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A Quadratic Analysis of Trait Anxiety and Heart Rate Variability

Katlyn Schroder
The Graduate Center, City University of New York

A QUADRATIC ANALYSIS OF TRAIT ANXIETY AND HEART RATE VARIABILITY

by

KATLYN SCHRODER

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This manuscript has been read and accepted for the Graduate Faculty in Cognitive Neuroscience in satisfaction of the thesis requirement for the degree of Master of Science.

Date	Yu Gao Thesis Advisor
Date	Tony Ro Director

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT

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Advisor: Yu Gao

Trait anxiety refers to an individual's sensitivity to perceived threat. Though it is not itself diagnosable according to the DSM-5, trait anxiety scales are often administered in a clinical context and serve as an indicator for anxiety disorders. High levels of trait anxiety can result in prolonged periods of intense worry and dysfunction, even in those who are not diagnosed with an anxiety disorder. Previous studies have attempted to understand the relationship between trait anxiety and reactivity of the autonomic nervous system, especially in relation to vagal tone, but have found inconsistent results. One possible explanation for this inconsistency is that these studies primarily tested a linear relationship between trait anxiety and parasympathetic nervous system reactivity. It is possible that low HRV may be associated with increased trait anxiety, consistent with other types of emotion dysregulation, but high levels of heart rate variability become maladaptive and are also associated with higher trait anxiety. A quadratic relationship, sometimes referred to as the "too much of a good thing effect," was tested in order to determine whether both low and high levels of heart rate variability, an indicator of parasympathetic reactivity, would increase trait anxiety. Previous studies did not establish an ideal condition or domain of measurement for heart rate variability, so an exploratory analysis was conducted where regressions were used for both time-domain and frequency-domain measurements of

HRV. Analyses were run using data that was collected both during a task and during resting state to see if there was any particular condition where a quadratic relationship may be present. Because gender differences have previously been established in relation to anxiety, each regression was run a second time, split by gender. Results indicated neither a quadratic nor a linear relationship between trait anxiety and heart rate variability under any of these conditions. This study reinforces the possibility that individual differences in trait anxiety are not solely mediated by autonomic nervous system reactivity, but rather a combination of factors possibly including, but not limited to, autonomic nervous system reactivity.

ACKNOWLEDGEMENTS

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Introduction

Trait anxiety is a measurement of an individual's sensitivity to perceived stressors or threats, and their predisposition to respond (Endler & Kocovski, 2001; Spielberger, 1983). The State-Trait Anxiety Inventory (STAI), one of the most widely used and researched measures of general anxiety (Julian, 2011), measures trait anxiety with prompts such as "I feel nervous and restless," and "I have disturbing thoughts" (Spielberger, 1983). Scales that measure trait anxiety are administered in research and clinical settings and can be used to predict other disorders, including anxiety disorders. They are also used to distinguish between symptoms of anxiety and depression (Kvaal, Ulstein, Nordhus, & Engedal, 2005; Mundy et al., 2015). Despite its frequent usage to detect and predict clinical levels of anxiety, studies attempting to find a physiological predictor for differences in trait anxiety among healthy individuals have found inconsistent results.

Anxiety and Trait anxiety

The American Psychological Association (APA) defines anxiety as "an emotion characterized by feelings of tension, worried thoughts and physical changes like increased blood pressure" (American Psychological Association, 2020). At healthy levels, anxiety is an adaptive emotion that increases survivability by motivating individuals to cope with dangerous or threatening situations (Öhman, 1993; Spielberger, 2010). However, chronically high levels of anxiety can become maladaptive. Individuals who have high trait anxiety may experience intense periods of worry and tension in response to relatively benign stimuli, resulting in a recurring emotional, dysfunctional state despite a lack of potentially harmful threat.

Though trait anxiety is not diagnosable according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), trait anxiety (and other personality traits such as neuroticism which overlap with trait anxiety but are measured through separate scales) has been established as a predictor and/or initial screening tool for clinical anxiety disorders (Brandes & Bienvenu, 2006; Mundy, 2015). The scale has proven useful for this purpose across a wide age range. For example, the STAI-T was able to predict Diagnostic Interview Schedule for Children (DISC) anxiety disorders (generalized anxiety disorder, overanxious disorder, and social phobia) in multiethnic adolescents, with 20% of those who were screened being referred for a more comprehensive evaluation, and 38.5% of those referred being diagnosed with a DISC anxiety disorder (Hishinuma et al., 2001). It was also able to detect both anxiety disorders and mixed anxiety depressive disorders in geriatric patients, where the mean STAI-T sumscore was significantly higher in patients with a psychiatric disorder than those without one ($p<0.01$) (Kvaal et al., 2005).

Autonomic correlates of trait anxiety

Previous studies have attempted to use autonomic nervous system functioning as a biological explanation for high levels of trait anxiety. A popular method of examining the reactivity of the autonomic nervous system in relation to trait anxiety – in addition to other variables related to emotional self-regulation – is to measure the parasympathetic vagal control of the heart rate. When perceiving a stimulus or situation seen as potentially threatening or harmful, the sympathetic nervous system (SNS) increases the heart rate to increase blood flow to areas of the body necessary for fighting or fleeing. The pupils dilate, and digestion is slowed. When the threat ceases to be present, the vagus nerve – the main nerve of the parasympathetic nervous system (PNS) (Brodal, 2010; Thayer & Brosschot, 2005) – takes over, counteracting the effects of sympathetic activation by reducing the heart rate, constricting the pupils, and allowing digestion to resume. The SNS and PNS responses to changes in the environment are referred to as autonomic system reactivity.

Heart rate variability

One common measure of autonomic nervous system reactivity is heart rate variability (HRV). This involves measuring the variability in time intervals between successive heartbeats, or inter-beat intervals (IBIs). Time-domain, frequency-domain, and non-linear measurements are used to calculate HRV, with non-linear measurements being less common than the other two. Time-domain indices of HRV quantify the amount of time in between IBIs. A popular time-domain index used to quantify HRV is the root mean of successive square differences (RMSSD), which involves calculating the time difference between successive heartbeats in milliseconds (ms), squaring each result, and averaging them. This reflects the average change in IBIs, and is the primary time-domain measure used to estimate parasympathetic-mediated changes to HRV (Shaffer, McCraty, & Zerr, 2014). Frequency-domain indices of HRV estimate the distribution of power in four frequency bands: ultra-low frequency (ULF; frequencies <0.003 Hz), very-low frequency (VLF; frequencies between 0.0033–0.04 Hz), low-frequency (LF; frequencies between 0.04–0.15 Hz), and high-frequency (HF; frequencies between 0.15-0.40 Hz). The high-frequency band, also known as the respiratory band, is thought to reflect parasympathetic activity and correspond to heart rate variations related to the respiratory cycle (Shaffer & Ginsberg, 2017). Higher HRV indicates that the parasympathetic vagus nerve is more actively involved in suppressing sympathetic responses to environmental stressors, resulting in more variation between heartbeats.

Time-domain and frequency-domain measures of HRV in trait anxiety

There is no consensus as to whether HRV should be measured via time-domain or frequency-domain when being related to trait anxiety. Inconsistencies in findings regarding the relationship between trait anxiety and HRV exist within measurement domains. Several studies examining high-frequency HRV found that high trait anxiety was associated with lower levels of HRV (Bliel, Gianaros, Jennings, Flory, & Manuck, 2008; Miu, Heilman, & Miclea, 2009), while other studies found the opposite (Rajcani, Solarikova, & Brezina, 2017) or no significant relationship (Dishman et al., 2000; Kao et al., 2016). Likewise, time-domain indices such as RMSSD and mean R-R intervals have shown a negative relationship (Miu et al., 2009), a positive relationship (Rajcani et al., 2017) and no relationship (Dishman et al., 2000; Kao et al., 2016) to trait anxiety. Studies examining both time-domain and frequency-domain typically found consistent results between domains.

