Assessing the relationship between resting autonomic nervous system functioning, social anxiety, and emotional autobiographical memory retrieval

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Senior Honors Thesis 2018

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Acknowledgements

I would like to thank the Psychology Department Honors Program for providing me with the opportunity to conduct an independent research study. I would also like to thank the Cognitive and Affective Neuroscience Laboratory for providing a supportive environment to learn and grow in my research experience. Specifically, I would like to thank Dr. Elizabeth Kensinger for supporting me in my research endeavors as a research assistant and honors thesis student these last two years. I would also like to thank both Jaclyn Ford and Sarah Kark for serving as excellent mentors to me and for creating a positive, intellectually stimulating learning environment; I could not have asked for better mentors to guide me through the process of writing a thesis.

Abstract

Individuals with social anxiety disorder (SAD) tend to have emotional memory biases in the encoding and retrieval of social memories. Research has shown reduced heart rate variability (HRV) in clinical populations suffering from anxiety, including social anxiety. Heightened sympathetic activation—as measured by the electrodermal activity (EDA)—has also been associated with anxiety disorders. The aim of the present study was to examine the relation between HRV, social anxiety, and re-experiencing of emotional autobiographical memories. 44 healthy young adults were recruited from the Boston College campus through SONA. Participants were given an online survey that instructed them to retrieve 40 specific events from the past in response to 40 socially relevant cues. For each event, participants were instructed to provide a brief narrative, make several ratings for the event (on a scale from 1-7), and indicate the specific emotions they experienced both at the time of retrieval and of the event. Approximately one month after the completion of the memory survey, participants engaged in a 2-hour memory retrieval session while undergoing psychophysiological monitoring (heart rate, skin conductance, and respiration). Following the retrieval task, participants completed self-report questionnaires of social anxiety symptom severity and trait emotion regulation strategy (i.e., tendency to reappraise or suppress emotions). The present study found that positive memories had higher re-experiencing ratings as compared to negative memories. Contrary to the original study hypothesis, however, there was no significant interaction between average re-experiencing (or arousal) ratings of positive or negative social autobiographical memories and SAD likelihood. A nonlinear, cubic relationship was found between one of three metrics of HRV and social anxiety symptom severity. A significant effect was found between skin conductance and SAD likelihood, which was likely driven by an almost significance difference~~s~~ in skin conductance between the SAD unlikely and the SAD very probable groups; these findings provide further insight into the relationship between autonomic nervous system (ANS) functioning and social anxiety. Further, the present results suggest the intriguing possibility that there may be a nonlinear relationship between HRV and severity of social anxiety. Future research with a larger sample size is needed to corroborate these findings.

I. Introduction

Social anxiety disorder (SAD) is characterized by fear of negative evaluation and high levels of anxiety and avoidance in social situations (Jefferys, 1997). Cognitive models of SAD assume that differences in how individuals process social information play a causal role in the development or maintenance of the disorder (Clark et al., 1995; Rapee & Heimberg, 1997). People with SAD tend to perceive social situations as excessively dangerous; consequently, when entering into a social situation, SAD individuals become highly self-focused and they tend to process external social cues in a biased manner, such that threatening information is given priority (Clark et al., 1995). There are several other cognitive processing biases that can lead to and in turn reinforce a negative internal representation of the self in SAD (Clark et al., 1995; Hofmann, 2007; Rapee & Heimberg, 1997). These cognitive processing biases include high perceived social standards (Moscovitch & Hofmann, 2007), poorly defined social goals (Hiemisch et al., 2002), increased attention on the self in social situations (Hirsch & Clark, 2004), a tendency to interpret ambiguous information as negative and a tendency to overestimate negative evaluation by others (Hackmann et al., 1998). Cognitive models of SAD also predict that SAD individuals selectively retrieve information about themselves and their social performance, thereby reinforcing and maintaining negative images about themselves and their performance in social contexts (D'Argembeau et al., 2006). Similarly, there is substantial evidence suggesting that people with SAD exhibit attentional biases towards perceived threats (Becker et al., 2001; Clark et al., 2003). Thus, SAD individuals appear to have biases in the encoding and retrieval of social memories.

There are inconsistencies in the primary literature with respect to whether there are clear differences between people with SAD and non-anxious individuals regarding the specificity and

affective intensity of their autobiographical memories for social events. Consequently, evidence for an explicit memory biases in SAD is mixed. Anxious individuals tend to provide more negative emotional content when retrieving autobiographical memories based on self-concept related cues (Strauman, 1992). Individuals with SAD tend to view their autobiographical memories through the perspective of an external observer, and consequently tend to recall more self-referential information compared to the recall of external sensory details (D'Argembeau et al., 2006). Furthermore, during autobiographical memory retrieval, SAD individuals who had a negative self-image in mind were more anxious and took more time to retrieve positive memories and took less time to retrieve negative memories (Stopa & Jenkins, 2007). While the aforementioned findings suggest that there is a difference between SAD individuals and healthy controls in the anxiety linked to or the specificity of memories retrieved in response to socially threatening stimuli, other studies reveal no differences between these groups (Melville et al., 1994).

Some studies have also found that non-clinical individuals with high social anxiety recalled more negative self-referent trait words (Breck & Smith, 1983) or fewer positive self-referent trait words (Mansell & Clark, 1999) than individuals with low social anxiety. However, the majority of studies that assessed memory for verbal stimuli have not found a memory bias in individuals with SAD (Brendle & Wenzel, 2004; Melville et al., 1994) or in non-clinical individuals with high social anxiety (Sanz, 1996). By contrast, other studies have reported that SAD individuals or people with high social anxiety do show enhanced memory for negative facial expressions (Foa et al., 2000) or a worsened memory for positive facial expressions (D'Argembeau et al., 2003). Some evidence further suggests that remembering visual images of the self from an observer perspective while in a social situation increases anxiety and worsens

performance (Hirsch et al., 2003). These findings seem to suggest that differences in the *subjective* experience of remembering (e.g., what sorts of information are given precedence for remembering) may play a critical role in the maintenance of SAD (D'Argembeau et al., 2006). Similarly, in one study, people with SAD and non-anxious controls were asked to recall social and non-social events, and rate the phenomenal characteristics of their memories for these events (D'Argembeau et al., 2006). D'Argembeau et al. (2006) found that the memories for social events of SAD individuals contained fewer sensorial details but more self-referential details than controls' memories. Thus, these findings suggest that SAD could play a role in emotional autobiographical memory retrieval.

The etiology and symptomatology of anxiety disorders are multifaceted, but one emerging aberration in anxiety disorders, including SAD, is reduced cardiac vagal control, as measured by heart rate variability (HRV). HRV is thought to reflect autonomic flexibility and has been associated with physical and emotional functioning, with higher rate variability associated with better mental and physical health outcomes (Thayer et al., 2010). Research has shown lower HRV in clinical populations suffering from anxiety, including social anxiety, which suggests reduced autonomic flexibility in this group (Alvares et al., 2013). The *Neurovisceral Integration Model* also associates hypervigilance and worry—two common symptoms of anxiety disorders—with reduced HRV (Thayer & Lane, 2000; Bornas et al., 2005; Chalmers et al., 2014). Chronic reduced resting HRV is linked to worry (Lyonsfields et al., 1995).

The link between reduced HRV and social perception and behavior has been established by *Polyvagal Theory*, a biobehavioral model linking ANS activity to social engagement. The theory proposes that the ANS evolved in mammals in order to modulate an individual's affective states and subsequent social behavior (Porges, 1995). *Polyvagal Theory* places special emphasis

on the vagus nerve, which is the primary nerve of the parasympathetic nervous system and is crucial to healthy HRV. In particular, the theory emphasizes the role of the vagus nerve in promoting engagement or disengagement with one's social environment. Cardiac vagal control inhibits sympathetic activity, thereby promoting prosocial behavior and regulate an individual's affective experience (Porges, 2006). Under this model, it is plausible that ANS dysfunction in SAD could influence how SAD individuals experience negative and possible social events in their life (i.e., memory encoding) and could influence the extent to which individuals with SAD re-experience their memories later.

Just as *Polyvagal Theory* would predict, clinical conditions linked to diminished social functioning and capacity for social engagement are associated with dysregulated autonomic cardiac control and reduced HRV (Alvares et al., 2013; Chalmers et al., 2014). It would therefore be expected that SAD—characterized by social avoidance and disengagement—would also be reflected in reduced autonomic cardiac regulation; furthermore, this dysregulated ANS activity may also be linked to social inhibition, avoidance, and fear (Alvares et al., 2013). In fact, a meta-analysis of anxiety disorders and HRV found that, overall, anxiety disorders—such as SAD, post-traumatic stress disorder (PTSD), panic disorder, and generalized anxiety disorder (GAD)—are characterized by lower HRV relative to controls (Alvares et al., 2013; Chalmers et al., 2014).

