2009). Thus, high HF-HRV reflects activity of a healthy regulation system that is able to respond quickly to environmental demands, whereas a low HF-HRV is an indicator of autonomic and cognitive inflexibility broadly associated with general psychopathology.

Interestingly, besides other facets of psychopathology, also suicidal ideation shows marked associations with vagally mediated cardiovascular functioning. For example, studies found that students with lifetime suicide ideation (Forkmann et al., 2016) as well as patients suffering from major depression or a lifetime history of major depression with suicide ideation (Chang, Tzeng, Kao, Yeh, & Chang, 2017; Rottenberg, Wilhelm, Gross, & Gotlib, 2002; Wilson et al., 2016) exhibited lower rHF-HRV than non-suicidal controls. Another study found differences in resting respiratory sinus arrhytmia, which is indexed by rHF-HRV, in a diagnostically heterogenous sample of women with and without a lifetime history of suicide attempts (Tsypes et al., 2017). These results point to the possibility that reduced cognitive control capacity indicated by HF-HRV constitutes a risk factor for suicide ideation and behavior.

Most studies by now have focused on differences in rHF-HRV between participants with or without suicide ideation or behaviour, whereas HF-HRV reactivity (ΔHF-HRV), that is, the response to environmental demands, has rarely been studied in suicidal individuals. This is surprising, as it has been shown that both rHF-HRV, as well as ΔHF-HRV contribute uniquely to physical, as well as mental health outcomes (e.g., Salomon, 2005; Yaroslavsky, Rottenberg, & Kovacs, 2014). Porges (1995) proposes within the Polyvagal Theory, that the vagal pathway works to “brake” energy-expenditure, whenever there are no demanding environmental conditions. However, this vagal brake can be withdrawn when environmental conditions become more demanding (vagal withdrawal). The functionality of this mechanism is

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thought to be highly adaptive (Rottenberg, 2007). Consistent with this formulation, greater ΔHF-HRV (i.e., lower HF-HRV during a stressor as compared to the resting baseline recording, indicating larger vagal withdrawal towards the stressor) is associated with lowered psychopathology (e.g., Rottenberg, Salomon, Gross, & Gotlib, 2005; Yaroslavsky, Rottenberg, & Kovacs, 2013). With regard to suicidal individuals, Wilson et al. (2016) found blunted ΔHF-HRV during a laboratory stress-induction task in depressed women with a lifetime history of suicide attempts versus those without a lifetime history of suicide attempts.

So far, most studies on HF-HRV and suicide ideation/suicide attempts have solely focused on samples of healthy controls or patients suffering from major depressive disorders. Indeed, this approach is problematic because it fails to identify risk factors that are common across disorders. This problem could be addressed by considering diagnostically heterogeneous samples (for a comparable line of arguments see Tsypes et al., 2017). As outlined above, both general psychopathology as well as suicide ideation show largely overlapping associations with HF-HRV. Moreover, deficits in executive functioning, including cognitive control, cognitive flexibility, or emotion regulation are associated with most forms of psychopathology (see reviews in Aldao, Nolen-Hoeksema, & Schweizer, 2010; Snyder, Miyake, & Hankin, 2015) as well as with suicide ideation (Westheide et al., 2008; Marzuk, Hartwell, Leon, & Portera, 2005; Miranda, Gallagher, Bauchner, Vaysman, & Morroquin, 2012; Rajappa, Gallagher, & Miranda, 2012; Neasciu, Fang, Rodriguez, & Rosenthal, 2018). Taken together, this suggests that cognitive impairment, as indexed by low HF-HRV, might be a superordinate risk factor for both general psychopathology (see Beauchaine & Thayer, 2015) as well as suicide ideation. Previous work has shown that the association between executive functions and suicide ideation/ behavior is independent of current symptomatology (Bredemeier & Miller, 2015; Richard-Devantory, Berlim, & Jollant, 2014). It is thus likely that low HF-HRV, as an index of executive functioning, is of transdiagnostic relevance for suicide ideation.