Trait anxiety and heart rate variability

HRV has been studied extensively and is typically lowered in individuals with emotion regulation issues including, but not limited to anxiety (Zhang, Fagan, & Gao, 2017). However, studies that examined the relationship between HRV (or similar measures of parasympathetic vagal control, such as respiratory sinus arrhythmia) and trait anxiety in healthy adults have found inconsistent results. Some studies have found an inverse relationship between trait anxiety and HRV, consistent with the findings with other types of emotion dysregulation (Fuller, 1992; Miu et al., 2009). Other studies failed to find a significant relationship between trait anxiety and HRV, or had inconsistent findings across conditions (Danilova, Korshunova, Sokolov, & Chernyshenko, 1995; Dishman et al., 2000; Gaburro et al., 2011). One recent study found that adults with high trait anxiety had higher HRV than controls (Rajcani, Solarikova, & Brezina, 2017).

A potential explanation for these inconsistent results is that trait anxiety and vagal control of HRV share a quadratic relationship, as opposed to a linear one, conforming to what has previously been referred to as the "Too-Much-of-a-Good-Thing-Effect." Some studies suggest that, despite previous associations between higher levels of parasympathetic control and emotion regulation, it is possible that emotional and psychological processes become maladaptive beyond a certain point. For example, one study found that individuals with moderate Cardiac Vagal Tone (CVT) had higher levels of well-being, including higher life satisfaction and lower depressive symptoms, than individuals with low or high Cardiac Vagal Tone (Kogan et al., 2013). Another study found a quadratic relationship between respiratory sinus arrhythmia and child and caregiver reported sympathy and prosocial behaviors in 8 year-olds, but not 4 year-olds (Acland, Colasante, & Malti, 2019). Low vagal tone may result in higher levels of trait anxiety, similar to how it has resulted in emotion dysregulation previously. However, high trait anxiety may also be the product of maladaptively high parasympathetic vagal tone. A quadratic relationship between parasympathetic vagal tone and trait anxiety - where moderate parasympathetic vagal tone is associated with low trait anxiety whereas low or high parasympathetic vagal tone is associated with high trait anxiety - could potentially explain previous inconsistent results pertaining to trait anxiety and parasympathetic vagal tone.

Gender differences

Gender differences are often observed in both clinical anxiety disorders and non-clinical levels of anxiety, including trait anxiety. Both generalized anxiety disorder (GAD) (Donner & Lowry, 2013; Grant et al., 2005; Wittchen, Zhao, Kessler, & Eaton, 1994) and panic disorder

(Kessler et al., 1994; McLean, Asnaani, Litz, & Hofmann, 2011) are two to three times more common in women than in men. Post-traumatic stress disorder (PTSD) is also more prevalent in women than men (Kessler et al., 1995; Mclean et al., 2011). However, it is unclear whether this is due to women having increased susceptibility to developing PTSD, or are more likely to experience PTSD-inducing events, including sexual and combat-related assaults (Donner & Lowry, 2013).

Trait anxiety tends to be higher in women than men, though results are mixed (McLean & Anderson, 2009). Furthermore, gender often moderates the relationship between trait anxiety and other psychosocial and psychophysiological variables. For example, one study found that higher trait anxiety was associated with a higher cardiac defense response, but only in women (López et al., 2016).

There are several proposed explanations for why women tend to have more anxiety symptoms, both clinical and non-clinical. Previous studies have made attributions to factors including biological influences, stress and trauma, and cognitive factors (McLean & Anderson, 2009). It is also possible that women are more likely to report symptoms of anxiety and seek professional assistance for anxiety-related issues, thus leading to more documented accounts of women living with anxiety. Regardless of which explanation is correct, gender is an important variable to consider when studying anxiety because it frequently moderates the relationship between anxiety and other variables.

The current study

In this thesis, it was hypothesized that there would be a quadratic relationship between trait anxiety and HRV, a measure of reactivity of the vagus nerve and parasympathetic nervous system. Some of the previous studies examining the relationship between trait anxiety and HRV used time-domain indices while others used frequency-domain indices (typically the high-frequency band). Likewise, some studies examined these relationships during resting state while others used one of a variety of tasks, or both. This thesis would serve as an exploratory analysis where both time-domain (RMSSD) and frequency-domain (high-frequency band power) indices of HRV were considered, during resting state and during a stressful task. HRV was chosen as the physiological indicator of parasympathetic vagal control because it has widely been used for this purpose in previous literature. Like RSA, another frequently used indicator of vagal control, the high frequency band of HRV accounts for respiration-driven variations in heart rate (Shaffer & Ginsberg, 2017). Each analysis was run a second time with results split by gender, in order to see whether this relationship, if extant, was only present for men or women.

Methods

Participants

One hundred and twenty-two Brooklyn College students were recruited through flyers and subject pool to participate in a study examining the effects of the autonomic nervous system on emotion regulation. Participants included 79 women (65%) and 43 men (35%), and ranged from ages 18 to 25 years. Participants were included if they were Brooklyn College students over the age of 18 years, were not taking medications that could affect the central or autonomic nervous systems, and had normal or corrected-to-normal vision.

All study participants provided written informed consent after being told that they would be completing questionnaires and computerized tasks while undergoing continuous physiological recording. They completed the trait version of the State-Trait Anxiety Inventory (STAI-T; Spielberger et al., 1983) and a dictator task called the Ultimatum Game. After completing the session, participants were compensated monetarily if they were recruited via flyers or with course credit if they were recruited through subject pool. All study procedures and materials were approved by the City University of New York Institutional Review Board.

Trait Anxiety Scale

Trait anxiety was measured by the STAI-T, a well-known scale with relatively high internal consistency reliability (Barnes, Harp, & Jung, 2002). The questionnaire consists of 20 questions that assess for trait anxiety, and include items such as: "I worry too much over something that doesn't really matter." Participants responded using a 4-point Likert scale (i.e. "Not at all," "Somewhat," "Moderately so," and "Very much so") with total scores ranging from 20-80.

Resting Task

After electrodes were attached to their bodies, participants were asked to sit quietly for 2 minutes, focusing their attention on the computer screen in front of them, and not moving to the best of their ability.

Stress Task

Immediately following the resting task, participants completed task called the Ultimatum Game – a heavily studied economic decision making task. Participants made and received monetary offers with partners, who they were told were interacting with them in real time at another university. In the first round, the participant's partner had $10, and decided how much money to keep for themselves and how much money to give to the participant. After they made their proposal, the participant could either accept or reject their offer. If they accepted, the money was split as proposed. If they rejected the offer, neither the participant nor the partner received any money. The participant then played another round with the same partner, with the roles reversed. This is cycle was completed several times with different partners. The economic decision making during the task, during both the proposer and the responder roles, has previously resulted in physiological arousal (as measured by HRV) due to mental stress, particularly in response to giving and receiving low offers (Dulleck, Schaffner, & Torgler, 2014).

