Assessing the efficacy of an intervention aimed at increasing heart rate variability and decreasing perceived stress in individuals with personality disorders

A single case experimental design pilot study

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Abstract

Research suggests that stress plays an important role in maintaining pathology in individuals with personality disorders (PD). Individuals suffering from PD are at increased risk of exposure to stressful events. Heart Rate Variability (HRV) is a marker for stress; greater HRV corresponds to lower perception of stress and greater ability to handle stressful situations. HRV can be influenced through breathing. In this single case experimental design pilot study participants were instructed to do breathing exercises, twice every day and to measure their HRV and fill in a measure for perceived stress every morning. Five inpatients suffering from PD participated in this study. For one participant there was an increase in HRV during the intervention, corresponding to the expected effect that HRV would increase. Unexpectedly, for three participants no significant changes were found compared to their respective baselines. For three participants, increased HRV corresponded to lower perceived stress. However, one participant demonstrated a positive relationship between these variables, indicating a heterogenous and complex relationship. One participant completed no exercises. The results of this study convey the message that interventions aimed at stress reduction in individuals with PD, should be tailored carefully to individual needs.

Keywords: Personality disorder, heart rate variability, perceived stress, resonant frequency breathing

Contents

Introduction

In Western countries, a 12.6% prevalence of Personality Disorder (PD) is estimated (Volkert et al., 2018). Individuals who suffer from PD are at an elevated risk of numerous forms of severe impairment (Dixon-Gourdon et al., 2015; Paris, 2003). Considering the high incidence of PD and the risks of pathology in individuals suffering from PD, efficacious treatment should be uncovered in research. Contemporary literature suggests that stress plays a significant role in the development, severity, and prolongation of pathology in PD (White et al., 2020). Furthermore, subjective perception of stress may be elevated in this population, which may exacerbate pathology further (Glaser et al., 2008). This pilot study aims to assess an intervention aimed at the reduction of subjective stress and stress-reactivity in individuals with PD.

Personality Disorder

In the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5; American Psychiatric Association, 2013), the essential features of PD are defined as a lasting and inflexible pattern of impairment in the areas of cognition, affectivity, interpersonal functioning, and problems with impulse control. According to Millon et al. (2012) these maladaptive patterns can be recognized in the inflexibility to adapt behavior to situational needs, the tendency to repeat and intensify preexisting difficulties and a lack of resilience in facing stressful situations. The pattern of behavior imposes a clinically significant amount of suffering, or impairment in social, vocational, or other important areas of life (American Psychiatric Association, 2013). At face-value the mentioned patterns in emotion, cognition and behavior give reason to think that individuals who suffer from PD might report elevated stress. To understand the relationship between stress and PD, it might be helpful to first understand the development of these lasting patterns of impairment.

Development of Personality Disorder

The development of PD is believed to start at an early age (Young et al., 2006). Individuals develop behavior, emotions, and cognitions suitable to their respective environment, to cope with the problems and challenges they encounter. An important factor in this process, is the child's emotional temperament. Different emotional temperaments result in different individual problems and challenges in life and differences in coping with such situations. When the environment is characterized by dysfunctionality, the individual might learn coping strategies that are functional in that environment. Nonetheless, when the individual matures and the environment changes, these coping strategies may turn into maladaptive behavioral, emotional, and cognitive patterns in later life (Millon et al., 2012; Young et al., 2006). The environment partially shapes the personality of the individual and can have long-lasting effects on mental wellbeing. This implies that lasting maladaptive patterns in PD can be (partially) attributed to a dysfunctional childhood environment (Millon et al., 2012; Young et al., 2006).

Hypothetically, growing up in a dysfunctional environment might impose stress on the individual. It may be the case that increased experienced stress results in greater risk of the development of PD in later life. According to White et al. (2020), stress plays a critical role in the etiology of PD. There is a relationship between various forms of negative childhood experience and PD later in life. The most negative impact seems to stem from childhood abuse and neglect. However, there are numerous other forms of stressful experiences that predict personality disorder, such as poverty, parental relationships characterized by conflict, distant parent-child relationship, or death of (one of the) parent(s). These experiences are defined as enduring and pervasive experiences by Millon et al. (2012).

As was hypothesized, the development of PD seems to be related to the amount of stress experienced by the individual.

In addition to this relationship, individuals suffering from PD also seem to attract more stress in their lives. In the literature review of White et al. (2020), the stress generation theory by Hammen (1991) is postulated, in the light of the bidirectional relationship between stress and PD. Hammen found that certain personality features can increase the likelihood of experiencing stress. This tendency is also observed in individuals suffering from PD, meaning that these individuals will generate more stressful experiences in their life than healthy individuals (Allen et al., 2022; White et al., 2020). Such stressful experiences predict decreased psychosocial functioning (Pagano et al., 2004). Negative life-events may also be defined as stressors, to which the individual is subjected and as a result, experiences stress. Adding to this Glaser et al. (2008) found that individuals with BPD experience increased emotional reactivity to stress compared to controls. Suggesting that those suffering from PD, suffer more from stress on an emotional level, while also being exposed more to stressful situations than healthier counterparts. Consequently, the question arises how stress should be defined.

Stress

Stress can according to Selye (1976, p. 14) be defined as a "*stereotyped pattern of biochemical, functional and structural changes essentially involved in coping with any type of increased demand upon vital activity, particularly adaptation to new situations."* In this definition, stress is the bodies' reaction to demands from the environment, or so-called stressors. This stress response is needed for the individuals' survival, to adapt to the challenges life offers and to avoid dying (O'Connor et al., 2021). McEwen (1998) states the body has multiple systems to facilitate adaptation to challenges that may threaten

homeostasis. Homeostasis can be defined as the tendency of the body to maintain inner stability (Lu et al., 2021). Physiological changes are regulated mainly by the Autonomic Nervous System (ANS) and the Hypothalamic-Pituitary-Adrenal (HPA)-axis. These systems protect and adapt the individual from and to these challenges. This process of protection and adaptation is called allostasis and is essential in maintaining homeostasis, achieving stability through change (McEwen, 1998).