Due to the fact that vagal influences on cardiac control are much faster than sympathetic influences (Thayer & Lane, 2000), when the fast vagal modulation is reduced the organism is less able to organize an appropriate response to environmental demands, resulting in diminished emotion self-regulation and behavioral inflexibility (Bornas et al., 2005). Consequently, vagally-mediated HRV would seem to be a good marker of both the ability to self-regulate emotions and the ability to behave appropriately when confronted with environmental demands, such as

threatening or fearful stimuli (Bornas et al., 2005). This idea would suggest that reduced HRV in SAD might be related to the emotional experience of social memories.

According to the *Neurovisceral Integration Model* (Thayer & Lane, 2000), efferent nerve fibers from the prefrontal cortex modulate parasympathetic activity and vagal inhibition of cardiac activity. The *Neurovisceral Integration Model* further describes a network of neural structures that allow individuals to adaptively respond to environmental, physiological, behavioral, cognitive, or emotional demands. A healthy autonomic nervous system is characterized by high levels of adaptive variability, or high HRV (Friedman, 2007), whereas a diseased system exhibits very little to no variability, or low HRV (Thayer, Yamamoto, & Brosschot, 2010). Similarly, healthy cardiac functioning is characterized by increased HRV, whereas reduced HRV has been associated with CVD, mortality, and poorer emotional functioning (Thayer et al., 2010). The central autonomic network (CAN) is a critical feature of the *Neurovisceral Integration Model*. This network is a group of brain regions—including the insular cortex, amygdala, hypothalamus, and periaqueductal gray matter (PAG)—that modulates autonomic, endocrine, and behavioral responses in both goal-directed actions and in adaption to environmental demands (Chalmers et al., 2014). The functionality of the CAN is reduced in anxiety, such that sympatho-excitatory responses are no longer effectively inhibited; this impaired inhibition leads to behavioral inflexibility, which may be related to the severity of anxiety (Huston & Tracey, 2011; Chalmers et al., 2014).

The link between HRV, SAD, and emotional memory biases in SAD might be related to their overlap in the brain. Regions of the brain associated with emotional and cardiac function overlap with regions involved in autobiographical memory retrieval. For instance, the medial prefrontal cortex, hippocampus, amygdala, and insular cortex are associated with both emotional

and cardiac function and autobiographical memory retrieval (Svoboda et al., 2006; Adhikari et al., 2010). It has also been found that individual differences in HRV are associated with the capacity to control cognitive function, especially in the presence of emotional stimuli (Gillie & Thayer, 2014). Recent work also suggests that HRV is a marker of emotional regulation and brain network health (Mather & Thayer, 2018).

While HRV is thought to reflect autonomic flexibility and a balance between sympathetic and parasympathetic influences, heightened sympathetic activation—as measured by the electrodermal activity (EDA) —has also been associated with anxiety disorders (Vahey & Becerra, 2015). For instance, Nikolić et al. (2016) investigated autonomic arousal in children of parents with and without SAD, as children of parents with SAD are at a higher risk of developing the disorder themselves (Beidel, 1988). The researchers found that children of parents with SAD showed increased EDA in response to socially stressful tasks (Nikolić et al., 2016). Another study examined the psychophysiological and emotional responses to peer victimization memories in people with SAD (Sansen et al., 2015). People in the SAD and high peer victimization group showed increased skin conductance levels during the memory task compared to SAD individuals in the low peer victimization group, as well as compared to non-SAD individuals in the low or high peer victimization memory group (Sansen et al., 2015). Holistically, these results suggest that anxiety, and SAD in particular, is associated with increased EDA.

The current research examined the relationship between HRV, social anxiety, and re-experiencing of emotional autobiographical memories.

The present study: aims and hypotheses

Holistically, the literature presented above indicates that (1) SAD influences the phenomenology associated with both positive and negative autobiographical memory and (2) there is a strong relation between anxiety (SAD, for instance) and reduced HRV. From these findings, the aim of the present study was (1) to examine the relationship between the psychophysiological measures, HRV and skin conductance, and social anxiety, (2) to examine the effects of social anxiety on the sense of re-experiencing and arousal of positive and negative social autobiographical memories, and (3) to examine the relationship between social anxiety severity and HRV on autobiographical memory retrieval. Given these aims, the following hypotheses were made: (1) reductions in HRV and increased skin conductance will be associated with increases in social anxiety; (2) higher social anxiety scores will be associated with greater re-experiencing and arousal of negative events and lesser re-experiencing and arousal of positive events during retrieval; and (3) participants with higher SAD and reduced HRV will have stronger arousal and re-experiencing responses to negative memories, compared to positive memories, during retrieval.

II. Methods

a. Participants

Participants were 44 native English speakers between the ages of 18-35 who have no history of psychiatric illness or neurological disorders. Participants were recruited from the Boston College campus through the SONA Systems software. Demographic information (e.g., socioeconomic status, household income, exposure to combat or trauma) was collected to identify potential confounds that should be included as covariates in the study. No participant was excluded on the basis of gender, ethnicity, or race. Participants not already in our database

were screened for eligibility (e.g., participants must be native English speakers, have no history of psychiatric illness or neurological disorder, and have no use of medications that cross the blood-brain barrier). Upon completion of screening, all eligible participants were given written informed consent in accord with the requirements of the Institutional Review Board (IRB) at Boston College. To maintain confidentiality, all eligible participants were assigned an ID number; the participants' names were only listed within a secured database.

b. Session 1: Initial Autobiographical Memory Generation

Following informed written consent, participants were given an online survey (to be completed at home and in one sitting) that instructed them to retrieve 40 specific events from the past in response to 40 socially relevant cues (e.g., friend, family, boyfriend/girlfriend). The retrieval of positive and negative memories was split equally in the trials (e.g., 20 positive memories and 20 negative memories). In order to control for order effects, the assignment of cue words to the positive or negative conditions was counterbalanced across all participants.

For each event (positive or negative), participants were asked to provide a short, but sufficiently detailed account, so that they would be able to retrieve the same memory at a later time if re-presented with their cued phrase. Along with providing a brief phrase for each event, participants were also asked to make several ratings (on a scale from 1-7) for the event, which included: the significance of the event, memory vividness, extent of re-experiencing the event during retrieval, emotional arousal, and valence associated with the event at both the time of retrieval and at the time the event took place. Participants also indicated the specific emotions (e.g., fear, anxiety, happiness, surprise) they experienced both at the time of retrieval and the time of the event itself. Finally, participants were asked to indicate how old they were at the time the event occurred, and to specify whether they viewed the event from their own perspective

(field perspective) or whether they viewed the event from the perspective of an outside observer (observer perspective).

Upon completion of the online memory survey, participants came into the laboratory to fill out a number of self-report questionnaires to assess anxiety, depression, emotion regulation, and physical fitness. These self-report measures included the Liebowitz Social Anxiety Scale (LSAS), Beck Anxiety Inventory (BAI), Beck Depression Inventory (BDI), Emotion Regulation Questionnaire (ERQ), and a physical fitness questionnaire that asked participants to specify how many minutes overall per week they spend with physical activities, and to rate (on a scale from 0-8) the frequency of their engagement with the following physical activities: aerobics, resistance training, stretching, organized sport, and outdoor activities.

c. Session 2: Memory Retrieval and Physiological Measurements

Approximately one month after the completion of the online memory survey, participants took part in a 2-hour psychophysiology session in the laboratory. The time separating the completion of the survey and coming in for session 2 of the study should be a sufficient amount of time to ensure that participants forget the specific wordings of the narratives they provided in session 1. After the completion of a video consent form, participants were set up to undergo psychophysiological monitoring (e.g., skin conductance response (SCR) and heart rate (HR)) during the retrieval task. Psychophysiological data was collected using MindWare's BioLab acquisition software sampling at 1000 Hz from Ag/AgCl electrodes for SCR and Silver ECG electrodes for HR. Respiration data was collected for movement-related artifact collection.

There was a five-minute resting baseline before the memory task began. During the retrieval task, participants were shown a brief title representing all 40 events from session 1 on a computer screen located right in front of them (e.g., "getting ready for the first day of school").

Participants were then given 30 seconds to recall the event and were asked to press a button when the event was recalled. Participants were then asked to elaborate in as much detail as possible for the next 30 seconds. Following the recall and elaboration of each event, participants rated their subjective experience associated with each event at the time of retrieval (e.g., emotional arousal and valence). Just as was the case in session 1, ratings were on a 1-7 scale in session 2. To minimize confounds, titles cuing positive and negative memories were intermixed. A baseline motor task (right or left button presses to → or ←, respectively) was included to ensure sufficient jitter in order to isolate the response to each memory retrieval event.