Physiological Measurements

Electrocardiogram (ECG) data were collected continuously at 1000 Hz using a Biopac MP150 system with ECG 100C amplifier and analyzed offline with the AcqKnowledge 4.2 software (Biopac Systems Inc., Goleta, CA, United States). ECG signal was recorded using two pre-jelled Ag-AgCl disposable vinyl electrodes placed at a modified Lead II configuration. Skin conductance sensors were attached to the distal phalanges of the pointer and middle fingers of the non-dominant hand in order to measure electrodermal activity (EDA), though this data was not used for the current study. All physiological measurements were recording during tasks and rest.

Physiological data processing

All processing and analysis of ECG data was performed using the Biopac Acqknowledge 4.2 software. Resting and task physiological recording files were cut so that HRV data reflected ECG recordings that took place during the resting period and Ultimatum Game task. ECG waveforms were filtered using a bandpass filter of 1Hz and 35Hz. All ECG signals were visually inspected for movement artifacts and incorrect detection of peaks. Missing peaks were added, and misplaced peaks were deleted. RMSSD and high-frequency power values were obtained within the Acqknowledge 4.2 software.

Data Analysis

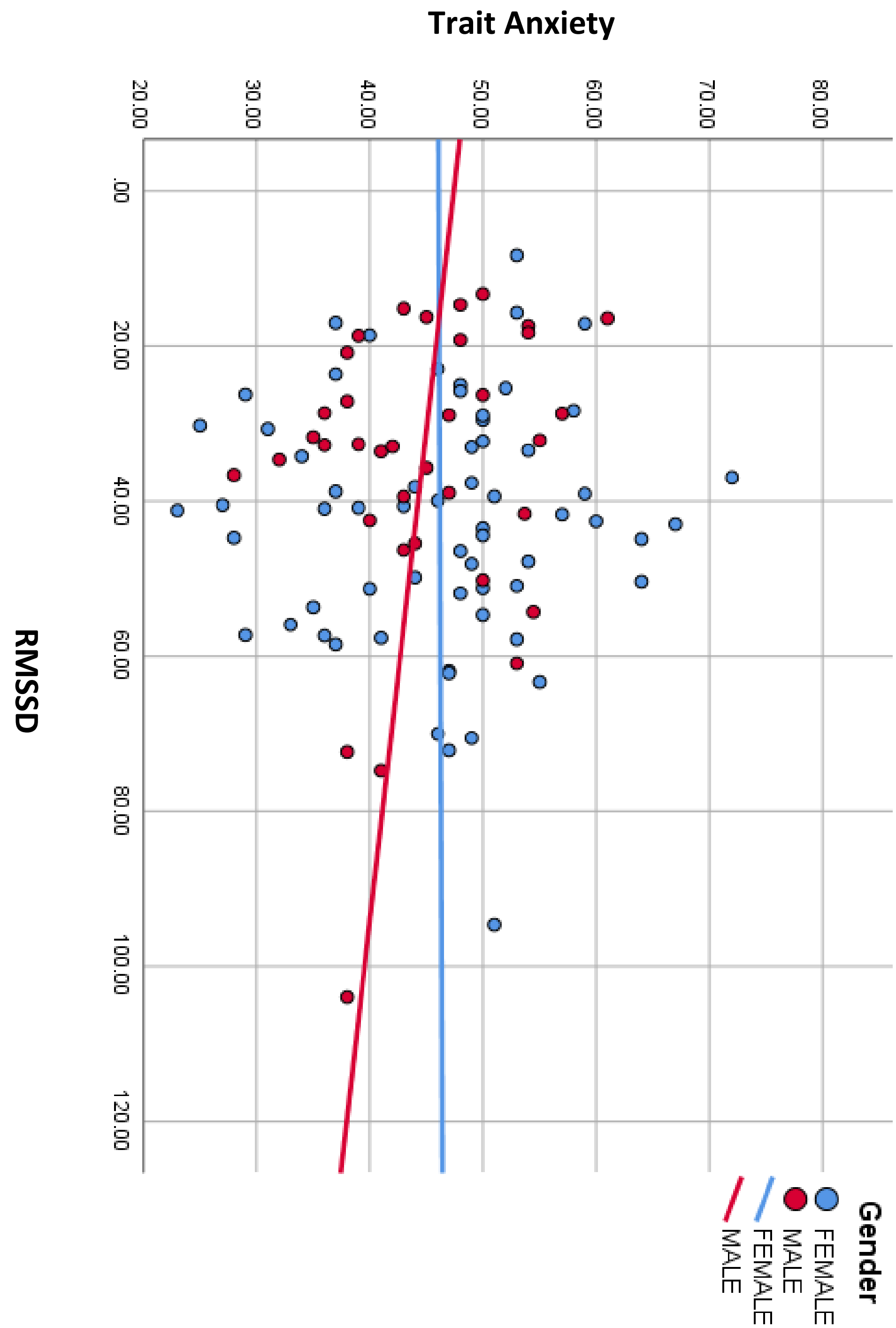
Participants who experienced technical issues including movement artifacts and equipment malfunction during physiological recording were excluded from further analysis. 23 outliers were removed, resulting in the analysis of 99 total participants. Both high-frequency power HRV variables (i.e., during task and resting period) were log transformed, as they were highly skewed (Bulmer, 1979). Descriptive statistics, correlational analyses, and group comparisons were calculated. The Statistical Package for the Social Sciences (SPSS; IBM Corp., Armonk, N.Y., USA) was used to run linear regressions on HRV and trait anxiety. There were four HRV variables: RMSSD during resting period, RMSSD while completing the Ultimatum Game task, high-frequency power during resting period, and high-frequency power while completing the Ultimatum Game task. Both linear and quadratic relationships were tested between each HRV variable and trait anxiety. Analyses were run a second time, split by gender.

Results

A preliminary examination of trait anxiety and HRV data using a scatterplot suggested a slight quadratic “U” shaped curve, but did not indicate a clear linear pattern (Figures 1-4). Eight linear regressions were run in order to assess for quadratic and linear relationships between HRV and trait anxiety, during resting state and during a task (Tables 1 & 3). Each regression was run a second time, with results separated by gender (Tables 2 & 4). According to our data, neither a quadratic nor linear relationship was found between trait anxiety and heart rate variability. Results remained insignificant after being split by gender.

Figure 1: Linear (a) and quadratic (b) distributions of RMSSD during rest and trait anxiety

(a)



(b)