As mentioned, one of the systems active in the process of allostasis is the ANS. This system receives and sends information to the heart, digestive system, and other organs. The ANS exists of two parts: The Sympathetic Nervous System (SNS) and the Parasympathetic Nervous System (PNS) (Kalat, 2015). When individuals are confronted with increased demands from the environment, the SNS is increasingly activated. When the SNS is activated, the body prepares itself for action, which in severely stressful situation leads to the responses known as ‘fight, flight or freeze’. This is accomplished partly by increasing heart rate and slowing down the digestive system. The other part of the ANS, the PNS essentially facilitates the opposite of what the SNS facilitates. Its main objectives are to prepare the body for future events by conserving energy and the regulation of bodily functions like digestion (Tindle & Tadi, 2022). Both the SNS and PNS are always active, but the circumstances in which the individual finds itself, influence which system is most active (Kalat, 2015). The process of allostasis is needed for survival but can also have detrimental effects on the wellbeing of the individual. These detrimental effects are referred to as allostatic load (McEwen, 1998). Allostatic load is manifested in the excessive activation of allostatic activity and the bodies inability to end allostatic activity after a stressor has resided. Allostatic load can have numerous adverse health outcomes, both physical and psychological (Guidi et al., 2021).

The effects of allostatic load on psychological processes are substantiated by research on prior stress exposure. Individuals who were exposed to adverse life events in childhood, react more strongly to stress than those who did not experience such events during childhood (Glaser et al., 2006). This increased reactivity to stress may be explained in the light of cognitive appraisal (Tafet, 2022). When an individual perceives stressors in the environment, the individuals' focus on specific details may lead to these details descending from sensory memory into short-term memory. Processing of this information in working memory may be done in combination with retrieval of knowledge and previous experiences stored in long-term memory, to evaluate the importance of the information and if applicable, devise coping strategies. When an individual has been exposed to adverse life-events, due to the emotional relevance, these experiences are stored in long-term memory. This information then, might be retrieved explicitly or implicitly and serves a function in the appraisal of current stressors.

The theories on cognitive appraisal and stress reactivity, imply that subjective stress might be elevated for people who experienced traumatic events. Subjective stress can be cause for unpleasant emotions, but evidence suggests that individuals with increased experience of subjective stress score higher on measures of allostatic load, which is predictive of adverse health outcomes (Christensen et al., 2019; Guidi et al., 2021; Glaser et al., 2006). Besides this, the experience of subjective stress is also directly predictive of poor health outcomes (Shields et al., 2023). Therefore, it seems important to link evaluation of stress-reduction interventions to indicators of subjective stress.

From a more physiological viewpoint, Marsman et al. (2019) found that individuals who suffered adversity in childhood or adolescence, have increased physical reactivity to stress. They found the existence of a dose-response relationship, in which higher levels of adversity accounted for higher levels of physical stress reactivity. In another study Marsman

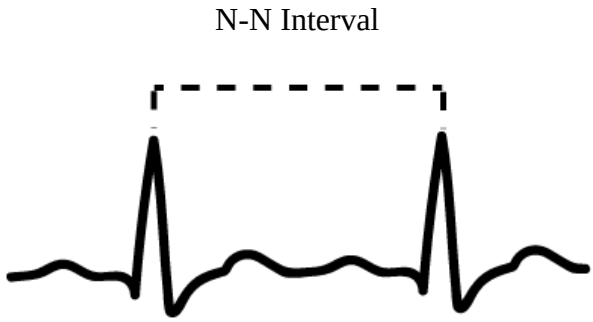
et al. (2021) found, that besides heightened reactivity to stress, physical habituation to stressors seems to decline in individuals who have been exposed to adversity in childhood. This underscores the need to address physical effects of pathology in interventions targeting trauma- and/or stress-related pathology.

Heart Rate Variability

Heart Rate Variability (HRV) can be used as an objective assessment for stress (Kim et al., 2018). Increased HRV is related to lower levels of stress and higher resilience to stress, reduced HRV corresponds to a reduced ability to react to stress and indicates that an individual might be suffering from chronic stress (Kim et al., 2018; McCraty & Shaffer, 2015). HRV is defined as the variability in length between consecutive heartbeats also known as the N-N interval, of which an example can be seen in Figure 1. It represents the hearts' ability to react when confronted with stressful situations. Meyer et al. (2016) suggest that early life adversity may account for decreased HRV, instead of separate classifications of psychopathology. Implying HRV as a transdiagnostic factor, since early life adversity is associated with different forms of psychopathology (White et al., 2020; Widom, 2000). Furthermore, The literature on HRV in individuals with PD is limited, which complicates the formation of substantiated assumptions about the nature of HRV in this population (Carr et al., 2018).

Figure 1

Example of an N-N Interval in an ECG-graph



If HRV is a reliable measure for psychological stress in the individual, it might be beneficial to influence HRV directly in individuals experiencing increased stress. This active influencing of HRV is possible, and one approach is through Resonant Frequency Breathing (RFB).

Resonant Frequency Breathing

A person's Heart Rate (HR) is modulated by respiration. The sinus node of the cardiac pacemaker, which determines heart HR, is influenced by the cardiac vagal nerve. The cardiac vagal nerve is modulated by the breath (Yasuma & Hayano, 2004). The pace of breathing influences HRV, by shortening the N-N interval during inspiration and by increasing the N-N interval during expiration. This means that changing the frequency and duration of the breath, influences HRV.