III. Data Collection and Analysis

a. *Behavioral Memory Data (Time 2)*

Behavioral data was collected using E-prime 2.0 (Psychology Software Tools, Inc).

b. Resting HRV

The two time-domain HRV indexes that were measured were the standard deviation of all R-R intervals (SDNN) and the square root of the mean-squared differences between successive R-R intervals (RMSSD). RMSSD is an estimate of the short-term components of HRV that is strongly associated with HF-HRV and may be less affected by changes in respiratory frequency (Quintana et al., 2016). Furthermore, RMSSD is one of the four recommended measures for time-domain HRV assessment by the Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology (1996). Spectral analysis is also commonly used to distinguish sources of heart rate variability because fluctuations of heart rate occur at different frequencies. Consequently, the frequency domain index that was measured was the ratio of the low frequency to high frequency spectral power band (LF/HF). The ratio of low frequency to high frequency spectral power (LF/HF) has been proposed as an index of sympathetic to parasympathetic balance of heart rate fluctuation (Huston & Tracey, 2011).

Generally certain measures might be more or less sensitive to emotional memory in SAD; the present study examined three measures—SDNN, RMSSD, and LF/HF—to determine which is the most sensitive to emotional memory in SAD using regression analysis.

Since measures of HRV are only valid within specific resting respiration frequencies and resting heart rates, those values were also exported for each participant. Respiration frequency is usually between 0.15 and 0.40 Hz in adults (Eckberg, 1983; Quintana et al., 2016). A reduction in respiration frequency is typically associated with an increase in heart period (Bruce, 1996; Quintana et al., 2016). Both heart rate (HR) and respiration rate also influence HRV (Gasior et al., 2016). Gasior et al. (2016) found that HR has a stronger negative correlation with HRV than does respiration rate, suggesting that HR is the main determinant of HRV reproducibility. All participants' respirations frequency and heart rate fell within the typical range for valid HRV analysis.

Electrocardiography (ECG) data for the baseline for each participant was cleaned and analyzed in Mindware HRV Analysis program, Version 3.1.5. All 5-minute baseline samples were initially processed through an automatic filter to detect potential artifacts. Artifacts were then confirmed via visual inspection and respiration- or movement-related artifacts were removed from analysis. If a participant's baseline HRV recording contained artifacts, the recording period was divided into clean, artifact-free segments. Next, HRV metrics were exported for the 5-minute baseline recording (or as clean segments of at least 60 seconds or longer) was exported from MindWare HRV Analysis program to Excel. For subjects who had more than one clean segment of at least 60 seconds, artifact-corrected HRV-related data (mean heart rate, respiration rate, and the *a priori* selected HRV measures) were averaged across clean

segments of data. Two subjects (2 male) were removed from all HRV analyses because they did not have artifact-corrected segments of at least 60 seconds in duration.

c. Resting Skin Conductance Level

Similarly, baseline EDA activity for each participant was cleaned and analyzed in MindWare EDA Analysis program, Version 3.1.5. EDA data were visually inspected for artifacts and respiration- or movement-related artifacts were removed from analysis. For each subject, clean segments of at least 30 seconds were exported from MindWare EDA Analysis program. Similar to the HRV analysis, for subjects who had more than one clean segment of 30 seconds or more, artifact-corrected EDA-related data (Tonic SCL, Total SCRs, and NS-SCRs) were averaged.

d. Event HRV During Memory Retrieval

ECG data for event-related HRV for each participant was cleaned and analyzed in Mindware HRV Analysis program, Version 3.1.5. Artifacts were visually inspected and then data was exported from MindWare HRV Analysis program into an excel spreadsheet to undergo further filtering. Since time-domain HRV measures, specifically RMSSD, are more reliable under ultra-short ECG indices compared to time-domain HRV measures (Noninvasive et al., 2011; Shaffer & Ginsberg, 2017), RMSSD and SDNN were the two event-related HRV measures that were analyzed. The threshold for outliers (*Z* score) was set to 2.5 standard deviations. Z-scores were calculated for both RMSSD an SDNN. Event-related RMSSD and SDNN values were cleaned. If the absolute value of the RMSSD or SDNN *Z* score was less than the threshold for outliers (which was set to 2.5 standard deviations), then the RMSSD or SDNN HRV value was kept. If the absolute value of the RMSSD or SDNN *Z* score was greater than the threshold for outliers, then the value was removed from further analysis. Similarly, *Z* scores for

event-related RMSSD and SDNN values were cleaned through the same filtering process. Once the ECG data for event-related HRV was cleaned, the following values were transferred into long format in excel for each participant: segment number; mean heart rate; respiration peak frequency; RMSSD raw; RMSSD event cleaned; RMSSD event cleaned *Z* score; SDNN raw; SDNN event cleaned; and SDNN event cleaned *Z* score.

One subject was removed from both baseline and event-related analyses because the heart beat perception task saved over the psychophysiology data that was collected during the memory retrieval task. Another subject was removed from event-related analyses because the computer program crashed midway through their session.

Descriptive statistics (e.g., mean, standard deviation) were reported for the following measures: age, education, BMI, LSAS, BDI, BAI, number of males, and number of females. LSAS cut off scores were used to split participants into three groups: SAD unlikely (LSAS score between 0 and 30), SAD probable (LSAS score between 31 and 59), and SAD very probable (LSAS score between 60 and 90). A one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the mean HRV values for the SAD unlikely, SAD probable, and SAD very probable groups. Three follow-up independent sample t-tests determined which groups differ from each other (Bonferroni corrected to $p<0.05/3$ for multiple comparisons). Pearson correlation tests were also ran to examine whether there is a significant negative correlation between HRV values and LSAS scores across all participants, which would replicate prior work demonstrating a link between high SAD symptom severity and low HRV.

If the present study does not find a relation between SAD and HRV, it is possible that the relation between HRV and emotional memory might relate more to general anxiety symptoms,

measured by the Beck Anxiety Inventory (BAI), or general emotional functioning, as measured by the ERQ. Independent Sample t-tests will also be run to determine whether there is a significant difference in mean HRV between low and high BAI scores, or between low and high ERQ scores.

With regard to autobiographical memory, average re-experiencing scores and arousal scores for each participant were entered into two separate 2x2 ANOVAs with within-subject factors of memory valence (negative, positive) and between subject factors of social anxiety severity group (high or low SAD). It was hypothesized that high SAD individuals will show enhanced negative re-experiencing and reduced positive re-experiencing, compared to low SAD individuals.

IV. Results

Participant Descriptive Statistics

Descriptive statistics (mean, standard deviation) from time 2 were computed for the following variables: age (19.45, 1.64); education (13.74, 1.20); BMI (22.37, 3.39); BDI (6.29, 7.41); BAI (10.86, 10.35); number of minutes of physical activity per week (244.63, 185.81); number of males (9), and number of females (33) (Table 1). Participants were split into three SAD groups (SAD unlikely, SAD probable, SAD very probable) to see if there were differences in these measures between the SAD groups. Demographic data are presented in Table 2 as a function of SAD group, and statistical differences between the groups are noted (*t*-tests were Bonferroni corrected to a significance threshold of $p < 0.017$).

A full range of LSAS scores was found in the participants (Table 3). Although a full range of LSAS scores were found, a potential limitation is that there were only 7 participants in the SAD very probable group.

Outliers for the HRV measures were identified and removed from analyses. Outliers were determined based on whether the subject's RMSSD, SDNN, or LF/HF values were at least two standard deviations above or below the mean RMSSD, SDNN, or LF/HF value for all participants. For RMSSD, 3 subjects (1 male, 2 female) were removed as outliers. For SDNN, one subject (female) was removed as an outlier. For LF/HF, 3 subjects (3 female) were removed as outliers. Two other subjects (2 male) were also not included in any analyses because they did not have baseline HRV artifact-corrected clean segments of at least 60 seconds.

Normality tests were ran to determine whether the HRV measures were normally distributed across participants. The Shapiro-Wilk test revealed that RMSSD and SDNN were normally distributed ($p = 0.893$ and $p = 0.475$, respectively). However, LF/HF was not normally distributed ($p = 0.001$). Consequently, LF/HF ratio values were Log-transformed to attain a normal distribution. The descriptive statistics (mean, standard deviation) for the HRV values (Log_LF/HF, RMSSD, and SDNN) in the three SAD groups are presented in Table 3; these values do not include the outliers that were removed.