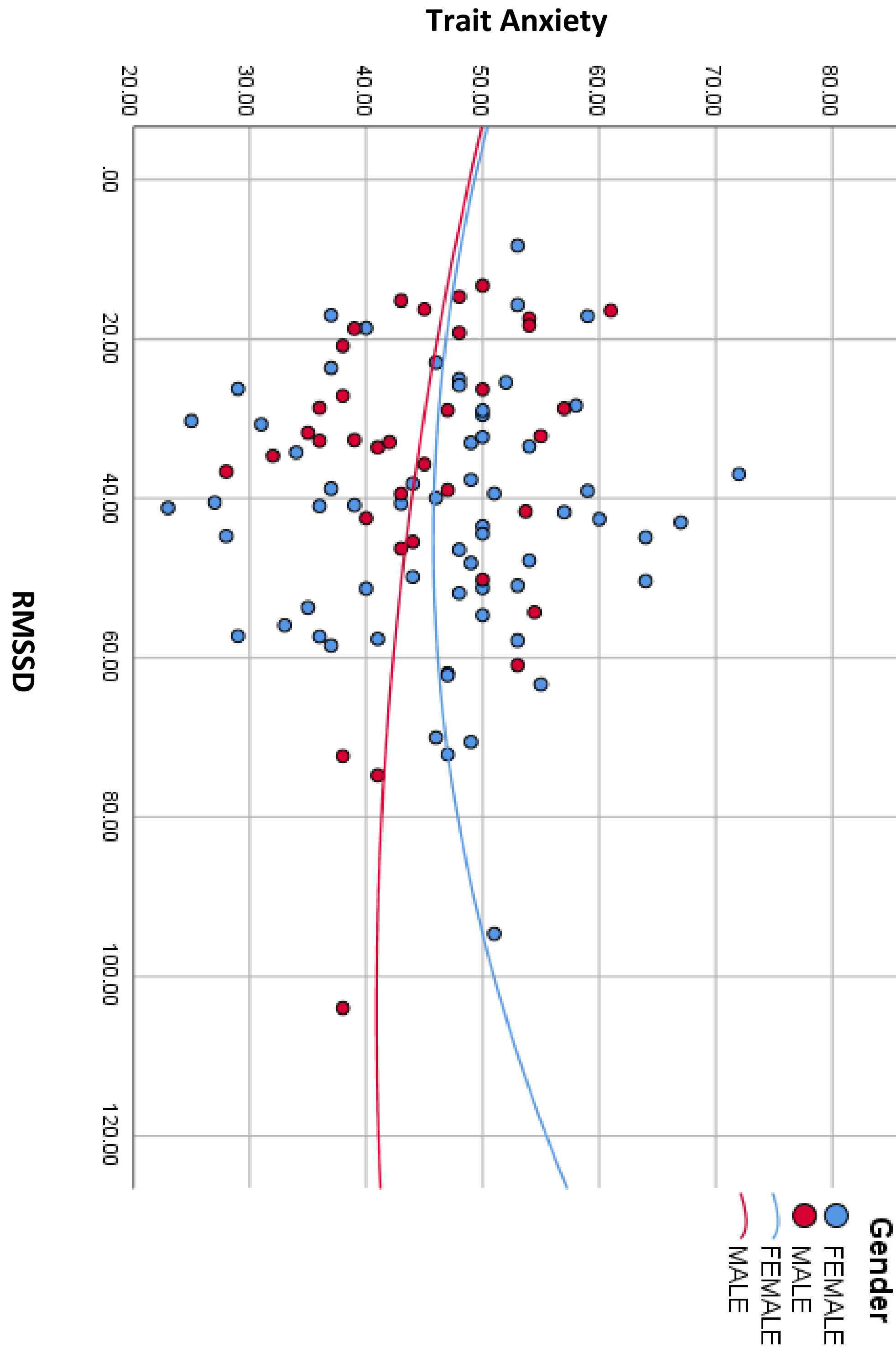
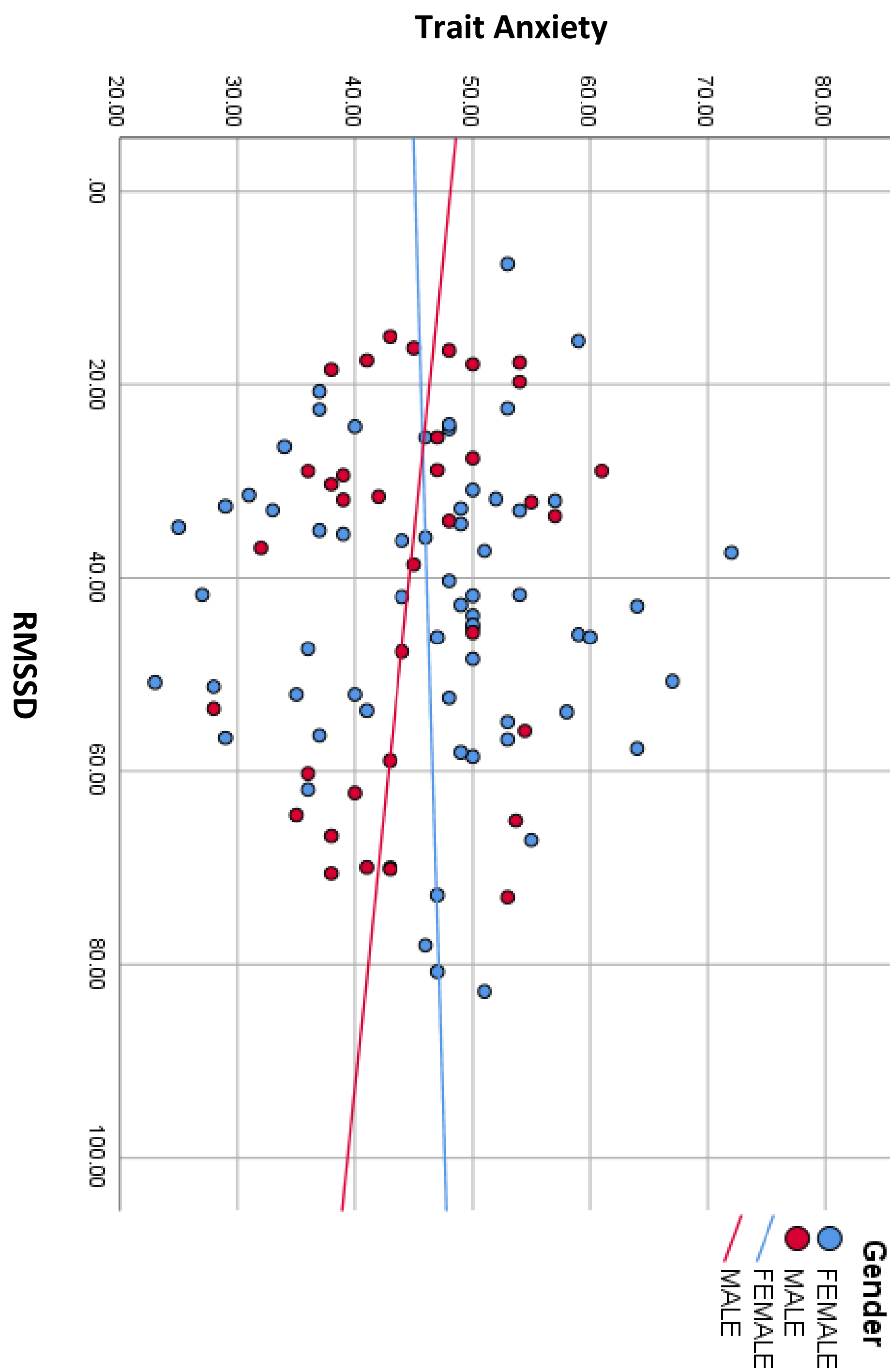

Trait Anxiety
20.00
30.00
40.00
50.00
60.00
70.00
80.00
RMSSD
.00
20.00
40.00
60.00
80.00
100.00
120.00
Gender
FEMALE
MALE
FEMALE
MALE

Figure 2: Linear (a) and quadratic (b) distributions of RMSSD during task and trait anxiety

(a)