One method that might increase HRV in such a way is Resonant Frequency Breathing (RFB). The Resonant Frequency (RF) is the pace of breathing at which the heart optimally resonates with the breath. The optimal breathing frequency varies from person to person but

is normally within a range of 5-7 breaths per minute. Evidence suggests that breathing at RF increases HRV (Sevoz-Couche & Laborde, 2022; Steffen et al., 2017).

The review study by Sevoz-Couche and Laborde (2022) implies that training RFB for several weeks can decrease stress and anxiety in different populations. Increasing training duration enhances the positive effects of RFB significantly. In a biofeedback 4-week intervention targeting RFB by Zucker et al. (2009), participants reported decreased suffering from Post-Traumatic Stress Disorder (PTSD) symptom severity, and increased HRV. In this experimental study, participants were asked to adhere to 20 minutes of RFB daily, with the use of a biofeedback device.

Research Questions

To summarize, individuals who suffer from PD are more likely to have suffered childhood adversity and as a result, may experience increased reactivity to stress. Individuals suffering from PD, are more prone to have experienced recent negative life events. Such events have a negative influence on psychological functioning and individuals with PD, seem to perceive stress as more severe than healthy individuals. Greater reactivity to stressors indicates increased psychopathology and severeness of the disorder. This implies that interventions aimed at stress-reduction might be advantageous in reduction of PD symptomatology and severity. When stress and perceived stress can be decreased by intervention, this might then reduce symptomatology of PD. Stress can be measured objectively using HRV and perceived stress can be measured subjectively. RFB interventions can be deployed to increase HRV and decrease perceived stress. This suggests that perception of stress and physical stress reactivity might be decreased in individuals who exercise breathing at their RF.

The current research aims to answer two research questions. The first question to be answered is: “Does a 5-week intervention aimed at improving Resonant Frequency Breathing increase Heart Rate Variability and reduce subjective stress in patients with personality disorders?”. To answer the first question two hypotheses will be tested. The first hypothesis to be tested is: “A 5-week intervention to improve Resonant Frequency Breathing is associated with an increased Heart Rate Variability in patients with Personality Disorder.” The second hypothesis to be tested is: “A 5-week intervention to improve Resonant Frequency Breathing is associated with decreased subjective stress in patients with personality disorder.” The second research question is: Is Heart Rate Variability associated with subjective stress in patients with personality disorder? This research question will be answered by testing the third and last hypothesis: “Increased Heart Rate Variability is related to a decrease in perceived stress in patients with personality disorder.”

Methodology

Ethics Statement

The current study was approved by the committee for scientific research from Mediant, as well as the BMS ethics committee of University Twente (case number: 221028).

Study Design

In this study, a Single Case Experimental Design (SCED) was used, in combined with the use of Experience Sampling Methodology (ESM), in the form of a ‘beginning-of-day’ diary study. In SCED participants provide their own baseline, to facilitate within-subject comparison. The goal of SCED is to assess if a relationship exists between a manipulated independent variable and a change in the dependent variable (Smith, 2012). The goal of ESM is to provide participant data in daily life as opposed to experimental design, in which participants are assessed in a controlled environment (Myin-Germeys & Kuppens, 2021).

This study used an event-contingent design, in which participant were asked to fill in the measures directly after waking up. The duration of this study encompassed 40 days. The first 4 days served as a baseline-measurement for two independent variables: HRV and subjective stress. Participants were asked to note down their HRV measure and a measure on perception of stress. After 4 days, participants started the intervention. Participants were instructed to exercise RFB twice daily and to fill in the measurements every day, for five weeks.

Intervention

After the baseline-week, participants were instructed to start the breathing exercises to train their RFB. The RF for every participant was determined by the physiotherapist that oversaw the intervention. After the RF was determined, participants were instructed to install a 'breath-pacer' application on their smartphone. For iPhone the application *Breath+ Simple Breath Trainer* was used. For Android the *Paced Breathing* application was used. The schema for the breathing exercises is shown in Table 1. Participants were given a protocol (see Appendix A) in which they could see the daily time dedicated to the exercises.

Table 1

Daily Routine of Breathing Exercises.

Week	1	2	3	4	5
Training	2*5min	2*8min	2*12min	2*15min	2*20min

Participants

Participants were recruited from the residential treatment facility, de Boerhaven, which is part of the organization Mediant, in the eastern part of the Netherlands. The clinic is specialized in the treatment of individuals with cluster B and C personality disorder, based on

Schema Focused Therapy (SFT). The treatment facility offers a 9-month to 1-year treatment, providing psychotherapy, drama therapy, psychomotor therapy, art therapy, pharmacotherapy, and socio-therapy. The clinic treats male as well as female patients from 18-40, but the population mainly consists of young adult, female patients. Participants were selected based on indication by their psychotherapist and personal interest in participation in the intervention.

Measures

Perceived Stress

For the assessment of perceived stress, in this study a validated 1-item stress measure was used (Elo et al., 2003; Larsson et al., 2015). Since validity in SCED and ESM stems from recurrent measurements, and participant burden should be limited as much as possible, this form of assessment was chosen (Eisele et al., 2021). The one-item measure used in this study was: “Stress means a situation in which a person feels tense, restless, nervous, or anxious, or is unable to sleep at night because his or her mind is troubled all the time. Do you feel this kind of stress these days?” This measure had to be answered on a 5-point Likert scale from 1 (*not at all)* to 5 (*very much)* and was translated in Dutch for this study.

Heart Rate Variability

An often-used measure for HRV is the Standard Deviation of the N-N intervals (SDNN). The N-N interval is the time between consecutive heartbeats, often measured in milliseconds (ms) (Figure 1). SDNN is a time-domain measure, preferable calculated over a five-minute time-period for short-term measurement (Malik et al., 1996; Shaffer & Ginsberg, 2017). According to Kim et al. (2020), SDNN is one of the most straight-forward measurements of HRV and can be used as objective index of physiological resilience against stress.