Heart Rate Variability and Social Anxiety

Contrary to my hypotheses, a one-way analysis of variance (ANOVA) revealed no significant difference in SDNN across SAD groups ($F(2, 36) = 1.235$, $p = 0.303$). However, two separate one-way ANOVAs revealed trends toward SAD group differences in RMSSD ($F(2, 34) = 2.177$, $p = 0.129$) and Log_LF/HF ($F(2, 34) = 2.675$, $p = 0.083$). However, the possible lack of statistical power to detect effects, particularly from the small SAD very probable group, prompted follow-up analyses to examine patterns in the data. Follow-up independent *t*-tests and correlation analyses were conducted for each of the HRV measures that showed a trend in the

ANOVA (RMSSD and Log_LF/HF) and Bonferroni corrected to $p<0.05/6$ for multiple comparisons with the significance threshold set to $p<0.01$ (2 HRV measures, 3 *t*-tests each).

As predicted, RMSSD was lower in the SAD very probable group compared to the SAD unlikely group ($t(15.371) = 2.434$, $p = 0.028$), but this test did not survive the Bonferroni corrected threshold (Figure 1a). Further *t*-tests revealed no significant differences in RMSSD between the SAD unlikely and the SAD probable groups ($t(30) = -0.437$, $p = 0.665$), nor was there a significant difference between SAD probable and the SAD very probable groups ($t(19) = 2.354$, $p = 0.029$) (Table 3). These data suggest that the very probable SAD group might show reduced HRV compared to unlikely group, with the caveat that this subgroup was very small (n=5). Correlation analyses suggested a trend toward the expected negative linear relationship between LSAS and RMSSD ($r = -0.265$, $p = 0.114$) (Figure 2a).

For Log_LH/HF values, results suggest a potential difference between the SAD probable and the SAD very probable groups ($t(20) = -2.335$, $p = 0.030$) (Figure 1b). However, no significant difference was observed between the SAD unlikely and SAD probable groups ($t(30) = 1.810$, $p = 0.080$), nor between the SAD unlikely and SAD very probable groups ($t(18) = -0.553$, $p = 0.587$) (Table 3). However, these data and plots showed an intriguing *non-linear relationship* was observed in the Log_LF/HF data. As such, the relation between Log_LF/HF and LSAS data were tested for a linear, quadratic, and cubic fit using the "curve estimation" function in SPSS. The best fit for the data was the cubic fit ($r^2 = 0.235$, $F(3, 33) = 3.381$, $p = 0.03$), compared to the linear fit ($r^2 = 0.070$, $F(1, 35) = 2.635$, $p = 0.114$) and the quadratic fit ($r^2 = 0.130$, $F(2, 34) = 2.551$, $p = 0.093$) (Figure 2b). The larger r^2 value for the cubic fit suggests the U-shape of the data could exhibit an additional inflection point if there were more high LSAS participants.

The high LF/HF ratios observed in the individuals with the highest LSAS scores (indicative of SAD very probable) may be driven by one component (LF or HF) since LF/HF is a ratio of these two components. We looked into whether the significant cubic fit between Log_LF/HF and LSAS was driven more strongly by the LF or HF component (both of which were Log-transformed). There was no significant cubic fit between Log_LF or Log_HF and LSAS scores ($r^2 = 0.054$, $F(3, 33) = 0.622$, $p = 0.606$; and $r^2 = 0.053$, $F(3, 33) = 0.615$, $p = 0.610$, respectively).

Heart Rate Variability and General Anxiety or General Emotional Functioning

It is possible that the relationship between HRV and anxiety might be related more to more general anxiety symptoms or to general emotional functioning, such as emotion regulation style. Independent sample *t*-tests were conducted to determine whether there was a significant difference in mean HRV (RMSSD, SDNN, and Log_LF/HF) between low and high BAI scores, based on a median splits analysis of the BAI data.

There was no significant difference in mean RMSSD between the low and the high BAI groups ($t(35) = -0.206$, $p = 0.838$) (Figure 3a). Similarly, there was no significant difference in mean SDNN between the low and the high BAI groups ($t(38) = -0.623$, $p = 0.537$) (Figure 3b). Finally, there was no significant difference in mean Log_LF/HF between the low and the high BAI groups ($t(35) = 1.184$, $p = 0.245$) (Figure 3c). Independent sample *t*-tests were conducted to determine whether there was a significant difference in mean HRV (RMSSD, SDNN, and Log_LF/HF) between low and high ERQ scores. There was no significant difference in mean RMSSD between the low and the high ERQ reappraisal groups ($t(34) = 1.142$, $p = 0.262$) (Figure 4a). Similarly, there was no significant difference in mean SDNN between the low and the high ERQ reappraisal groups ($t(37) = 0.332$, $p = 0.742$) (Figure 4b). Finally, there was no significant

difference in mean Log_LF/HF between the low and the high ERQ reappraisal groups ($t(34) = 0.081$, $p = 0.936$) (Figure 4c). There was also no significant difference in mean RMSSD between the low and the high ERQ suppression groups ($t(35) = -0.115$, $p = 0.909$) (Figure 5a). Similarly, there was no significant difference in mean SDNN between the low and the high ERQ suppression groups ($t(38) = -0.135$, $p = 0.893$) (Figure 5b). Finally, there was no significant difference in mean Log_LF/HF between the low and the high ERQ suppression groups ($t(35) = 0.504$, $p = 0.617$) (Figure 5c).

Skin Conductance and Social Anxiety

While the HRV measures examined here are thought to tap into cardiac vagal tone and the balance between the sympathetic/parasympathetic nervous systems, skin conductance measures sympathetic arousal. Since anxiety disorders are often characterized by heightened sympathetic arousal (Vahey & Becerra, 2015), it would seem plausible that there would be differences in skin conductance between the three SAD groups. A one-way ANOVA was conducted to see if there was a difference in skin conductance level across the three SAD groups. A significant difference in mean skin conductance (SC) was observed between the SAD groups ($F(2, 39) = 4.475$, $p = 0.018$), suggesting skin conductance varied across SAD groups.

Independent sample *t*-tests were conducted to determine which social anxiety groups differ from each other (Bonferroni corrected to $p<0.05/3$ for multiple comparisons with the significance threshold set to $p<0.017$). There was a trend towards a significant difference in mean skin conductance between the SAD unlikely (M = 5.59) and the SAD very probable (M = 15.94) groups, although this trend did not meet the Bonferroni correction threshold for significance of $p < 0.017$ ($t(6.566) = -2.031$, $p = 0.084$) (Figure 6). However, there was no significant difference in skin conductance between the SAD unlikely (M = 5.59) and the SAD

probable (M = 8.13) groups ($t(33) = -1.204$, $p = 0.237$), nor between the SAD probable (M = 8.13) and the SAD very probable (M = 15.94) groups ($t(7.586) = -1.477$, $p = 0.180$) (Figure 6). Pearson correlation tests examined whether there was a significant positive correlation between skin conductance and LSAS scores across all participants, which would replicate prior work demonstrating a link between high SAD symptom severity and high skin conductance levels. A significant positive correlation was found between mean skin conductance and LSAS scores across all participants ($r = 0.342$, $n = 42$, $p = 0.026$) (Figure 7). Thus, the results from the independent *t*-tests and correlation analyses suggest that mean skin conductance increases linearly with anxiety.

HRV and Social Anxiety as Potentially Dependent on Skin Conductance Levels

Since there was a significant difference in mean skin conductance across SAD groups, it was hypothesized that the relationship between HRV and LSAS may depend on high or low skin conductance levels. To test this possibility, a median split was conducted on mean skin conductance (median = 6.193). Participants were split into low or high skin conductance groups (0 or 1, respectively), based on whether his or her mean skin conductance fell below or above the median skin conductance. Following the median split, a one-way ANOVA was run to see if splitting participants by high or low skin conductance drove a significant difference in mean HRV (RMSSD, SDNN, and Log_LF/HF) across SAD groups (unlikely, probable, or very probable). For individuals with high skin conductance, there was a trend towards a significant difference in mean RMSSD across SAD groups ($F(2, 14) = 3.355$, $p = 0.064$). An independent sample *t*-test was conducted to see if there was a significant difference in mean RMSSD between the three SAD groups (Bonferroni corrected to $p<0.05/3$ for multiple comparisons with the significance threshold set to $p<0.017$). In the high skin conductance group, there was a trend

towards a significant difference in mean RMSSD between the SAD probable and the SAD very probable groups ($t(9) = 2.381$, $p = 0.041$), and also between the SAD unlikely and the SAD probable groups ($t(12) = -2.014$, $p = 0.067$) (Figure 8). Since skin conductance is also a measure of sympathetic arousal (in which high skin conductance levels are correlated with increased anxiety), these results support the plausibility that skin conductance could play a role in the relationship between HRV and social anxiety.

To further investigate the potential role of skin conductance on the relationship between RMSSD and social anxiety, a Pearson Correlation Test was conducted with participants split based on low or high skin conductance. Interestingly, there was a significant negative correlation between RMSSD and LSAS scores in the low skin conductance group ($r = -0.455$, $p = 0.044$, $n = 20$). However, there was not a significant negative correlation between RMSSD and LSAS scores in the high skin conductance group ($r = -0.067$, $p < 0.798$, $n = 17$).