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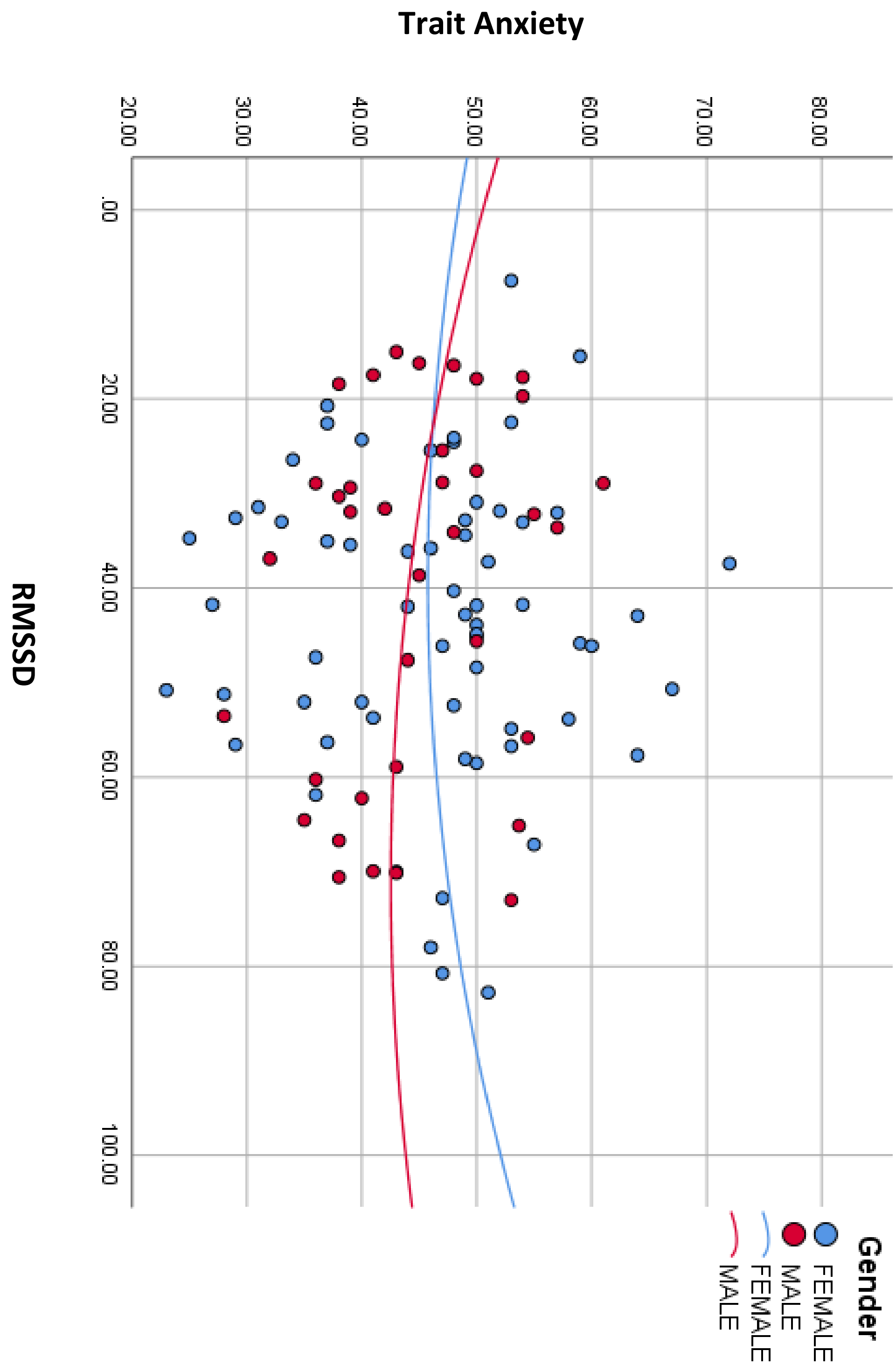
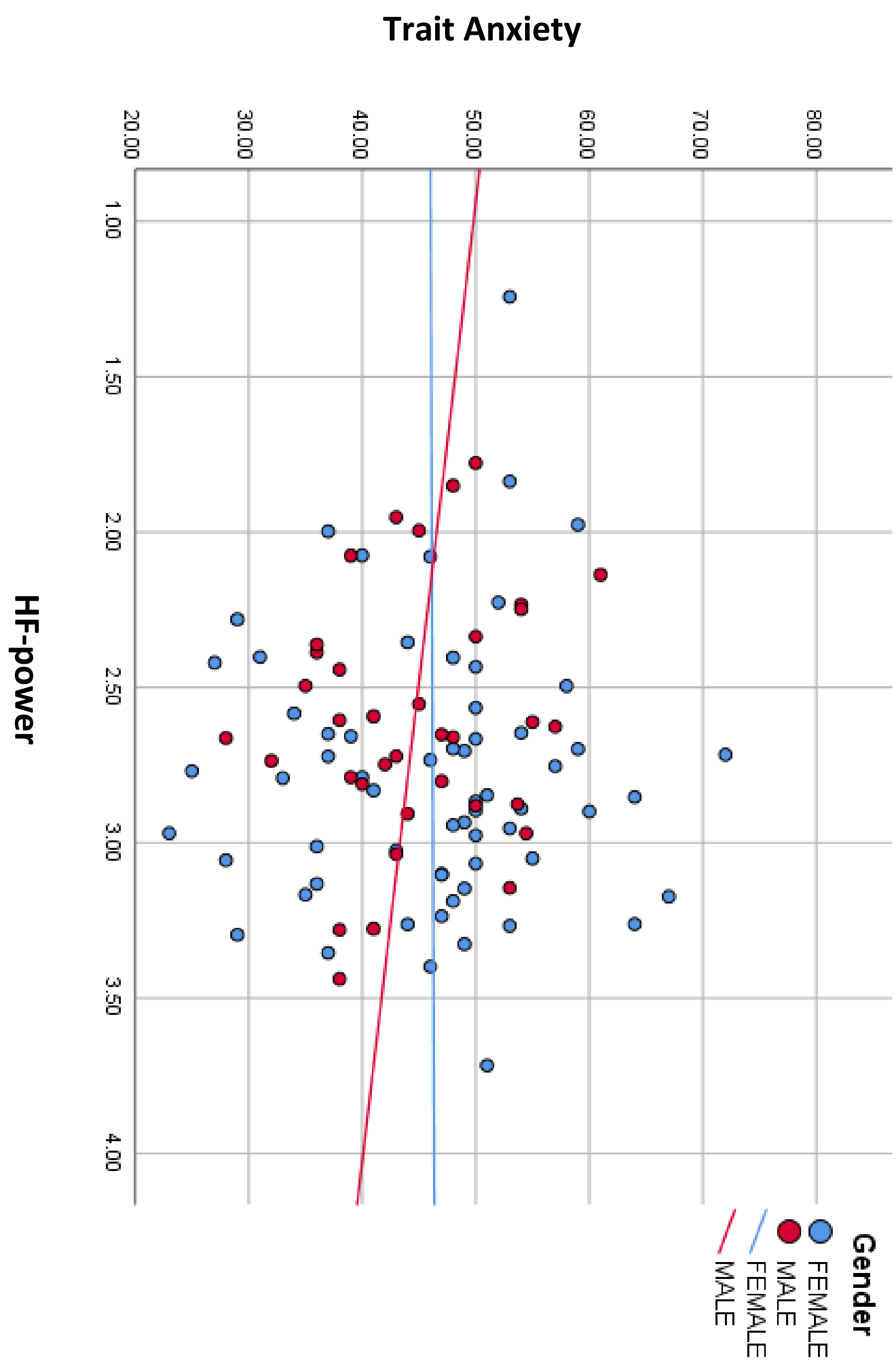

Trait Anxiety
20.00
30.00
40.00
50.00
60.00
70.00
80.00
.00
20.00
40.00
60.00
80.00
100.00
RMSSD
Gender
FEMALE
MALE
FEMALE
MALE

Figure 3: Linear (a) and quadratic (b) distributions of HF-power HRV during rest and trait anxiety

(a)



(b)