To assess HRV, participants were instructed to measure HRV every day in the morning, just after waking up. This was accomplished with the Kyto 2935 (provided by Mediant), in combination with the Elite HRV application. This HR and HRV monitor was used as a non-invasive method, to measure HR and HRV using an ear clip. The sensor was connected to participant phones via Bluetooth. In the Elite HRV application, daily measurements were shown, and saved.

Procedure

Participants in this study were instructed by a physiotherapist on how to use the Kyto 2935, and the Elite HRV application in a starting session. The physiotherapist determined the RF for all participants in their starting session. In this session informed consent forms were signed by participants (see Appendix B). Participants were instructed to monitor their HRV for 5 minutes, for four days in the first week, as to have a baseline. Participants were instructed to fill in measures of perceived stress and HRV in the provided protocol (Appendix A) in the morning, every day for the remaining five weeks. After completion of the 5-week intervention, participants were asked to answer two open questions about their experiences with the intervention and the experiences of stress in relation to the intervention (Appendix C). The assisting physiotherapist was asked about the experienced troubles, what actions helped to increase adherence, and what she had noticed in general in working with the participants during the intervention.

Statistical Analysis

After receiving the filled in participant protocols, the data was entered in a Microsoft Excel dataset and structured in long data format. If extreme outliers were present in the data, these were to be deleted. According to Field (2013), replacing the score of an outlier to the next highest score and adding one unit to this score, can be viewed as an ethical way to deal

with extreme outliers. In preparing the data for analysis, one measurement of SDNN was changed due to it being an extreme outlier ($z = 6.14$). Two dummy variables were created. One dummy variable was created in the dataset where a value of 1 marked a baseline measurement and a value of 0 marked a measurement during the experimental phase. A second dummy variable Study describing the author of the study was used as to prepare the data for analysis.

Multilevel analysis

For analysis of the data a multilevel analysis was conducted. The tool used to analyze the data is known as MultiSCED (Declerq et al., 2020). This web-based application has been developed to aid researchers in analyzing their multi-level data in a straightforward manner. The authors assert it has the benefits of more sophisticated statistical programs, while omitting the burden of the challenging nature of such programs. For MultiSCED a Comma Separated Values (CSV)-file is needed to upload the data-file, for this reason the Excel data-file was exported to this extension. After uploading the CSV-file in MultiSCED, separator character was set to comma and decimal character to dot. MultiSCED has been used to test both Hypothesis 1 & 2.

H1: A 5-Week Intervention to Improve Resonant Frequency Breathing is Associated with an Increased Heart Rate Variability in Patients with Personality Disorder.

In MultiSCED, SDNN, the measure for HRV, was set as the response variable. The number to identify the participant was used as case variable. The dummy variable study was set as study variable. The dummy variable indicating baseline or experimental phase was used as phase variable, where the value 1 was defined as the phase control group. The variable used to determine day of measurement was used as time variable in this analysis. The data was checked in the data summary. Fixed effects were chosen as intercept and baseline. Plots of

the data were visually inspected and regression results examined. Significance was determined at $p < .05$.

H2: A 5-Week Intervention to Improve Resonant Frequency Breathing is Associated with Decreased Subjective Stress in Patients with Personality Disorder.

In MultiSCED, the perception of stress was set as response variable. The number to identify the participant was used as case variable. The dummy variable study was set as study variable. The dummy variable indicating baseline or experimental phase was used as phase variable, where the value 1 was defined as the phase control group. The variable used to determine day of measurement was used as time variable in this analysis. The data was checked in the data summary. Fixed effects were chosen as intercept and baseline. Plots of the data were visually inspected and regression results examined. Significance was determined at $p < .05$.

Correlation Analysis

To test the third hypothesis, correlation analysis was done using SPSS 28.0.1.0. Spearman correlation analysis were conducted, since the variable for perceived stress is best defined as being of ordinal scale. For this analysis separate datafiles were created for all participants in addition to the use of the complete datafile.

H3: Increased Heart Rate Variability is related to a decrease in perceived stress in patients with personality disorder

Individual and total-sample bivariate correlation coefficients were calculated. A one-tailed test of significance was chosen since the direction of the correlation was already hypothesized. The variables analyzed for every participant were the measure of HRV and the measure of perceived stress. Missing values were excluded pairwise. Significance was determined at $p < .05$.

Results

Descriptive Statistics

The results in this study are based on data of 5 female participants. Table 2 provides an overview of individual and total adherence to the daily diary entries. The measure for perceived stress was filled in slightly more (62.1%) than the measure for HRV (61%). Participant 2 demonstrated outstanding adherence to the diary entries with full completion of all entries. Participant 5 demonstrated the least adherence to the diary entries for both measurements (10.3%). A frequency table assessing the overall completion of the breathing exercises is shown in table 3. Adherence to the breathing exercises was limited. However, participants 2 and 3 both scored relatively well on adherence, completing 2 daily exercises 74.3% and 94.3% of the time respectively. Participant 5 demonstrated the least adherence and completed no exercises. Assessing all participants, completion of no exercises daily was most common (48.6%).