Thus, seeking to both replicate and extend previous research, the first aim of the present study was to investigate the usefulness of HF-HRV as a biomarker for suicidal ideation in an unselected, diagnostically heterogeneous patient sample including men and women. In line with previous research, we predicted that regardless of mental disorder, suicidal ideation should be associated with lower rHF-HRV. Moreover, if HF-HRV constitutes a transdiagnostically relevant biomarker for suicidal ideation, this effect should be independent of current symptomatology. Therefore, we aimed to test for the unique contribution of rHF-HRV to suicide ideation by controlling for current depression, anxiety, and general distress.

The second aim of the present study was to investigate the association between ΔHF-HRV and suicide ideation. Therefore, participants were shown a sadness-inducing film clip, a task that has previously been shown to successfully induce ΔHF-HRV in depression- (Rottenberg et al., 2005) and emotion-research (Kreibig, 2010). In line with the literature, we hypothesized that enhanced suicidal ideation is predictive of blunted ΔHF-HRV in response to a sad film.

Finally, in an exploratory set of analyses, we assessed the usefulness of combining indices of rHF-HRV and ΔHF-HRV to assess differences in suicidal ideation. Indeed, rHF-HRV and ΔHF-HRV have been shown to contribute uniquely to psychopathology (Yaroslavsky et al., 2014). Moreover, first evidence shows that a combination of ΔHF-HRV and resting rHF-HRV lead to a better prediction of depression risk than either factor alone, and that patients with a combination of low rHF-HRV and blunted ΔHF-HRV towards a sad movie showed more severe symptoms of depression than patients showing a rather normative HF-HRV pattern with high rHF-HRV and large ΔHF-HRV toward the movie (i.e., see Yaroslavsky et al., 2013, 2014). Within the present work, we aimed to determine whether these combined indices are also useful in research on suicide ideation.

2. Method

2.1. Participants

Participants in this study were individuals starting treatment at an outpatient university clinic in Bochum, Germany. All patients were informed that the clinic regularly conducts research and provided informed consent prior to participation. In order to assure a standard of quality, all clients seeking help at the clinic are asked to fill out questionnaires and take part in a short laboratory assessment (see below) prior to their intake. No compensation is given to participants for doing so. This study-design was reviewed and approved by the local Ethics Committee.

A total of N = 190 (n = 74 male) patients, aged 18–73 (M = 37.0, SD = 13.4) took part in the laboratory assessment. Of those, n = 85 answered questions on suicide ideation and were included in the current analyses. Patients who took part in the suicide ideation assessment did not differ from non-participating individuals in age, $t_{(188)} = 1.70$, n.s., sex, $\chi^2_{(1)} = 2.50$, n.s., diagnosis, $\chi^2_{(1)} = 0.54$, n.s., as well as their scores on the DASS depression, $t_{(186)} = 1.24$, n.s., anxiety $t_{(188)} = 1.00$, n.s., and stress subscales, $t_{(186)} = 1.57$, n.s. Due to equipment failure ECG data were lost for two of these N = 85 participants.

Fifty-seven participants (67.1%) of those who took part in the risk screening were female, 28 participants (32.9%) were male. Ages ranged from 19 to 66, with an average age of $M = 38.8$ ($SD = 13.72$). The most common diagnoses were affective disorders (43.5%), as well as neurotic, stress-related and somatoform disorders (38.8%), followed by behavioral syndromes associated with physiological disturbances and physical factors (9.4%), personality disorders (5.9%) and other disorders (2.4%). All diagnosis were derived by Masters-level clinicians via a semistructured clinical interview (Diagnostisches Interview Psychischer Störungen, DIPS; Schneider & Margraf, 2006). All participants were Caucasian. As in previous studies within the outpatient clinic (Teismann et al., 2018; Teismann, Glaesmer, von Brachel, Siegmann, & Forkmann, 2017), approximately half of the sample (51.8%; $n = 44$) reported some level of suicide ideation (i.e., DSISS scores > 0) within the last two weeks. Suicide ideators did not differ from non-ideators, regarding age, $t(83) = -1.24$, $p = .218$, and sex, $\chi^2 = 0.05$, df = 1, $p = .815$. However, suicide ideators and non-ideators differed in primary diagnosis, $\chi^2 = 8.124$, df = 1, $p = .004$: suicide ideators suffered more often from a depressive disorder (59.1% vs. 26.8%), whereas non-ideators suffered more often from an anxiety disorder (53.7% vs. 22.7%).