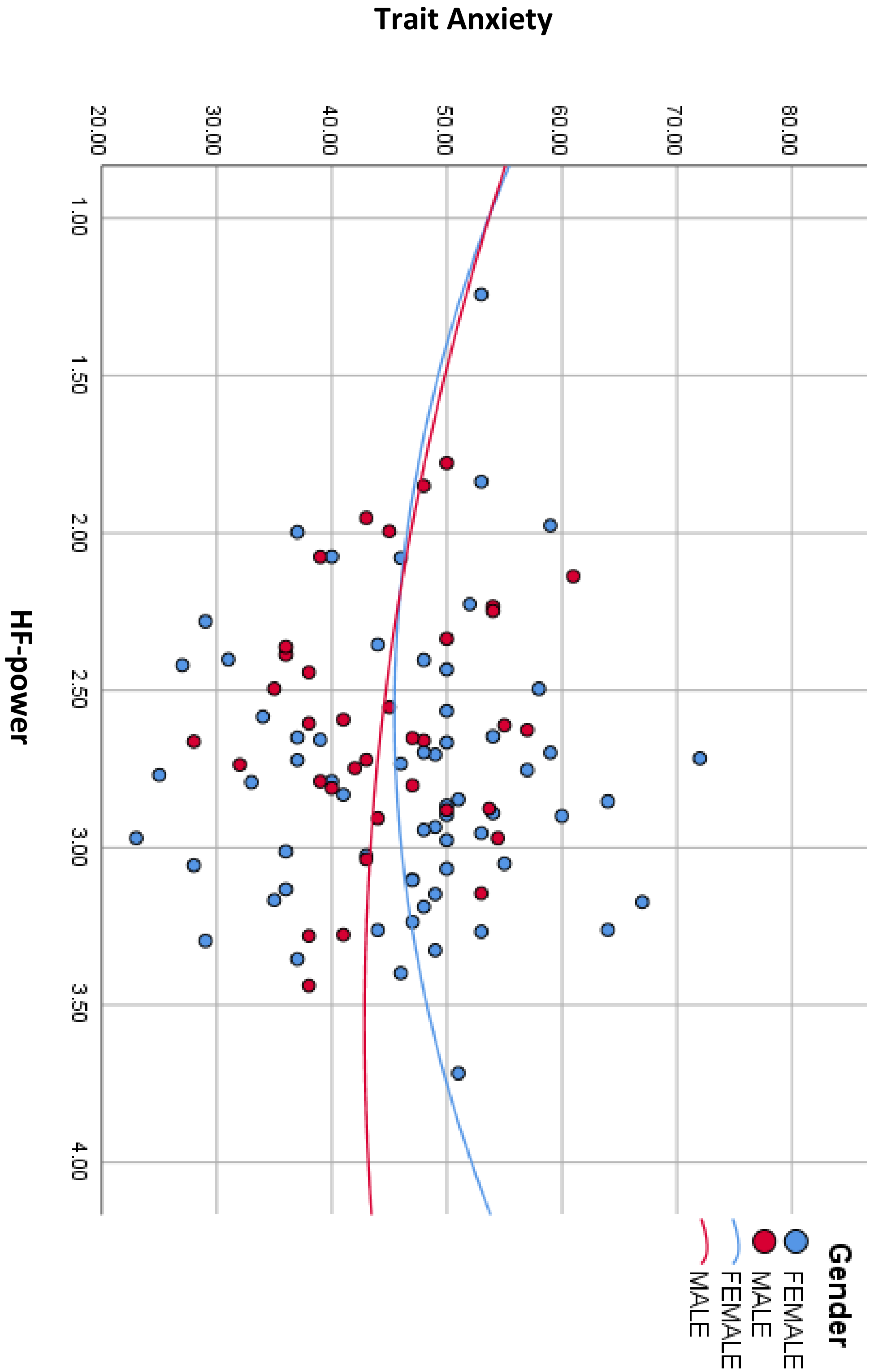
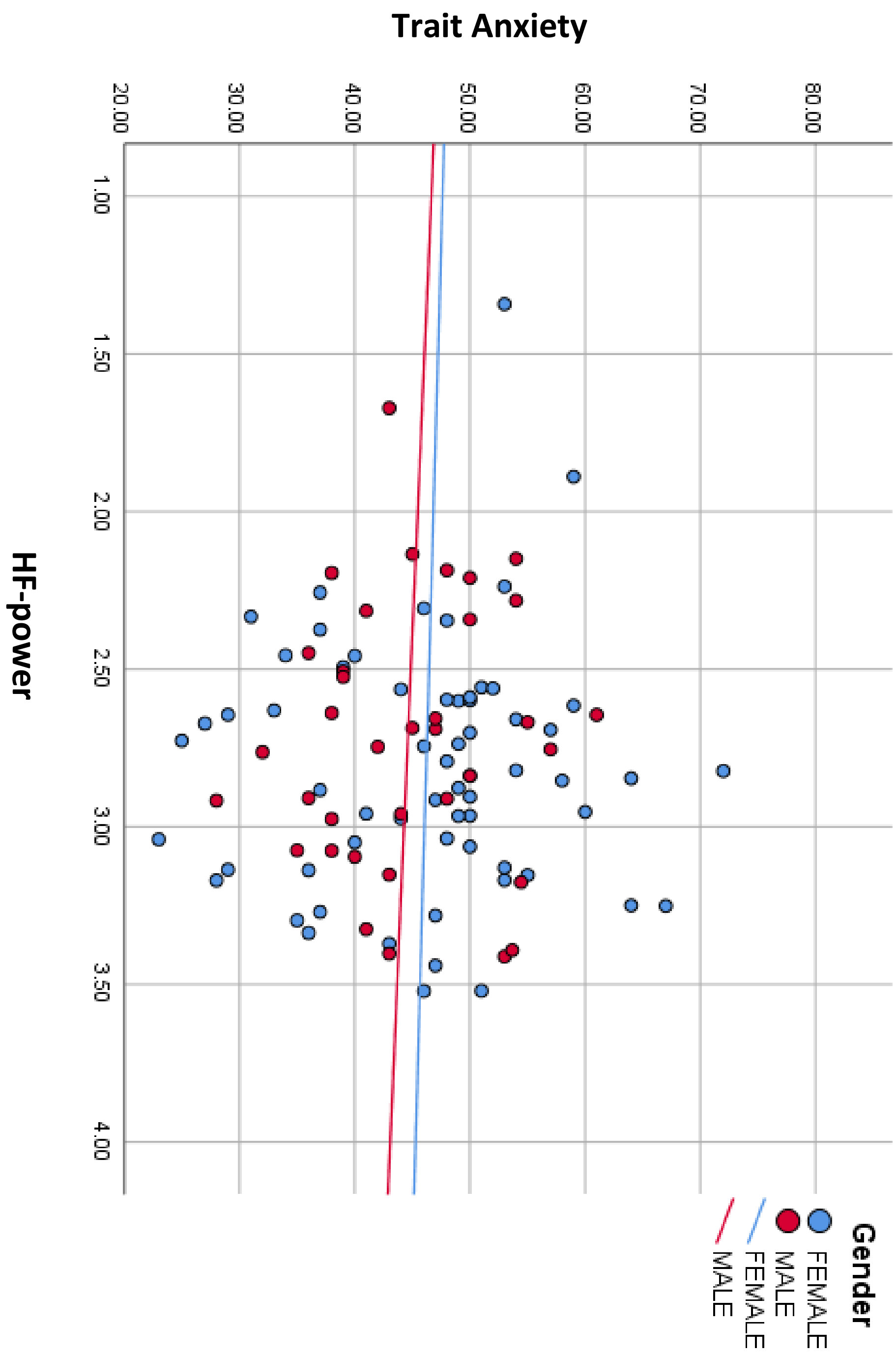