Autobiographical Memory and Social Anxiety

Two, 2x3 between-subjects ANOVA with factors of memory valence (negative, positive) and SAD group (unlikely, probable, very probable) examined the effects of social anxiety on 1) re-experiencing ratings and 2) arousal ratings of positive and negative autobiographical memories. There was a significant main effect of valence for average re-experiencing ratings; positive memories had higher re-experiencing ratings as compared to negative memories ($F(1, 38) = 5.144$, $p = 0.029$). However, there was no significant interaction between valence and SAD group for average re-experiencing ratings ($F(2, 38) = 1.194$, $p = 0.314$) (Figure 9). Contrary to my hypothesis, there was no significant valence by SAD group interaction for average arousal ratings ($F(2, 38) = 0.461$, $p = 0.634$), nor was there a significant main effect of valence ($F(1, 38) = 0.689$, $p = 0.412$) (Figure 10).

Independent-sample *t*-tests were conducted to see whether there was SAD group differences in the average re-experiencing and arousal ratings for negative and positive autobiographical memories (Bonferroni corrected to $p<0.05/6$ for multiple comparisons with the significance threshold set to $p<0.01$ (2 event-related average re-experiencing or arousal rating measures, 3 *t*-tests each). There were no significant differences in average re-experiencing ratings for negative and positive autobiographical memories between SAD groups (all $p > 0.1$) (Table 4). There was a trend towards a significant difference in average arousal ratings of negative autobiographical memories between the SAD unlikely and the SAD very probable groups ($t(22) = -2.063$, $p = 0.051$). There was also a trend towards a significant difference in average arousal ratings of positive autobiographical memories between the SAD unlikely and the SAD very probable groups ($t(22) = -2.303$, $p = 0.031$), as well as between the SAD probable and the SAD very probable groups ($t(22) = -2.279$, $p = 0.033$) (Table 9).

Since the very probable group was so small, additional 2x2 ANOVAs examined group by memory valence interactions when the sample was split into two social anxiety groups (high LSAS, low LSAS) on the basis of a median split. There was no significant interaction between average re-experiencing of positive and negative autobiographical memories and high or low SAD ($F(1, 39) = 0.463$, $p = 0.500$). There was also no significant interaction between average arousal of positive and negative autobiographical memories and high or low SAD ($F(1, 39) = 0.026$, $p = 0.873$).

Event-Related HRV and Social Anxiety

Two repeated-measures ANOVA with factors of valence (negative, positive) of event-related HRV (RMSSD or SDNN) and SAD group (unlikely, probable, very probable) were conducted. The analyses revealed a trend towards a significant main effect of event-related

RMSSD ($F(1, 38) = 3.349$, $p = 0.075$) in the predicted direction, but no significant main effect of SAD group ($F(2, 38) = 0.459$, $p = 0.635$) (Figure 11), nor a significant interaction between event-related RMSSD and SAD group ($F(2, 38) = 0.094$, $p = 0.910$). There was also no significant main effect of event-related SDNN ($F(1, 38) = 0.576$, $p = 0.453$), nor a significant main effect of SAD group ($F(2, 38) = 1.875$, $p = 0.167$) (Figure 12).

Physical Activity and Heart Rate Variability

Since previous literature has suggested a linear, positive relationship between physical activity and HRV, where reduced HRV is associated with reduced physical activity (Alvares et al., 2013), the present study sought to corroborate these findings. A significant positive correlation was found between RMSSD and physical activity ($r = 0.580$, $p = 0.001$, $n = 35$) and between SDNN and physical activity ($r = 0.397$, $p = 0.013$, $n = 38$). However, there was a non-significant negative correlation between Log_LF/HF and physical activity ($r = -0.327$, $p = 055$, $n = 35$).

Given both the present findings on the relationship between physical activity and HRV, as well as the present findings on the relationship between HRV and social anxiety, a fit test was conducted to look for a linear relationship between physical activity and LSAS. One subject (female) was removed from analyses as an outlier because her physical activity was greater than two standard deviations above the mean physical activity of 274.52 minutes per week (1500 minutes per week). There was a significant effect for a linear relationship between physical activity and LSAS ($r^2 = 0.139$, $F(1, 39) = 6.275$, $p = 0.017$) (Figure 13). However, this significant effect was lost when the outlier was included in analyses ($r^2 = 0.049$, $F(1, 40) = 2.039$, $p = 0.161$). Thus, with the outlier removed from analyses, these data suggest higher social anxiety is associated with reduced physical activity.

V. Discussion

The aims of the present study were (1) to examine the relationship between the psychophysiological measures, HRV and skin conductance, and social anxiety, (2) to examine the effects of social anxiety on the sense of re-experiencing and arousal of positive and negative social autobiographical memories, and (3) to examine the relationship between social anxiety severity and HRV on autobiographical memory retrieval.

From the first aim, it was hypothesized that reductions in HRV would be associated with increased social anxiety. Contrary to this hypothesis, a *nonlinear relationship* was found between Log_LF/HF values and social anxiety. More specifically, there was a significant cubic fit between Log_LF/HF values and LSAS scores across participants. This cubic fit seemed to be driven by one of the subjects (female) with an LSAS score of 86, which happened to be the most socially anxious person in our study. Furthermore, a significant linear fit was found between physical activity and LSAS, suggesting that the cubic fit between Log_LF/HF and LSAS was not driven by physical activity.

The higher LF/HF ratio observed in the SAD very probable group (n= 5) was puzzling because it did not corroborate much of the literature on HRV and SAD, which has consistently reported a linear, inverse relationship between these variables (Thayer & Lane, 2000; Bornas et al., 2005; Alvares et al., 2013; Chalmers et al., 2014). There does not appear to be much literature suggesting a nonlinear relationship between HRV and anxiety. However, one study reported that nonlinear HRV indices might provide additional information about behavior in relation to cognition and mood compared to linear HRV indices (Young & Benton, 2015). In future work, it will be critical to fill in the 80+ LSAS score side with more participants, to be able to better gauge whether the curve between Log_LF/HF values and LSAS goes down

(indicative of a cubic fit with two inflection points) or goes back up (indicative of a u-shaped quadratic distribution with one inflection point).

It is worth exploring the implications of these two alternatives (e.g., whether there is a cubic or a quadratic nonlinear relationship between LF/HF and social anxiety levels). If there is a cubic relationship (as the findings from the present study suggest), the high LF/HF ratios observed in the individuals with the highest LSAS scores (indicative of SAD very probable) may be driven by one component (LF or HF) since LF/HF is a ratio of these two components. This hypothesis was tested; however, there was no significant cubic fit between Log_LF or Log_HF and LSAS scores. Thus, it does not appear that either Log_LF or Log_HF separately drives the significant cubic fit between Log_LF/HF and LSAS.

Another possible explanation for the nonlinear relationship between Log_LF/HF and LSAS may have to do with skin conductance levels, since heightened sympathetic activation—as measured by the electrodermal activity (EDA) —has also been associated with anxiety disorders (Vahey & Becerra, 2015). The findings from this study corroborated previous literature, which has suggested that increased skin conductance is associated with increased social anxiety (Sansen et al., 2015; Vahey & Becerra, 2015; Nikolić et al., 2016). A significant effect was found between SAD group (SAD unlikely, SAD probable, and SAD very probable) and skin conductance. This effect was likely driven by an almost significant difference in skin conductance between the SAD unlikely and the SAD very probable groups. Furthermore, the present study found a significant positive correlation between skin conductance and LSAS scores across all participants.

Given that skin conductance levels linearly increased with social anxiety severity, this study tested the possibility of whether the nonlinear relationship between Log_LF/HF and LSAS

may really be about group differences in skin conductance levels rather than differences in HRV. The present study found that for individuals with high skin conductance, there was a trend towards a significant difference in mean RMSSD across SAD groups. Furthermore, this trend was likely driven by a trend towards a significant difference in mean RMSSD between the SAD probable and the SAD very probable groups, as well as between the SAD unlikely and the SAD probable groups. Interestingly, in the high skin conductance group, mean RMSSD increased between the SAD unlikely and the SAD probable groups and decreased between the SAD probable and the SAD very probable groups. On the contrary, in the low skin conductance group, mean RMSSD decreased with increased anxiety. These results provide support for the idea that sympathetic and parasympathetic activation are independent of each other. Low sympathetic arousal, as indexed by reduced skin conductance, was associated with a negative correlation between RMSSD and LSAS. However, increased sympathetic arousal, as indexed by heightened skin conductance, seemed to be associated with a nonlinear relationship between RMSSD and LSAS. One would expect there to be a negative correlation between HRV and social anxiety and a positive correlation between skin conductance and social anxiety, where individuals with high social anxiety (higher LSAS scores) would have reduced HRV *and* increased skin conductance. The present correlation findings were surprising, however, because the significant negative correlation between RMSSD and social anxiety was only seen in the low skin conductance group. In the high skin conductance group, there seems to be something potentially adaptive with having moderate social anxiety (SAD probable) with regards to RMSSD. Overall, these findings provide suggestive evidence for the independence of HRV and skin conductance as measures of social anxiety.