All participants received therapeutic help. Therefore, participants were informed to turn to the respective therapist in charge in case of suicidal thoughts or impulses.

2.2. Measures

2.2.1. Depressive symptom inventory – suicidality subscale (DSI-SS; Joiner, Pfaff, & Acres, 2002)

The DSI-SS is a 4-item self-report questionnaire designed to assess the frequency and intensity of suicidal ideation and impulses in the past two weeks ("I am having thoughts about suicide and have formulated a definite plan"; "I always have thoughts of killing myself"; "In some situations I have impulses to kill myself"; "I am having thoughts about suicide and I am considering possible ways of doing it"). Scores on each item range from 0 to 3, with higher scores indicating greater severity of suicidal ideation. The first validation study of the German version of the DSI-SS (Von Glischinski, Teismann, Prinz, Gebauer, & Hirschfeld, 2016) found good internal consistency (Cronbachs $\alpha = .90$) for the scale. In accordance, internal consistency was good in the current sample, $\alpha = .93$.

2.2.2. Depression-anxiety-stress scales 21 (DASS; Henry & Crawford, 2005)

The DASS is a 21-item self-report measure, which showed excellent psychometric properties in its validation study (Henry & Crawford, 2005). Participants are asked to indicate to what extent the seven statements on depressive symptoms (DASS-D; e.g., "I just couldn't seem to get going."), anxiety (DASS-A; e.g." I felt I was close to panic.") and stress (DASS-S; e.g. "I found it hard to wind down.") applied to them over the past week (0 = *did not apply to me at all*; 3 = *applied to me very much or most of the time*). Internal consistency in the current sample were α = .93, α = .86, α = .88 for the DASS-D, DASS-A and DASS-S, respectively.

2.3. Emotion film stimuli and subjective ratings

Each participant saw one of two short clips taken from two famous motion pictures (The Champ, 2:38 min, MGM, United Artists film studios, 1979; My sister's keeper, 3:36 min, Warner Bros, Paramount, 2009). Each clip shows an actor watching a beloved person dying. The clips were chosen because they have been shown to reliably elicit sadness in previous research (e.g., Gross & Levenson, 1995). After watching the movie, each participant was asked to indicate on a visual analogue scale (0 = not at all, 100 = very much) how intensely he felt each of the six basic emotions (happiness, surprise, anger, disgust, fear, sadness) while watching the film. In the current study, the films did not differ in terms of sadness ratings, $t(82) = 0.45$, p = .657, or ΔHF-HRV, $t(80) = 0.13$, p = .897. Thus, both film clips were highly similar in their sadness elicitation potency.

2.4. Physiological assessment

A lead II ECG was recorded with a sampling rate of 1000 Hz using disposable Ag/AgCl electrodes attached to the right calvicle and the lowest rib within the axilliar line. A ground electrode was attached to the participtant's forehead. ECG data were digitized with 16 bit using a Biopac MP100 system with ECG100 preamp. Online, a 50 Hz notch filter was applied to the data. Offline, ECG data were bandpass filtered (5–35 Hz, 24 dB/oct), and ectopic heartbeats, as well as measurement artifacts were corrected. After trend-removal, Interbeat interval data were processed through an end-tapered Hamming Window and fast fourier transform was applied to the data. HF-HRV was extracted as the natural logarithm of mean power within the frequency band between 0.15-0.40 Hz (Laborde, Mosley, & Thayer, 2017). All HF-HRV parametrization was done using Kubios HF-HRV (version, 2.1).

2.5. Procedure

Upon arrival at the laboratory, participants were seated in a recliner in a dimly lit room. Then, electrodes were attached and participants were instructed to sit quietly for 3 min in order to accomplish the baseline HRV measurement. Then, after participants were instructed to watch the film clips carefully, emotion induction began. After the films ended, all participants participated in a conditioning experiment, an emotion regulation procedure, and an approach avoidance task (reported elsewhere).