Table 2

Number of Participant Diary Entries for HRV and Perceived Stress

Participant	HRV Entries N - (%)	Perceived Stress Entries N - (%)
1	27 - (69.2%)	30 - (76.9%)
2	39 - (100%)	39 - (100%)
3	28 - (71.8%)	39 - (100%)
4	21 - (53.8%)	9 - (23.1%)
5	4 - (10.3%)	4 - (10.3%)
Total	119 - (61.0%)	121 - (62.1%)

Table 3

Number of Exercises Completed Daily

Participant	0	1	2
1	18 (51.4%)	14 (40.0%)	3 (8.6%)
2	1 (2.9%)	8 (22.9%)	26 (74.3%)
3	0 (-)	2 (5.7%)	33 (94.3%)
4	31 (88.6%)	4 (11.4%)	0 (-)
5	35 (100%)	-	-
Total	85 (48.6%)	28 (16.0%)	62 (35.4%)

Descriptive statistics on the two independent variables of interest in this study are shown in table 4. Individual differences in average HRV fall within one standard deviation of the mean of the total sample for four of the participants. Participant 1 exhibited greatest

variance in SDNN (*M* = 80, *SD* = 29.7), participant 5 the greatest average SDNN (*M* = 122.2, *SD* = 16.6). Whereas participant 3 measured the lowest average SDNN (*M* = 41.8, *SD* = 8.1). Perceived stress differed individually, participants 1 and 4 reported lower average perception of stress than the total sample mean. Participant 5 reported the greatest average perceived stress. Considering the possibilities for answering the measure for perceived stress, it seems that two of the participants experienced stress sometimes, and three of the participants experienced stress on a regular basis.

Table 4

Descriptive statistics SDNN and Perceived Stress

	SDNN		Perceived Stress		
Participants	Min - Max	*M* ± *(SD)*	Min - Max	*M* ± (*SD)*	Median
1	34.5 – 140.0	80 ± (29.7)	1.5 - 4	2.4 ± (0.7)	2
2	40.1 – 87.6	61.1 ± (14)	1 - 5	3.2 ± (1.1)	3
3	18.0 – 58.8	41.8 ± (8.1)	2 - 5	3.8 ± (0.7)	4
4	40.9 – 74.5	50.8 ± (8.4)	1 - 4	2.0 ± (1.0)	2
5	103.58 - 142.4	122.2 ± (16.6)	3 - 5	4.25 ± (1.1)	4.5
Total	18.0 – 142.4	61.1 ± (24.6)	1,0 - 5,0	3.1 ± (1.1)	3

Qualitative data

The open-ended questions that were given to the participants in this study were answered by all participants. Four participants indicated difficulty in finding time to do the exercises. Furthermore, four participants reported that discipline was required to adhere to the exercises and two of these participants indicated that discipline dwindled with the advancing

of time. Participant 1 reported that she perceived the adherence to the exercises as stress-inducing. Participant 3 reported feeling pressured to complete all exercises, which she explained through perfectionism. Participant 4 reported that due to personal circumstances she failed to do some exercises, which resulted in a decrease in motivation. However, this participant did report increased consciousness in relation to symptoms of stress. Ultimately, none of the participant reported differences in their perception of stress.

The recommendations of the contributing physiotherapist in stimulating adherence, consisted of planning specific times to execute the exercises and regular contact between participants and the physiotherapist. She also indicated that low motivation with respect to the intervention, resulted in early disengagement.

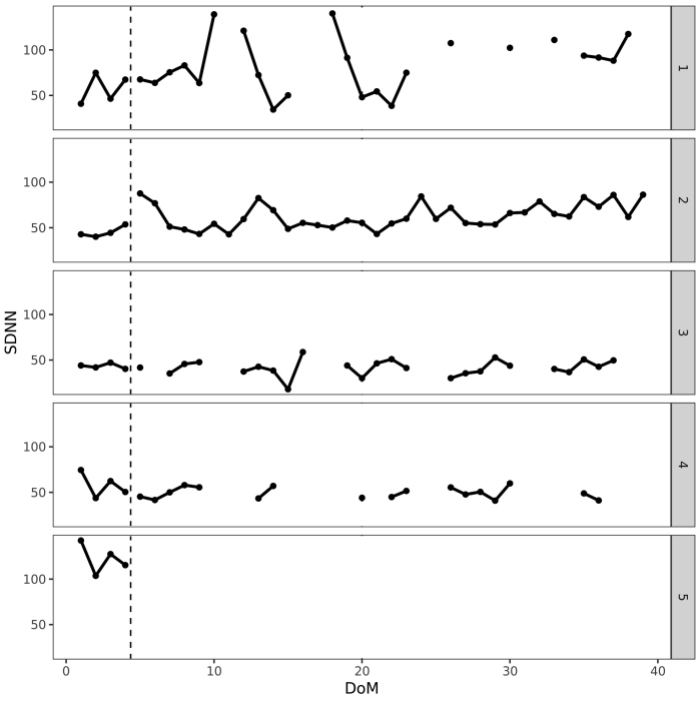
Resonant Frequency Breathing and Heart Rate Variability

The first hypothesis that was tested was: "A 5-week intervention to improve Resonant Frequency Breathing is associated with an increased Heart Rate Variability in patients with Personality Disorder." A visualization of the data on individual HRV over time, for each participant is shown in figure 2. Visual inspection of the data gives the impression that both participant 1 and 2, had increased HRV at the end of the intervention period, compared to baseline. Participant 1 seems to have had the greatest variance in the measurements of HRV. Participants 3 and 4 did not seem to differ in their HRV after the intervention, compared to their individual baseline. Notably, when comparing the visual differences in baseline measurements, participant 5 unmistakably had the greatest HRV values. Within-subject analysis reveals a significant increase in HRV for participant 2, when baseline HRV is compared to HRV during the period of intervention ($B = 17.69$, $p = .015$). For participant 1 ($B = 26.49$, $p = .1$), participant 3 ($B = -1.77$, $p = .691$), and participant 4 ($B = -8.59$, $p = .065$), HRV did not significantly differ from their respective baseline periods during the

period of intervention. Within-subject analysis was not possible for participant 5, since this participant only completed the baseline measurements. Due to the varying nature of the results in this study, for one participant the hypothesis is accepted, for the remaining participants the hypothesis is rejected.

Figure 2.