From the second and third aims, it was hypothesized that higher social anxiety scores would be associated with greater re-experiencing and arousal of negative events and lesser re-experiencing and arousal of positive events during retrieval, and that participants with higher SAD and reduced HRV would have stronger arousal and re-experiencing responses to negative memories, compared to positive memories, during retrieval.

There was a significant main effect of valence for average re-experiencing ratings; positive autobiographical memories were given higher re-experiencing ratings as compared to negative autobiographical memories. Contrary to my hypothesis, there was no significant interaction between valence and SAD group for average re-experiencing or arousal ratings. The present study also found no significant main effect of event-related HRV (RMSSD or SDNN), nor a significant interaction between event-related HRV and SAD group. One potential caveat was that baseline pre-stimulus HRV was not subtracted off from the event-related HRV when calculating event-related HRV. It could be that a main effect of event-related HRV or a significant interaction between event-related HRV and SAD group could only be observed when subtracting off pre-stimulus HRV. It could also be that higher-resolution analysis models such as multi-level modeling are needed in order to observe event-related effects.

The present findings on autobiographical memory retrieval and social anxiety did not corroborate previous findings that have shown that individuals with high social anxiety levels have a tendency to show greater re-experiencing of negative events during retrieval (Strauman, 1992; D'Argembeau et al., 2006; Stopa & Jenkins, 2007). One study, for instance, examined negative autobiographical memories in SAD, Panic Disorder (PD), or healthy controls (O'Toole et al., 2016). Participants were asked to retrieve memories cued with verbal phrases that were associated either with social anxiety (SA) or with panic anxiety (PA). The researchers found that

among the participants with SAD, retrieval of SA-cued memories was associated with stronger imagery and was rated as more traumatic (O'Toole et al., 2016).

The lack of a significant interaction between average re-experiencing (or arousal) ratings of positive and negative memories and SAD likelihood may be explained by the possibility that cued autobiographical memory paradigms (as done in this study) might not reveal SAD differences. However, a free recall type of task could reveal memory biases between healthy and socially anxious individuals. Regarding the inconsistency in the literature on memory biases and social anxiety, two review papers suggested that memory biases in SAD are most likely to be seen when the stimuli directly relate to the central concerns of negative evaluation by others (Coles & Heimberg, 2002; Heinrichs & Hofmann, 2001). Cognitive models of SAD suggest that individuals with SAD are biased towards negative evaluation of the self in social and performance situations, and that following a social-evaluative performance, people with SAD are more likely to ruminate about the negative aspects of the event (Rapee & Heimberg, 1997). Since free-recall is a paradigm that allows for rumination, it seems plausible that memory biases between healthy and socially anxious individuals would be most evident in a free-recall task, where those with increased social anxiety would likely show increased rumination and bias towards negative evaluation or negative performance-related events. One study, for instance, examined post-event rumination and recall bias for a social performance event in a free-recall task in high and low socially anxious individuals (Edwards et al., 2003). The researchers found that social anxiety was associated with increased rumination of a negative event during the free-recall task (Edwards et al., 2003).

To summarize, the present study examined the relation between HRV, social anxiety, and re-experiencing of emotional autobiographical memories. The present study found that although

positive autobiographical memories were given higher re-experiencing ratings than negative memories, there was no significant interaction between re-experiencing (or arousal) ratings and SAD likelihood. There was, however, a nonlinear, cubic relationship between one of three metrics of HRV and social anxiety symptom severity. This nonlinear relationship may suggest that a subset of individuals in the SAD very probable group are engaged in cognitive mechanisms to normalize their otherwise low HRV, as seen in the individuals with the most severe social anxiety. A significant effect also was found between skin conductance and SAD likelihood, which was likely driven by almost significant differences in skin conductance between the SAD unlikely and the SAD very probable groups. This finding has important clinical applications in the treatment of SAD; skin conductance levels could be used in biofeedback training designed to reduce anxiety, since skin conductance increased linearly with social anxiety severity. Further research with a larger sample size (and specifically larger representation within the SAD very probable group) is needed to determine whether there is indeed a nonlinear relationship between Log_LF/HF and social anxiety, and whether this nonlinear relationship is cubic or quadratic.

Figures and Tables

Table 1. Descriptive Statistics for All Participants (n = 42, except for physical activity, n = 41)

	Range	Mean (SD)
Age	17-24	19.45 (1.64)
Education (years)	12-16	13.74 (1.20)
BMI	17.43-29.76	22.37 (3.39)
BDI	35	6.29 (7.41)
BAI	37	10.86 (10.35)
Physical activity (min) per week*	900	244.63 (185.81)

* Outlier removed

Table 2. Descriptives That Differed Between SAD Groups Using *t*-test for Equality of Means.

	SAD Unlikely M (SD)	SAD Probable M (SD)	SAD Very Probable M (SD)
N	17	17	7
Age	20.18 (1.78)*	19.11 (1.57)	18.57 (0.54)
Education (years)	14.41 (1.31)*	13.99 (0.93)	12.86 (0.38)
BDI	2.24 (1.92)*	7.11 (6.93)	14.00 (10.55)
BAI	4.76 (5.39)*	13.11 (10.94)	19.86 (9.99)
Physical activity (min) per week	252.50 (177.96)~	261.18 (129.85)*	92.86 (81.39)

Age: *Mean age significantly differed between the SAD unlikely and the SAD very probable groups ($t(22) = 3.373$, $p = 0.003$)
Education: *Mean education significantly differed between the SAD unlikely and the SAD probable groups ($t(28.724) = 2.643$, $p = 0.013$), and between the SAD unlikely and the SAD very probable groups ($t(20.834) = 4.452$, $p = 0.001$)
BDI: *Mean BDI significantly differed between the SAD unlikely and the SAD probable groups ($t(19.743) = -2.872$, $p = 0.010$)
BAI: *Mean BAI significantly differed between the SAD unlikely and the SAD probable groups ($t(25.099) = -2.886$, $p = 0.008$), and between the SAD unlikely and the SAD very probable groups ($t(22) = -4.833$, $p = 0.001$)
Physical activity: *Mean physical activity significantly differed between the SAD probable and the SAD very probable groups ($t(22) = 3.160$, $p = 0.005$); ~ There was a trend towards a significant difference in number of minutes of physical activity between the SAD unlikely and the SAD very probable groups, but did not meet the Bonferroni corrected significance threshold of $p < 0.017$ ($t(21) = 2.250$, $p = 0.035$)

Table 3. LSAS Scores and HRV Values Across SAD Groups. Mean (SD).

SAD Group	LSAS	Log_LF/HF (M, SD)	RMSSD (M, SD)	SDNN (M, SD)
1-"Unlikely SAD"	15.77 (7.13)	0.046 (0.34)	36.82 (16.67)	57.82 (19.83)
2-"Probable SAD"	44.28 (8.73)	-0.14 (0.23)	39.19 (13.96)	55.75 (16.66)
3-"Very likely"	71.43 (8.42)	0.14 (0.24)	23.63 (7.74)	54.62 (31.27)

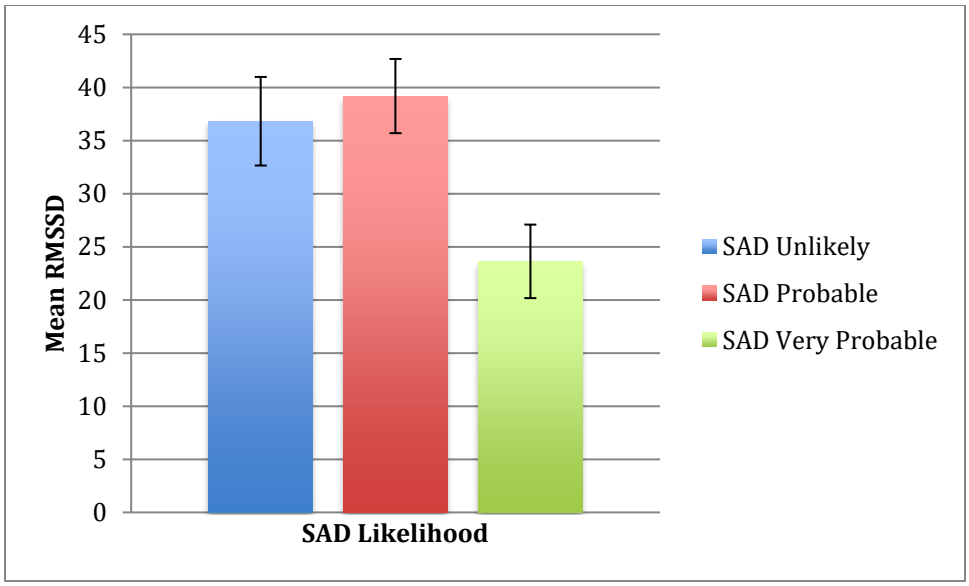

Figure 1a. Mean RMSSD for SAD Likelihood Groups. Error bars represent 1 SE.