2.6. Data analyses

We used mixed model ANOVA to test for the relationship between suicide ideation and rHF-HRV/ ΔHF-HRV. Because sex is known to influence HF-HRV (e.g., Huikuri et al., 1996), we included it as a between subject factor (SEX, i.e., male, female). We further included suicide ideation (SI) as a continuous between-subject factor, and experimental phase (PHASE, i.e., resting baseline, sad movie) as a within subject factor. With this approach, we avoid dichotomization of the questionnaire data, which typically reduces statistical power and most likely result in artificial groups that distort the underlying continuous relationship. If suicide ideation would influence both rHF-HRV and ΔHF-HRV towards the sad movie, this should result in a significant interaction of SI x Phase. This interaction was followed-up with simple regression analysis, including SI as the dependent variable, as well as HF-HRV during baseline (rHF-HRV) and ΔHF-HRV (i.e. **Δ**HF-HRV = Sad Film-Baseline) as predictors. To check whether the association between HF-HRV and suicide ideation is dependent of current psychopathology, we controlled for current anxiety, depression and stress (i.e. the DASS scales) in a second set of regression analyses. Finally, we controlled for possible confounds that may have affected the HRV-measurement. Thus besides depression, anxiety and stress, we also entered psychotropic medication use, weekly amount of alcohol and daily amount of nicotine consumption as predictors in the regression analyses.

To test whether the film clips elicited sadness, we calculated a mixed model ANOVA with the within subject factor Basic Emotion Rating (i.e., Happiness, Sadness, Disgust, Anger, Fearfulness, Surprise) and Sex (i.e., male female) and suicide ideation as a continuous between subject factor (SI). Significant main effects and interactions were followed up with planned contrasts, *t*-Tests and simple regressions.

In a set of exploratory analyses, we assessed the usefulness of combining ΔHF-HRV and rHF-HRV to assess suicidality. We used an approach highly similar to previous research (for details see Yaroslavsky et al., 2014). In brief, resting vagal reactivity was centered at its median to determine groups with high versus low resting vagal tone, while ΔHF-HRV above and below zero represents vagal withdrawal and augmentation, respectively. The categories were combined into four HF-HRV patterns: high rHF-HRV/ vagal withdrawal (N = 20); low rHF-HRV/ vagal withdrawal (N = 15); high rHF-HRV/ vagal augmentation (N = 22); and low rHF-HRV/ vagal augmentation (N = 26). We then tested whether suicide ideation scores differed between the four groups using univariate analysis of variance. We calculated Cohen's effect size *f* for all ANOVA effects, and R^2 for follow-up regression analysis. The alpha level was set to .05. All analyses were conducted using SPSS (Version 24, IBM corporation).

3. Results

3.1. Questionnaire data

Zero order correlations showed that higher suicidal ideation was significantly associated with higher scores on the depression, $r = .466$, $p < .001$, anxiety, $r = .302$, $p = .005$, and stress subscale of the DASS, $r = .339$, $p = .002$. As expected, DASS scales were significantly intercorrelated. Higher scores on the depression subscale were associated with higher scores on both the anxiety, $r = .582$, $p < .001$, and stress, $r = .649$, $p < .001$, subscale. Also, the anxiety and the stress subscale showed a significant positive association, $r = .506$, $p < .001$.

3.2. Film rating

Table 1 shows descriptive statistics of subjective intensity ratings of the six basic emotions in response to the sad movie. The ANOVA revealed a significant main effect for basic emotion, $F(5,410) = 51.34$, $p < .001$, $f = 0.79$. As expected, planned contrasts showed that the predominant emotion elicited by the movies was sadness, as such sadness was rated as significantly more intense than any other basic emotion: happiness, $F(1,83) = 253.21$, $p < .001$, fearfulness, $F(1,83) = 137.05$, $p < .001$, anger, $F(1,83) = 72.46$, $p < .001$, disgust, $F(1,83) = 210.67$, $p < .001$, and surprise, $F(1,83) = 155.68$, $p < .001$. Basic emotion ratings were different for men and women, $F(5,410) = 2.42$, $p = .043$, $f = 0.17$ (interaction of basic emotion x sex). Follow up *t*-tests showed that men felt slightly more anger in response to the sad movie, as compared to women, $t(83) = 2.38$, $p = .020$. Men and women did not differ in ratings of sadness, happiness, disgust,