Daily Reported HRV in SDNN over Time per Participant



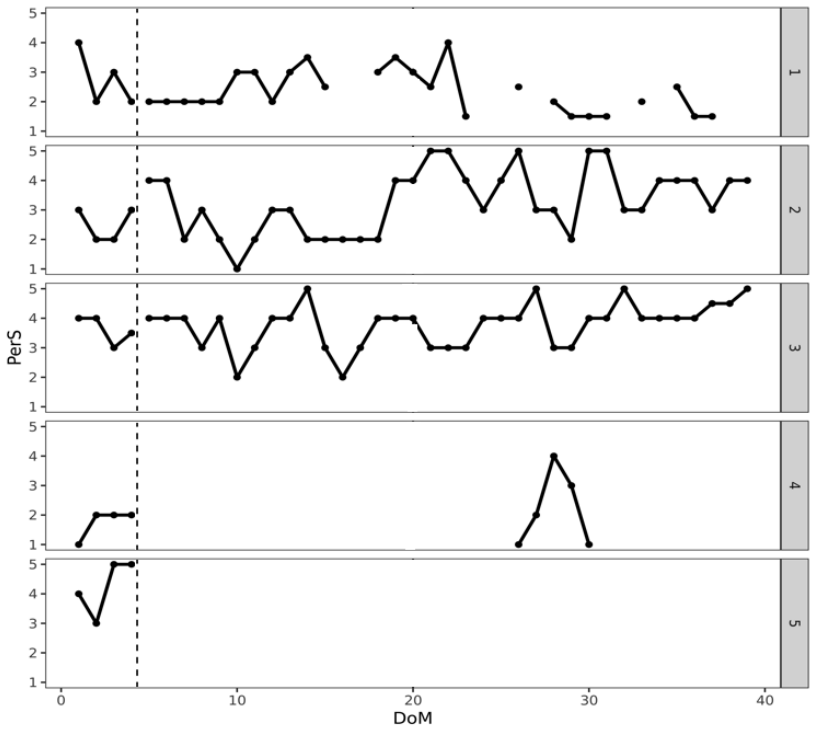
Resonant Frequency Breathing and Perceived Stress

The second hypothesis that was tested was: "A 5-week intervention to improve Resonant Frequency Breathing is associated with decreased subjective stress in patients with personality disorder." A graphic visualization of the data on individual perception of stress is provided in figure 3. Visual inspection of the data reveals decreased perception of stress for participant 1 compared to their baseline, considering the last measurements. However, at the first weeks of the intervention, the perceived stress seemed to be equal or even increased

compared to baseline. Participants 2 and 3 seemed to have experienced increased perceived stress during the intervention, compared to baseline. Remarkably, participant 5 reported the greatest levels of perceived stress during the baseline measurements. Within-subject analyses did not show significant differences in the subjective experience of stress, when the period of intervention was compared to the baseline period (Participant 1: *B = -0.40, p = .323,* Participant 2: *B = 0.79, p = .171,* Participant 3: *B = 0.15, p = .711,* Participant 4: *B = 0.45, p = .539).* Within-subject analysis was not possible for participant 5, since this participant only reported perceived stress during the baseline period. Due to these results, the second hypothesis is rejected.

Figure 3.

Perceived Stress Over Time



Perceived Stress and Heart Rate Variability

The third hypothesis that was tested was: "Increased Heart Rate Variability is related to decreased perceived stress in patients with personality disorder." SDNN and perceived stress were correlated negatively when the total sample is assessed ($rs(106) = -.227$ $p = .01$). Increased HRV thus corresponded to a decrease in the perception of stress. For participants 1-4, significant individual correlations were found (participant 1: $rs(26) = -.375$, $p = .029$, participant 2: $rs(39) = .492$, $p < .001$, participant 3: $rs(28) = -.320$, $p = .048$, participant 4: $rs(9) = -.612$, $p = .04$.) For participant 5 there was no correlation found ($rs(4) = .316$, $p = .342$). The third hypothesis is therefore accepted for three of the participants and the total sample. However, for participant 2 the third hypothesis is rejected, this individual demonstrated increased perception of stress when HRV was elevated. Due to the low number of measurements, the hypothesis is accepted nor rejected for participant 5.

Discussion

The goal of this research was to assess an intervention aimed at the reduction of subjective stress and stress-reactivity in individuals with PD. Contrary to the expectations represented in the first hypothesis, for three participants there was no increase in HRV during the 5-week intervention. However, for one participant HRV did increase during the intervention. One participant only completed the baseline measurements, and intervention efficacy could therefore not be assessed. Inconsistent with the second hypothesis, there was no evidence that the 5-week intervention improved perceived stress for participants in this study. In line with the third hypothesis, for the total sample, HRV has a negative association with perceived stress. For three participants increased values of HRV were accompanied with lower scores on perceived stress. However, the direction of the relationship between HRV and perceived stress is heterogeneous when considering participants individually. For one

participant, a positive relationship was found, meaning that this participants' increased HRV was accompanied by higher perceived stress. For one participant, there was no relationship found, which can be explained through only baseline adherence to the measurements. Considering the total sample, when HRV increased, participants reported decreased levels of subjective stress.

Comparing HRV in the current study to other studies, may present indication if individuals with PD differ compared to healthy controls, concerning HRV. Nunan et al. (2010) reviewed 27 studies using the same short-term HRV measure (SDNN). The difference in HRV in healthy individuals in their study (M = 50ms, SD = 16ms) and the current sample (M = 61.1ms, SD = 24.6ms) seems relatively low and within one standard deviation. However, average HRV is elevated in participants in this study, compared to healthy controls. Due to the small sample size, generalization to the target-population may not be valid. However, the current results are similar to a study by Meyer et al. (2016), who found no differences in HRV, when comparing individuals with PD with healthier controls. Indicating, that benefits of interventions aimed at increasing HRV in this population, may not be optimal.