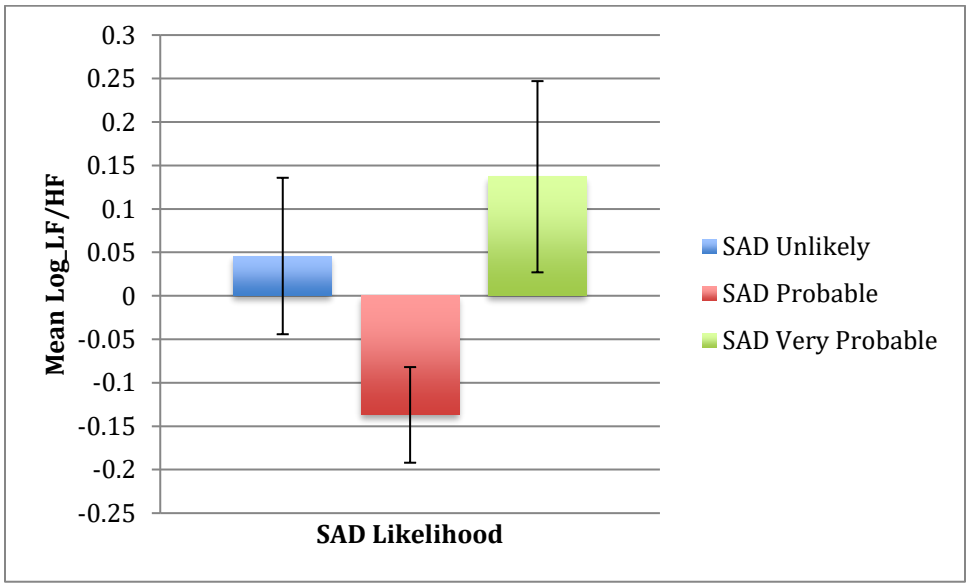

Figure 1b. Mean Log_LFHF Ratios for SAD Likelihood Groups. Error bars represent 1 SE.

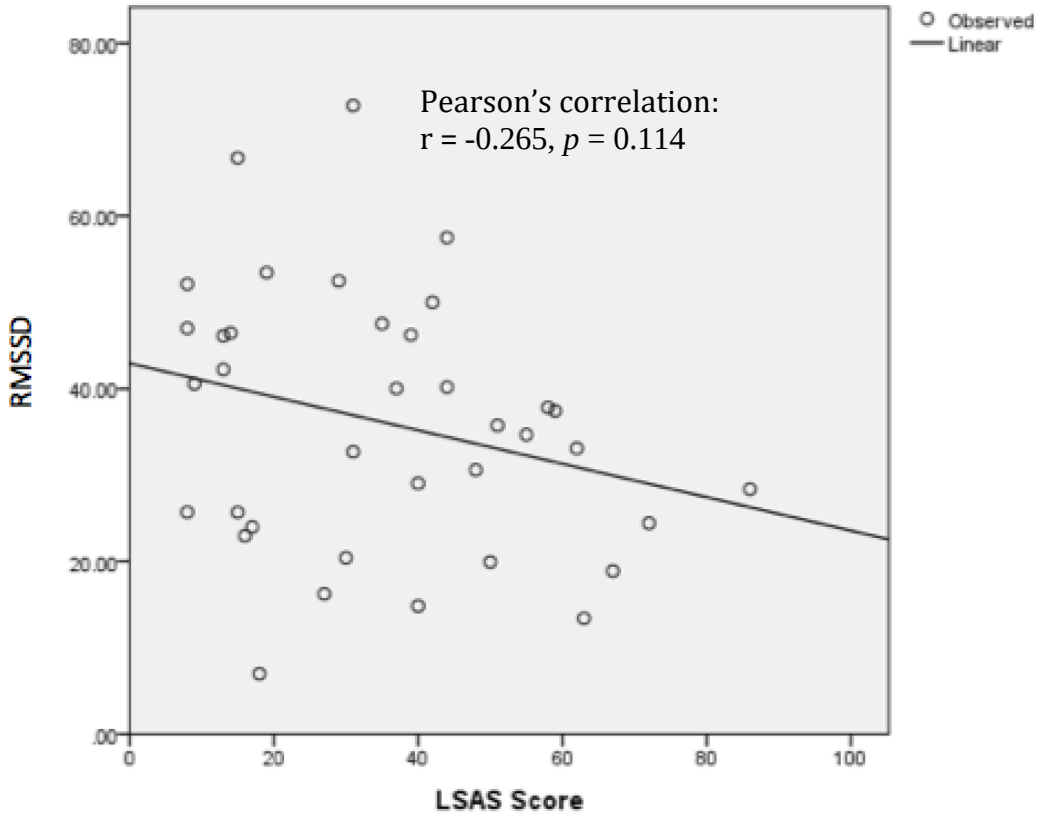

Figure 2a. Relationship Between RMSSD and LSAS.

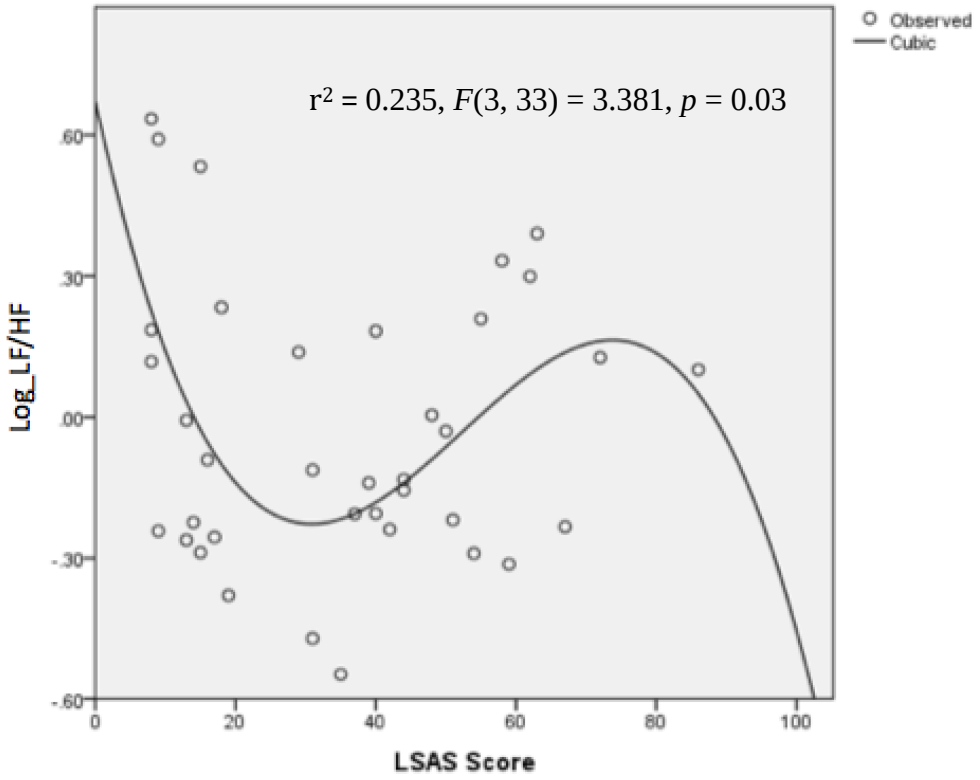

Figure 2b. Relationship Between Log_LF/HF and LSAS.