Table 1
Means and standard deviation of subjective intensity ratings for the six basic emotions in response to the sad movie.

	male		female		
	M	*SD*	*M*	*SD*	*t*(83)
Sadness	71.39	24.16	79.42	25.40	1.39 $^{n.s}$
Happiness	13.11	20.89	9.02	17.49	0.95 $^{n.s}$.
Fearfulness	34.11	32.48	32.82	33.34	0.16 $^{n.s}$
Anger	42.79	38.43	24.54	30.44	2.38 *
Disgust	18.14	25.22	17.09	26.51	0.18 $^{n.s}$
Surprise	29.04	31.10	16.53	26.52	1.93 $^{n.s}$

Note ***$p < .001$, *$p < .05$, *n.s.* $p > .05$.

fearfulness, and surprise (see Table 1). The interaction of basic emotion by suicide ideation was significant at trend level, $F(5, 410) = 2.25$, $p = .057$, $f = 0.17$. Simple follow-up regression revealed that higher scores on suicide ideation were related to lower subjective experience of sadness in response to the movie, $F(1,84) = 8.69$, $p = .004$, $R^2 = .095$, beta = -.308, $p = .004$. After controlling for depression, anxiety and stress, this association was still significant at trend level, $F(1,83) = 6.79$, $p = .002$, $R^2 = .030$, beta = -.203, $p = .082$. There were no associations between suicide ideation and other basic emotion ratings.

3.3. HF-HRV

The ANOVA results show that in general, rHF-HRV was larger for women, as compared to men, $F(1,81) = 5.04$, $p = .027$ (main effect for sex). Furthermore, rHF-HRV was larger at rest, as compared to watching a sad movie, $F(1,81) = 5.97$, $p = .017$, $f = 0.27$ (main effect for phase). Finally, rHF-HRV varied between baseline and watching the sad movie as a function of suicide ideation, $F(1,81) = 7.36$, $p = .008$, $f = 0.30$[1] (interaction suicide ideation by phase). The interaction phase by sex was not significant, $F(1,81) = 1.60$, $p = .21$, $f = 0.13$.

Follow-up simple regression indicates that blunted **Δ**HF-HRV towards the sad film, $F(1,82) = 7.38$, $p = .008$, $R^2 = .084$, $\beta = .289$, $p = .008$, but not low rHF-HRV baseline, $F(1,83) = 2.60$, $p = .110$, $R^2 = .031$, $\beta = -.175$, $p = .110$, was predictive of higher scores on suicidal ideation within the whole sample. The association between ΔHF-HRV and suicidal ideation was independent of current symptoms of anxiety, depression and general distress ($\beta = .228$, $p = .023$, see Table 2), as well as psychotropic medication, nicotine, and alcohol consumption ($\beta = .208$, $p = .040$, Table 2).

Due to the significant overall differences between men and women in HF-HRV, separate follow-up regression analyses for both sexes appeared reasonable. Unfortunately, the low number of men ($n = 28$) made it impossible to conduct meaningful analysis with a male-only sample. In women, however, lower rHF-HRV, $F(1,55) = 6.53$, $p = .013$, $R^2 = .108$, $\beta = .328$, $p = .013$, as well as perturbed **Δ**HF-HRV towards the sad movie, $F(1,54) = 5.28$, $p = .026$, $R^2 = .091$, $\beta = .301$, $p = .026$, was associated with higher scores on suicidal ideation. Again, these associations were independent of depression, anxiety, and general distress (i.e., rHF-HRV with suicide ideation: $\beta = -.313$, $p = .012$, **Δ**HF-HRV with suicide ideation: $\beta = .250$, $p = .043$; see also Tables 3 and 4), as well as psychotropic medication, nicotine and alcohol consumption (rHF-HRV with suicide ideation: $\beta = -.278$, $p = .013$, **Δ**HF-HRV with suicide ideation: $\beta = .229$, $p = .062$, see also Tables 3 and 4).

3.4. Combining rHF-HRV and ΔHF-HRV

Univariate ANOVA indicates that suicide ideation scores varied as a

[1] Post hoc calculations of achieved test power revealed that for the given effect size of $f = 0.3$ the achieved power for this interaction was *1-β = .77*.