Trait Anxiety
HF-power
20.00
30.00
40.00
50.00
60.00
70.00
80.00
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Gender
FEMALE
MALE
FEMALE
MALE

Figure 4: Linear (a) and quadratic (b) distributions of HF-power HRV during task and trait anxiety

(a)



(b)

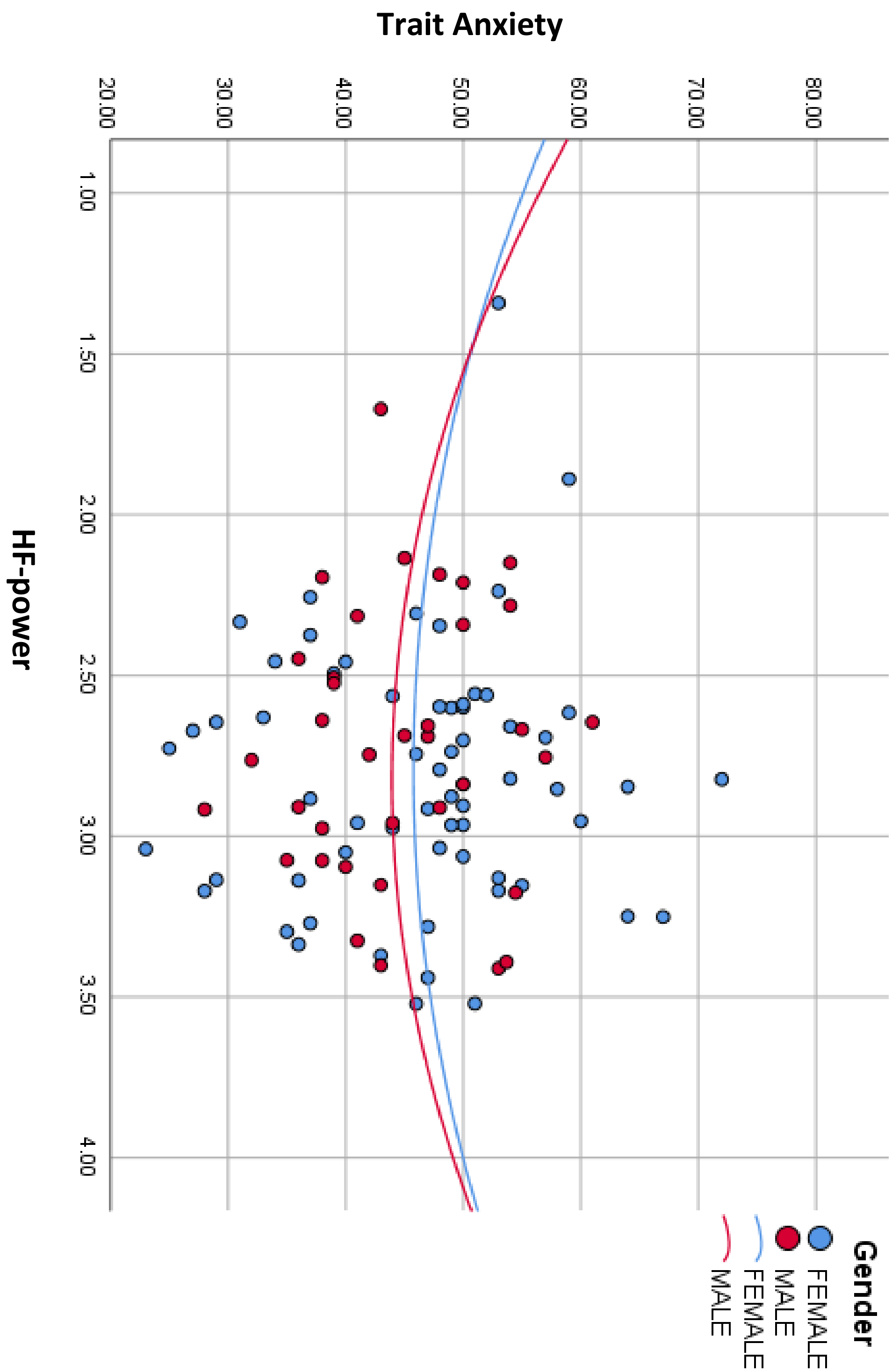

Trait Anxiety
20.00
30.00
40.00
50.00
60.00
70.00
80.00
1.00
1.50
2.00
2.50
3.00
3.50
4.00
HF-power
Gender
FEMALE
MALE
FEMALE
MALE

Table 1. Quadratic correlations between two measures of HRV and trait anxiety

	Unstandardized β	*Standard Error*	*Standardized β*	*t*	*Sig. (p)*
RMSSD rest	.000	.002	.079	.219	.827
RMSSD task	.001	.003	.243	.497	.620
HF rest	-.577	2.257	-.026	-.256	.799
HF task	3.325	3.573	.781	.930	.354

RMSSD = Root Mean of Successive Square Differences, HF = High-frequency power spectrum component

Table 2. Quadratic correlations between two measures of HRV and trait anxiety, split by gender

	Male					Female				
	Standardized β	Standard Error	Unstandardized β	t	Sig. (p)	Standardized β	Standard Error	Unstandardized β	t	Sig. (p)
RMSSD rest	.001	.002	.194	.324	.748	.002	.003	.249	.503	.616
RMSSD task	.002	.005	.352	.333	.741	.002	.004	.244	.429	.669
HF rest	1.650	6.487	.449	.254	.801	3.296	4.452	.711	.740	.462
HF task	3.770	6.227	1.097	.605	.549	2.902	4.917	.583	.590	.557

RMSSD = Root Mean of Successive Square Differences, HF = High-frequency power spectrum component

Table 3. Linear correlations between two measures of HRV and trait anxiety

	Unstandardized β	Standard Error	Standardized β	t	Sig. (p)
RMSSD rest	-.025	.056	-.045	-.443	.659
RMSSD task	-.022	.057	-.039	-.380	.705
HF rest	-.577	2.257	-.026	-.255	.799
HF task	-.702	2.408	-.030	-.291	.771

RMSSD = Root Mean of Successive Square Differences, HF = High-frequency power

Table 4. Linear correlations between two measures of HRV and trait anxiety, split by gender

	Male					Female				
	Standardized β	Standard Error	Unstandardized β	t	Sig. (p)	Standardized β	Standard Error	Unstandardized β	t	Sig. (p)
RMSSD rest	-.079	.067	-.198	-1.178	.247	.003	.085	.004	.031	.975
RMSSD task	-.087	.067	-.219	-1.308	.200	.025	.085	.038	.293	.770
HF rest	-3.239	3.218	-.170	-1.007	.321	.104	3.102	.004	.034	.973
HF task	-1.191	3.151	-.065	-.378	.708	-.782	3.416	-.029	-.229	.820

RMSSD = Root Mean of Successive Square Differences, HF = High-frequency power

Discussion

According to our results, trait anxiety (as measured by the State-Trait Anxiety Inventory) and HRV did not have a significant quadratic or linear relationship, when examined in the overall sample or in each gender group separately. This may indicate that parasympathetic nervous system reactivity is not singularly capable of predicting individual differences in trait anxiety; this finding could be true for several reasons. The vagus nerve is responsible for the PNS activation that follows a SNS response to threat or arousal. This may be well fit for individuals who have a diagnosed anxiety disorder and experience disproportionate SNS activation in response to threat. Whoever, it may not be fit for otherwise healthy individuals with high trait anxiety, who are more prone to feelings of anxiety but are not generally characterized as having a heightened SNS response. Indeed, the relationship between HRV and anxiety disorders such as generalized anxiety disorder has been more consistent in previous studies, where anxiety disorders have shown negative, linear correlations with HRV, with consistent findings across ages (Blom, Olsson, Serlachius, Ericson, & Ingvar, 2010; Llera & Newman, 2010; Lyonfields, Borkovec, & Thayer, 1995; Sharma, Balhara, Sagar, Deepak, & Mehta, 2011). While HRV is capable of predicting anxiety disorders, anxiety levels that are high but subclinical may not produce a large enough difference in ANS reactivity to predict individual differences with measurements of HRV.