Comparing perceived stress in the current sample to perceived stress in other studies, may provide evidence for the assumption that individuals with PD experience elevated stress. Larsson et al. (2015) investigated perceived stress in individuals recovering from a myocardial infarction, commonly known as a heart attack. A lower perception of stress (M = 2.1, SD = 1) is evident in their study compared to the current study (M = 3.1, SD = 1.1). In other words, individuals suffering from PD seem to experience greater stress then individuals recovering from myocardial infarction. The exacerbated perception of stress may be explained in the light of the stress generation theory (Hammen, 1991; White et al., 2020).

Individuals with PD are prone to attract stressful situations in their life, and consequently experience increased stress compared to healthier counterparts. The increased emotional reactivity to stress in the target population may then exacerbate the experience of subjective stress (Glaser et al., 2006; Glaser et al., 2008; White et al., 2020). This finding substantiates the assumption that interventions aimed at stress reduction, might be beneficial in reducing PD symptomatology and severity.

The answer to the first research question is that in the current study, subjective stress was not reduced during the intervention. These results indicate that individuals with PD, do not experience improvements in subjective stress, when they participate in an intervention aimed at increasing HRV. As such, these findings are contrary to findings presented in a literature review by Sevoz-Couche and Laborde (2022), independent of sample characteristics, including psychological pathology. In their research, decreases in stress and anxiety and increases in HRV were found. These changes were found to be the result of RFB interventions, similar to the intervention in the current study.

Various explanations of the absence of effects of the intervention in the current study can be given. One explanation might be the sub-optimal adherence to the intervention. Two participants in this study demonstrated satisfactory adherence. However, the adherence of the remaining participants can be defined as inadequate. Greater adherence might have produced different results, emphasizing the caution with which interventions in this population should be planned and executed. A second, credible explanation might be, that stress is a deeply rooted and multi-dimensional phenomenon, especially in PD (White et al., 2020). It therefore seems plausible, that simple breathing exercises may not fully elicit the preferred change in the perception of stress. Together, these explanations may partially account for the absence of effects following the intervention.

The answer to the second research question, is that HRV is associated with subjective stress in patients with PD. Although the direction of this relationship differs individually in the current sample, at sample level, increased HRV was related to lower perceived stress in patients suffering from PD. Thus, subjective stress is related to physiological markers of stress, but the relationship is more intricate than hypothesized. The relationship between HRV and perceived stress substantiates the idea that HRV can be used in the assessment of psychological stress (Kim et al., 2018). However, HRV is not the same as subjective stress, indicating that in assessment of stress both objective and subjective measures should be considered.

Strengths and Limitations

As stated before, literature on PD and HRV is scarce, this research provides new insight in the topics of HRV and perceived stress in individuals with PD. This pilot study can be defined as unique and was conducted in a unique setting. This study adds value to the literature, by charting individual objective and perceived stress in the target population. Moreover, it reveals specific problems regarding adherence to interventions. The specific use of ESM and SCED gives insight in stress and HRV in daily life. Furthermore, it discloses the difficulty to independently engage in health behavior, for a considerable amount of time.

One limitation to this study might be the choice for participant self-measuring HRV and self-reporting stress. There simply were no other clear possibilities to obtain the data for this study. However, the combination of objective measurement of a physical marker for stress with self-report of subjective stress is effective in comparing the relevance of these measures and clarifies the assumed relationship (Eisele et al., 2021). Furthermore, the independent use of ear-clip HR and HRV monitors is reliable in the short-term assessments used in the current study (Vescio et al., 2018).

A second limitation to this study can be found in methodological choices that were made in the design. The baseline consisted of four days, which might be too short to identify an effect during the intervention (Horner et al., 2005). A longer baseline period might have given a more representative assessment of the dependent variables pre-intervention, and consequentially improved validity of the effects in the current study (Smith, 2012). In addition to this, introduction of randomized phase start points would have solidified the intended experimental nature of the current study, improving internal validity (Kratochwill & Levin, 2014).

Implications for Research and Clinical Practice

An implication of the findings in this study that warrants further consideration, is the adherence to the intervention and diary entries. As stated before, the adherence in this study was unsatisfactory, although individual differences were apparent. In the answers on qualitative measures, four participants mentioned discipline was required to complete the exercises and two participants reported decreasing motivation and discipline in the progression of time. The contrasting experiences and differences in adherence indicate that tailored protocols might benefit adherence. Oyebode et al. (2021), propose idiosyncratic strategies for different stages of change when using mobile health applications. They suggest making use of self-monitoring, praise, reminder, and suggestion strategies when individuals have made the first steps in adopting new behavior. For individuals who are actively implementing new behavior suggestion, reminder, and social role strategies are recommended. The reminder and social role strategies are similar to the suggestions of the physiotherapist. Visualization of progress can provide the possibility for self-monitoring. Praise, suggestion, and reminder strategies may both be implemented through notifications. Social role strategies may be deployed through regular contact with their therapist, or other

participants in the study. These strategies can all be implemented with the applications used in the current study, by purchasing a subscription. Experimental investigation could be conducted to assess the effectivity of these strategies in the target population.

A second recommendation is mostly for future research. In the current study a negative relationship was found between HRV and perceived stress in the total sample. However, one of the participants demonstrated a positive relationship between HRV and perceived stress. In the light of this contrasting individual relationship, it seems important to investigate further individual differences in larger samples. Sommerfeldt et al. (2019) found that coherence between HR and subjective stress, is associated with increased psychological wellbeing. This illuminates the notion that individual differences in coherence between HRV and subjective stress might have implications for wellbeing. To the authors' best knowledge, such a contrary relationship has not yet been found in research. Future research mapping individual differences in this relationship and investigation possible relationships with other health constructs, deserves recommendation.