Table 2
Regression analysis of current symptoms of anxiety, depression and stress, as well as ΔHF-HRV predicting suicide ideation.

	Predictor	β	Delta R^2	$F_{(df)}$
Step 1			.220	$7.35_{(3, 78)}$***
	Depression	.410**		
	Anxiety	.035$^{n.s.}$		
	Stress	.055 $^{n.s}$		
Step 2			.051	$7.16_{(4, 77)}$***
	Depression	.393***		
	Anxiety	.017$^{n.s}$		
	Stress	.050$^{n.s.}$		
	ΔHF-HRV	.228*		
Step 3			.035	$4.65_{(7, 74)}$***
	Depression	.402***		
	Anxiety	−.001$^{n.s}$		
	Stress	.075$^{n.s.}$		
	ΔHF-HRV	.208*		
	Nicotine Consumption	.144$^{n.s.}$		
	Alcohol Consumption	−.034$^{n.s.}$		
	Psychotropic Medication	.104$^{n.s.}$		

Note ***$p < .001$, *$p < .05$, *n.s.* $p > .10$.

Table 3
Regression analysis of current symptoms of anxiety, depression and stress, as well as rHF-HRV predicting suicide ideation (female participants only).

	Predictor	β (p)	Delta R^2	$F_{(df)}$
Step 1			.250	$5.67_{(3, 51)}$**
	Depression	.446*		
	Anxiety	.061 $^{n.s.}$		
	Stress	.019 $^{n.s.}$		
Step 2			.090	$6.44_{(4, 50)}$***
	Depression	.495**		
	Anxiety	.059 $^{n.s.}$		
	Stress	.034 $^{n.s.}$		
	rHF-HRV	−.313*		
Step 3			.056	$4.41_{(7, 47)}$**
	Depression	.566***		
	Anxiety	−.075$^{n.s}$		
	Stress	.005$^{n.s.}$		
	rHF-HRV	−.278*		
	Nicotine Consumption	.228^{+}		
	Alcohol Consumption	.077$^{n.s.}$		
	Psychotropic Medication	.043$^{n.s.}$		

Note ***$p < .001$, *$p < .05$, +p < .10, *n.s.* $p > .10$.

Table 4
Regression analysis of current symptoms of anxiety, depression and stress, as well as ΔHF-HRV predicting suicide ideation (female participants only).

	Predictor	β	Delta R^2	$F_{(df)}$
Step 1			.250	$5.56_{(3, 54)}$**
	Depression	.446*		
	Anxiety	.061$^{n.s.}$		
	Stress	.019$^{n.s.}$		
Step 2			.061	$5.53_{(4, 49)}$**
	Depression	.451*		
	Anxiety	.015 $^{n.s.}$		
	Stress	.017 $^{n.s.}$		
	Δ HF-HRV	.250*		
Step 3			.072	$4.08_{(7, 46)}$**
	Depression	.528*		
	Anxiety	−.028 $^{n.s.}$		
	Stress	.010 $^{n.s.}$		
	Δ HF-HRV	.229^{+}		
	Nicotine Consumption	.195$^{n.s.}$		
	Alcohol Consumption	.108$^{n.s.}$		
	Psychotropic Medication	.133$^{n.s.}$		

Note ***p < .001, *p < .05, $^{+}$p < .10, n.s. p > .10.

function of HF-HRV pattern, $F(3, 83) = 3.18$, $p = .028$, $f = 0.35$. Polynomial contrast analysis revealed a significant linear trend ($p = .005$; i.e. high rHF-HRV/ vagal withdrawal, $M = 0.64$, $SD = 1.23$ < low rHF-HRV/ vagal withdrawal, $M = 1.73$, $SD = 1.98$ < high rHF-HRV/ vagal augmentation $M = 1.93$, $SD = 2.81$ < and low rHF-HRV/ vagal augmentation, $M = 2.55$, $SD = 2.58$). The quadratic trend, however, was not significant ($p = .633$).[2]