Consistency of ANS reactivity measurements and task design

There is no consensus regarding the “ideal” way to measure ANS reactivity when comparing it to trait anxiety. Several studies examining this relationship have used respiratory sinus arrhythmia (RSA) as a measurement of parasympathetic reactivity (Fuller, 1992; Jönsson, 2007; Watkins et al., 1998). RSA refers to the variation in heart rate in rhythm with the respiratory cycle, where R-R intervals become shorter during inhalation and longer during exhalation (Berntson, Cacciopo, & Quigley, 1993). Similar to HRV, dysfunctional emotion regulation and clinical levels of anxiety have been consistently associated with lower RSA (Kollai & Kollai, 1992; Schmitz, Krämer, Tuschen-Caffier, Heinrichs, & Blechert, 2011; Watkins et al., 1998). RSA and HRV are the two most common measures of cardiac vagal tone in trait anxiety studies, but authors do not tend to justify their choosing of one over the other. Though they both serve as a measure of parasympathetic vagal control, they are not equal to one another, because calculating RSA requires both ECG and respiratory data, whereas HRV calculations only requires ECG data. In order to be able to compare results and understand the relationship between trait anxiety and ANS reactivity, it is important for studies to establish the physiological measurement technique that best captures the variables of interest.

Consistency is also important when considering the different domains (i.e. time domain, frequency domain, and non-linear) in which HRV is calculated. Many studies choose a time-domain measure of HRV, often either RMSSD or pNN50, the percentage of successive R-R intervals that differ by over 50ms (Shaffer & Ginsberg, 2017). Others opt for a frequency-domain measure and, if they are interested in cardiac vagal tone, almost always use the high frequency (HF) power band. The HF power band consists of ECG frequencies between 0.15-0.4 Hz, and is often called the “respiratory band” because it reflects variations in HR relative to the respiratory cycle (Shaffer & Ginsberg, 2017). There is considerable variation between studies in the chosen method, without much justification for use of one over the other – many studies make use of several of these measures. In this thesis, an exploratory analysis was conducted to consider several of these measurements because there is no clear consensus regarding the most appropriate method to use. Again, these measurements all attempt to quantify PNS cardiac vagal control – but they are not identical, so it is important to clearly establish which one is the most appropriate given the aim of the study. This approach will allow future studies comparing trait anxiety and HRV, and using common methodology, to be compared more easily.

Some researchers measure HRV during resting state, while others measure it during a stress-inducing task. Some utilize both, subtracting resting HRV from task HRV in order to understand changes in HRV from a relaxed state to a stressed, physiologically aroused state. Those who measure HRV during rest are obtaining information about individuals' baseline variation in heart rate, irrespective of stress. This can provide insight into individual differences in the reactivity of the vagus nerve when no particular threat is present, and has become a common indicator of autonomic balance (Moses, Luecken, & Eason, 2007). Other researchers measure HRV during a stress-inducing task, in order to capture individual differences in vagal response while emulating stress that is experienced in everyday life. While studying trait anxiety, these are both reasonable strategies. Differences in HRV during rest reflect high sensitivity to perceived threat involves inherently different autonomic nervous system functionality regardless of whether a stressor is present. Meanwhile, measuring HRV during a stress-inducing task provides information about flexibility of the autonomic nervous system, providing physiological insight to how the autonomic response to stress differs in individuals who have high versus "normal" levels of trait anxiety. Studies with inconsistent results across conditions only found a significant correlation during a stress-inducing task (Danilova et al., 1995; Gaburro et al., 2011). These results suggest that HRV that is measured while the body physiologically responds to stress may be a better indicator of trait anxiety than HRV measured during rest. However, because no significant relationship was found in either condition, the results from this study suggest that neither resting HRV nor HRV during stress predicts trait anxiety.

Limitations of the current study

This study has a few limitations. First, trait anxiety was measured using the State-Trait Anxiety Inventory, which is only comprised of 20 questions. This is one of the most widely used questionnaires for measuring trait anxiety, and it is not uncommon for it to be used alone. However, studies that choose to only use this questionnaire are typically not centrally interested in trait anxiety and are using it as a moderating variable. In a study that is primarily focused on trait anxiety, using multiple questionnaires would increase the likelihood that participants' levels of trait anxiety are being accurately represented. For example, the Beck Anxiety Inventory (BAI; Beck & Steer, 1993), a 21-item questionnaire that measures the construct of anxiety, could be administered in addition to the STAI-T. Though it is not designed specifically to measure trait anxiety, the BAI could be used in combination with the STAI-T in order to gain more information about participants' trait anxiety levels.

Another limitation includes the usage of the Ultimatum Game as a stress-inducing task. This task was chosen because making and receiving offers with partners has previously been associated with mental stress (Dulleck et al., 2014), especially in comparison to a resting state task. However, this task is designed to measure emotion regulation, and is not typically used for the purpose of emulating a threatening situation in everyday life. Because the central interest of the study concers individual differences in HRV in response to perceived threat, it would be ideal to use a task that is specifically designed to evoke physiological arousal while under stress. The Trier Social Stress Test (Kirschbaum, Pirke, & Hellhammer, 1993), for example, makes use of several psychological stress inducing tasks that have been frequently used in previous studies examining the psychobiological effects of stress. This allows for measurement of HRV during tasks that are typically utilized in an experimental context, such as mental arithmetic tasks, in addition to tasks that emulate stress during real-life social contexts, such as public speaking tasks (Schubert et al., 2008).

A third limitation of this study is the relatively small sample size, particularly of male participants. Several studies have found statistically significant relationships between parasympathetic reactivity and psychological stress and/or emotion regulation in one gender (Lopez et al., 2016; Woo & Kim, 2015; Zhang, Fagan, & Gao, 2017). Small effects, if present, went undetected due to the sample size, which was only large enough to detect medium to large effects. Including more male participants and increasing the general sample size would increase the statistical power of the analysis, and may indicate a significant quadratic or linear relationship between trait anxiety and HRV.

Conclusions

The results of this study indicate that HRV alone is not capable of predicting trait anxiety as measured by the State-Trait Anxiety Inventory, and this holds true for both quadratic and linear correlations. Future studies examining this relationship should consider testing for a quadratic relationship, as other emotion regulation-related variables have shown this effect. Additionally, further research should be done to determine the most appropriate indices of HRV in the context of trait anxiety for more easily comparable results. Since HRV has shown an inconsistent relationship with trait anxiety across previous studies, it may be worth studying potential moderating variables, such as environmental living conditions and social support. This thesis provides evidence that inconsistent findings between trait anxiety and HRV were not necessarily due to an incorrect assumption of linearity, but rather that HRV is not capable of predicting individual differences in the State-Trait Anxiety Inventory's measurement trait anxiety on its own.

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