This pilot study assessed an intervention aimed at increasing HRV, to reduce perceived stress in inpatients with PD, through exercises targeting RFB. The intervention did not result in changes in perceived stress. The relationship between HRV and perceived stress in individuals with PD, has been confirmed in this study. However, the heterogenous nature of this relationship indicates complexity. The complexity and possible implications may serve as a rationale for further research. Furthermore, perceived stress levels seem elevated in the current study, indicating interventions aimed at reduction of subjective stress, may be more effective in reducing psychopathology. In conclusion, this research reveals, that in interventions aimed at stress reduction, adherence can be problematic in individuals with PD. Persuasive strategies might be of assistance in the pursuit of sufficient adherence.

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Appendix A. Intervention Protocol

Protocol HRV training

Week 0
Installeren HRV elite app
4 keer morning readiness meten
Doelen opstellen
VAS score gerelateerd aan de klacht
Geen ademhalingsoefeningen

Doelen:
……..
……..
……..

Voor start training:
Resonate frequentie ademhaling bepalen
Adempacer installeren

Start training:
Week 1
adem 2x per dag 5 minuten op de RF met behulp van een adempacer app

Week 2:
adem 2x per dag 8 minuten op de RF met behulp van een adempacer app

Week 3:
adem 2x per dag 12 minuten op de RF met behulp van een adempacer app

Week 4 of:
adem 2x per dag 15 minuten op de RF met behulp van een adempacer app

Week 11:
adem 2x per dag 20 minuten op de RF met behulp van een adempacer app

Belangrijk: na iedere meting (morning readiness) de gegevens opslaan (save button)

Overige oefeningen:
……..
……..
……..
……..
……..
……..
……..

Scorelijst

	Meting 1	Meting 2	Meting 3	Meting 4
WEEK 0				
HRV (SDNN)				
Stress gevoeld				

	Maandag	Dinsdag	Woensdag	Donderdag	Vrijdag	Zaterdag	Zondag
WEEK 1							
Adempacer							
HRV (SDNN)							
Reden geen oefening							
Stress gevoeld							
WEEK 2							
Adempacer							
HRV (SDNN)							
Reden geen oefening							
Stress gevoeld							
WEEK 3							
Adempacer							
HRV (SDNN)							
Reden geen oefening							

Stress gevoeld							
WEEK 4							
Adempacer							
HRV (SDNN)							
Reden geen oefening							
Stress gevoeld							
WEEK5							
Adempacer							
HRV (SDNN)							
Reden geen oefening							
Stress gevoeld							

Na iedere oefening met de adempacer bij de betreffende week/dag een kruisje (X) zetten.

Twee keer per dag de oefeningen met de adempacer gedaan = 2 keer een kruisje (XX)

Stress betekent een situatie waarin een persoon zich gespannen, rusteloos, nerveus of angstig voelt, of ’s nachts niet kan slapen omdat hij of zij zich zorgen maakt. Heb je deze stress de afgelopen dagen gevoeld?

Dagelijks score bijhouden op een schaal van 1-5 1= helemaal niet 5= heel veel

Bijzonderheden:

……..

……..

……..

……..

EVALUATIE

Doelen:

……...

……

……

	WEEK 0	WEEK 3	WEEK 6	WEEK 9	WEEK 11
VAS					

VAS gerelateerd aan de klachten: is een score van 0-10

(0=geen klachten, 10= onhoudbare klachten)

Appendix B. Informed Consent

TOESTEMMINGSVERKLARING
voor deelname aan wetenschappelijk onderzoek

Onderzoek naar de werking en effectiviteit van Hart Ritme Variantie Training.

Hierbij verklaar ik dat ik bereid ben deel te nemen aan onderzoek naar de werking en effecten van Hart Ritme Variantie Training.

Ik heb van de onderzoeker schriftelijke en mondelinge informatie gekregen over de inhoud, methode en doel van het onderzoek. Ik heb mijn vragen kunnen stellen en die zijn naar tevredenheid beantwoord. Ik begrijp waarover het onderzoek gaat. Ik heb voldoende tijd gehad om te beslissen of ik mee wil doen. Ik begrijp dat als ik niet meer mee wil doen, ik het onderzoek op ieder moment stop kan zetten.

Ik stem vrijwillig in met deelname aan onderzoek. De data mogen door de huidige en toekomstige onderzoekers gebruikt worden voor wetenschappelijk onderzoek naar klinische schematherapie en vaktherapie. De onderzoekers mogen daarvoor mijn dossier inzien. De onderzoekers mogen mij benaderen voor aanvullende vragen ten behoeve van het onderzoek.

Ik begrijp dat ik mijn vragen altijd kan stellen aan de huidige onderzoekscoördinator:
Karin Timmerman, K.Timmerman@mediant.nl, 088 - 373 6753.

Naam :
Geboortedatum :
Adres :
Postcode en woonplaats :

Email :
Telefoonnummer :

Datum :
Handtekening :

Ondergetekende, verantwoordelijke onderzoeker, verklaart dat de hierboven genoemde persoon zowel schriftelijk als mondeling over onderzoek is geïnformeerd.
Hij/zij verklaart tevens dat een voortijdige beëindiging van de deelname door bovengenoemde persoon, van geen enkele invloed zal zijn op de zorg die hem of haar toekomt. Alle gegevens van de deelnemers aan het onderzoek worden geanonimiseerd.

Naam :

Functie :

Datum :

Handtekening :

Appendix C. Retrospective Qualitative Measures

Onderzoek Hart Ritme Variantie (HRV)- Training
Vragen aan de participanten

Vraag 1.
Beschrijf in je eigen woorden jouw ervaring met het iedere dag volgen van het protocol van de HRV-training.

Vraag 2.
Wat was jouw ervaring met betrekking tot gevoelens van stress, tijdens en na het volgen van de HRV-training?