4. Discussion

The aim of the present study was to examine the association between suicide ideation and rHF-HRV and ΔHF-HRV in a patient sample suffering from a variety of mental disorders. We found that blunted ΔHF-HRV (indicating blunted vagal withdrawal) towards a sad mood induction significantly predicted higher levels of suicide ideation, even after controlling for current symptoms of depression, anxiety and stress. Thus, the current study provides evidence for a transdiagnostic association of low vagal control and suicide ideation. In addition, we found that a pattern of low rHF-HRV (i.e., as indicated by low vagal tone) and blunted ΔHF-HRV (i.e., blunted vagal withdrawal) was associated with higher scores on suicide ideation, while a normative pattern of high rHF-HRV (i.e., high vagal tone) and greater ΔHF-HRV (i.e., greater vagal withdrawal) was associated with low scores on suicide ideation. In women only, also lower rHF-HRV alone predicted higher levels of suicide ideation.

In sum, the current findings complement previous results showing an association between low vagal tone and suicide ideation in healthy controls (Forkmann et al., 2016) and in depressed patients (Chang et al., 2017; Rottenberg et al., 2002). In addition to vagal tone, and blunted vagal reactivity (cf. Wilson et al., 2016), we found that patients with an atypical response pattern of low vagal tone and blunted vagal reactivity (i.e., Yaroslavsky et al., 2013, 2014) showed higher levels of suicide ideation than patients with a normative pattern of high vagal tone and vagal withdrawal towards the sad mood induction. This finding was also substantiated through a significant prediction of suicide ideation with the interaction of rHF-HRV and ΔHf-HRV. Thus, it is likely that resting vagal tone interacts with vagal reactivity to predict suicide ideation. It was shown that this normative HRV response pattern is protective against symptoms of internalizing disorders (Hinnant & El-Sheikh, 2009) and promotes positive affect within stressful situations (Cribbet, Williams, Gunn, & Rau, 2011). High vagal tone is associated with executive control and enhanced emotion regulation abilities (Hansen, Johnsen, & Thayer, 2003; Thayer & Lane, 2000) and vagal withdrawal is the normative response towards a sad mood induction (Kreibig, 2010). Thus, it has been argued that a pattern of vagal withdrawal and high vagal tone promote appropriate adaptation to changing environmental demands (Yaroslavsky et al., 2013). To the extent that this pattern is disturbed in patients with high levels of suicide ideation, suicidality is associated with a dysregulation within this adaptation system. These results extend previous work showing the same disturbed pattern to be predictive of depression symptoms and depression risk (Yaroslavsky et al., 2013, 2014). To our knowledge, this study is among the first to study dynamic changes in vagal tone in suicide ideators. Importantly, associations were found in a diagnostically heterogeneous sample, and independent of current symptoms of depression, anxiety and stress. These results point to the possibility that low vagal tone and reactivity may be transdiagnostically associated with suicide risk and are in line with a recent study by Tsypes et al. (2017) in which women with diverse diagnoses and a history of suicide attempts were shown to exhibit significantly lower vagal tone than women with diverse diagnoses but without a history of suicide attempts. Also, they complement epidemiological data showing that despite the fact that odds ratios are higher for depression than any other diagnosis, virtually every mental disorder increases the risk of suicidality (Kessler, Borges, & Walters, 1999). Moreover, HRV has been argued to be a transdiagnostic biomarker of mental disorders (Beauchaine & Thayer, 2015), and in the same vein, is associated with determinants of suicidal behavior, for example rumination (Morrison & O'Connor, 2008; Woody, McGeary, & Gibb, 2014), worry (Brosschot, Van Dijk, & Thayer, 2007), hopelessness (Schwarz, Schächinger, Adler, & Goetz, 2003), and executive functioning, including emotion regulation (review in Thayer et al., 2009).

Taken together, various explanations possibly hold for the current results. First, Forkmann et al. (2016) speculate that low vagal tone is a marker of cognitive inflexibility that leads patients to view their coping options within problematic situations „in "black or white" terms, seeing suicide as the only way to escape an unbearable life "(p. 30). Second, low vagal tone may prolong negative emotions via perturbed emotion regulation skills (Butler, Wilhelm, & Gross, 2006; Gentzler, Santucci, Kovacs, & Fox, 2009; review in Appelhans & Luecken, 2006), which in turn may promote suicide ideation (Husky et al., 2017). Finally, there is evidence that low vagal tone is associated with difficulties in emotion regulation and impulse control (Beauchaine, 2015; Wilson et al., 2016) – both being associated with suicidal behavior (e.g., Dumais et al., 2005). Looking to a clinical implication of the present findings, recent research has demonstrated that experiencing positive emotions may enhance adaptive coping, as indicated by increases in resting and ambulatory HRV (Schwerdtfeger & Gerteis, 2014). The importance of positive affect has also been highlighted in the treatment of suicidal adults. As such, Joiner et al. (2001) found that patients prone to positive moods, as compared with those less prone to such moods, displayed more positive problem-solving attitudes following treatment for suicidal symptoms, and partly as a function thereof, displayed enhanced treatment response. Therefore, the promotion of positive affectivity within therapy sessions with suicidal individuals constitutes a therapeutic imperative (Willutzki & Teismann, 2013).

One of the strengths of the present study lies in the heterogeneity of the investigated sample, as well as in the assessment of resting vagal tone and vagal reactivity. Nonetheless, some limitations have to be considered when interpreting the current results. First, due to the cross-sectional design of the present study, no causal conclusions can be drawn. Future research is warranted to determine whether low rHF-HRV and ΔHF-HRV prospectively predicts suicide ideation as well as suicide attempts. Second, we did not investigate potential mechanisms explaining the association between low rHF-HRV as well as ΔHF-HRV and suicide ideation. Wilson et al. (2016) found increased anger in response to a stress challenge to be associated with a blunted ΔHF-HRV and lifetime suicide attempts. Further variables of potential interest are ruminative responses, as well as impulsive action tendencies. Future studies should also make use of formal mediation testing. Third, we only assessed suicide ideation using a 4-item measure (DSISS), covering suicide ideation within the last two weeks. For future studies, a more comprehensive assessment of suicide related outcomes could be useful (e.g., via the Self-Injurious Thoughts and Behaviors Interview, SITBI, Nock, Holmberg, Photos, & Michel, 2007). Fourth, participants in the current study were not requested to abstain from alcohol, nicotine or caffeine consumption prior to participating. Thus, we cannot entirely rule out acute effects of these variables on our HRV measures. However, evidence suggests that the effect of moderate acute caffeine (Rauh, Burkert, Siepmann, & Mueck-Weymann, 2006; Monda et al., 2009), alcohol (Murata et al., 1994) or tobacco consumption (Hayano et al., 1990) on the high frequency component of HRV might be limited.

[2] In addition, we also calculated the interaction term between rHF-HRV and ΔHF-HRV. This interaction was entered as a predictor for suicide ideation in an additional regression analysis. We found a significant regression equation, $F(4,77) = 6.45$, $p < .001$, $R^2 = .251$. In detail, controlling for depression, $\beta = .386$, $p = .007$, anxiety, $\beta = .018$, $p = .882$, and stress, $\beta = .050$, $p = .704$ and in line with the group-based analysis, we found that the interaction between rHF-HRV and ΔHF-HRV significantly predicted suicide ideation, $\beta = .212$, $p = .037$.

Moreover, we assessed participant's habitual use of alcohol and nicotine and controlled for these possible confounds in our regression analyses. Results indicate only very limited influence of these variables. Fifth, the assessment of trait suicidal ideation was not possible with the current questionnaire. Individual characteristics of suicide ideation, as for example chronicity or recency, might affect the individual manifestations of deficits in HF-HRV. For example, rHF-HRV might be more reflective of the trait-level of suicidal ideation, whereas the ΔHF-HRV might be closer linked to the state-level of suicidal ideation (we would like to thank an anonymous reviewer for this valuable hint). Finally, the low number of men made it impossible to conduct meaningful analysis with a male-only sample. Therefore, future studies have to examine whether the present findings generalize to men. Possibly, a more sophisticated assessment of suicide ideation (i.e., trait vs. state suicide ideation) might shed light on the differential relationship between rHF-HRV and ΔHF-HRV and suicide ideation in males and females.

In sum, the present study is the first to show that concurrent suicide ideation is related to lower vagal tone and perturbed vagal withdrawal - with this association being independent from current depression, anxiety and stress. Thus, we provide further evidence for a transdiagnostic association between suicide ideation and vagal control.

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