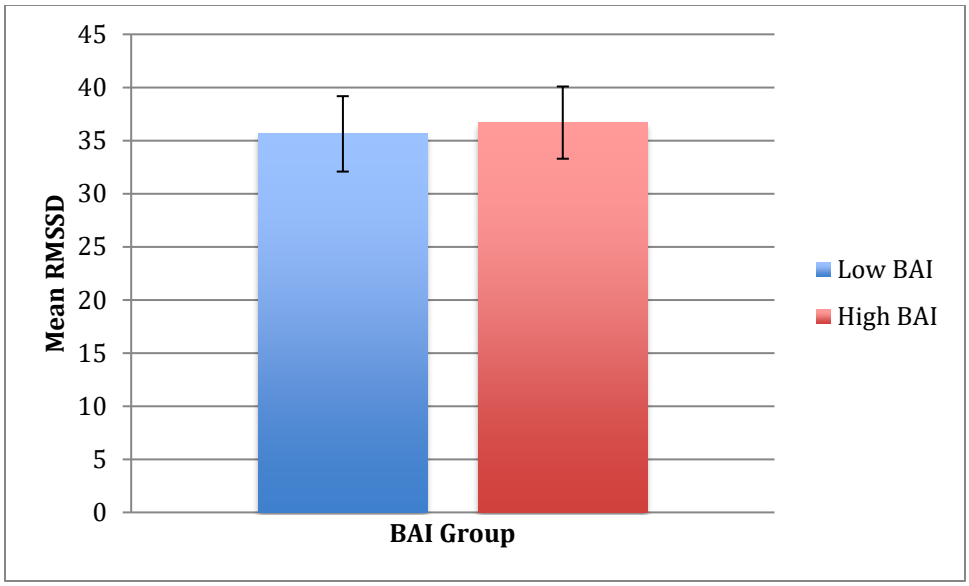

Figure 3a. Mean RMSSD for Low and High BAI Groups. Error bars represent 1 SE.

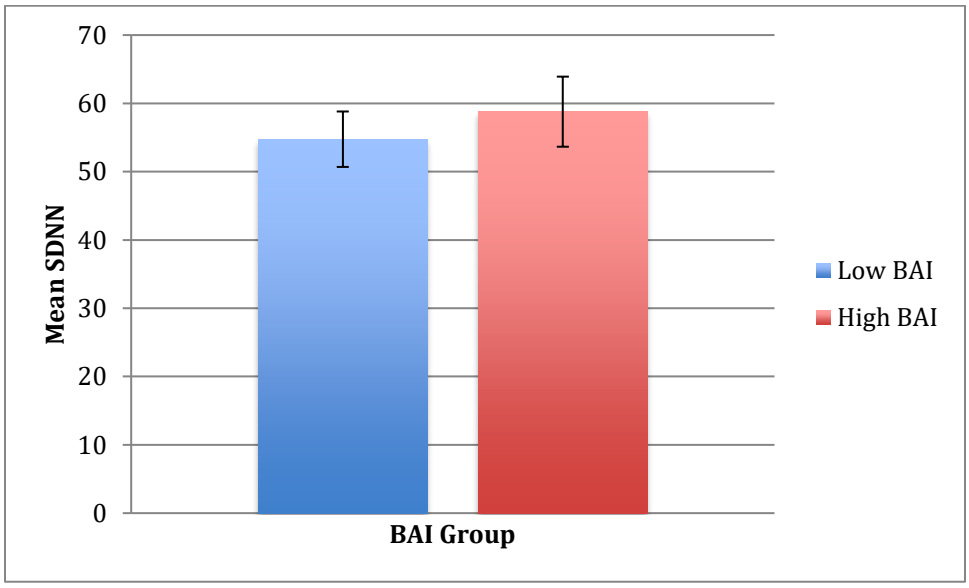

Figure 3b. Mean SDNN for Low and High BAI Groups. Error bars represent 1 SE.

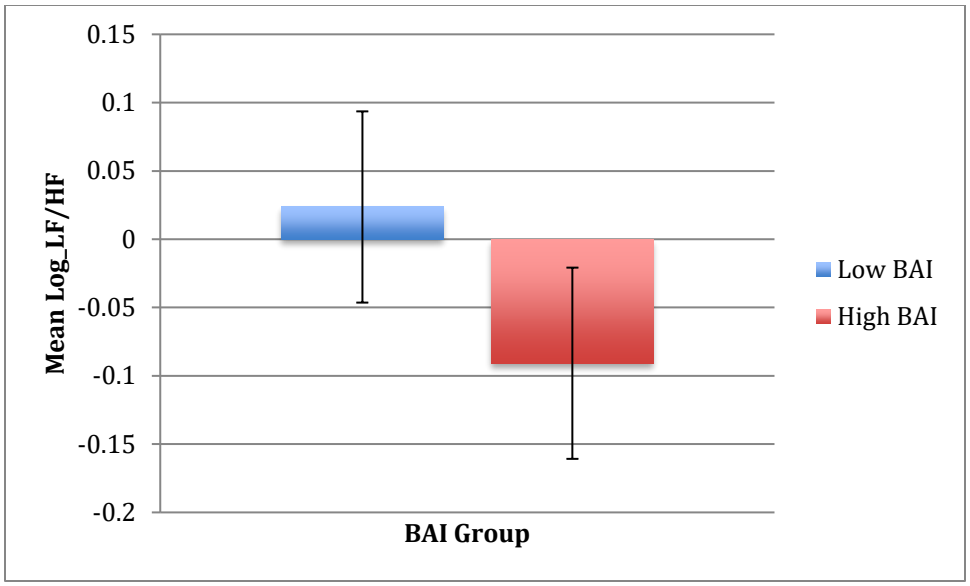

Figure 3c. Mean Log_LFHF Ratios for Low and High BAI Groups. Error bars represent 1 SE.

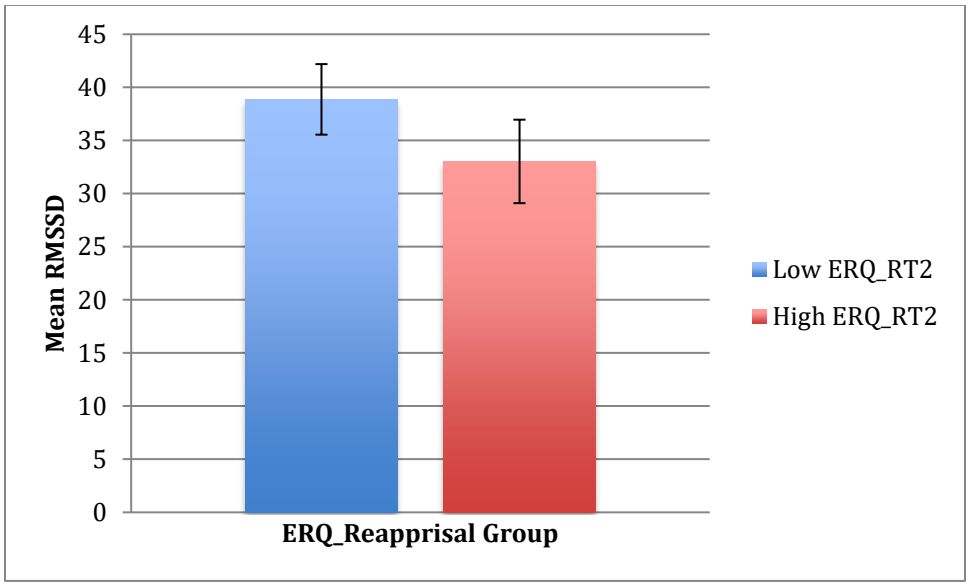

Figure 4a. Mean RMSSD for Low and High ERQ Reappraisal Groups. Error bars represent 1 SE.

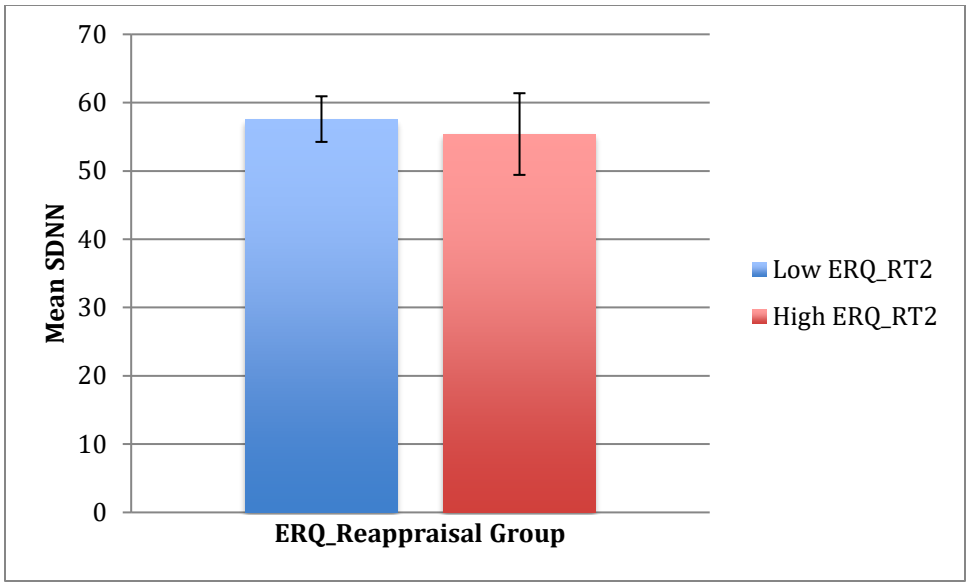

Figure 4b. Mean SDNN for Low and High ERQ Reappraisal Groups. Error bars represent 1 SE.

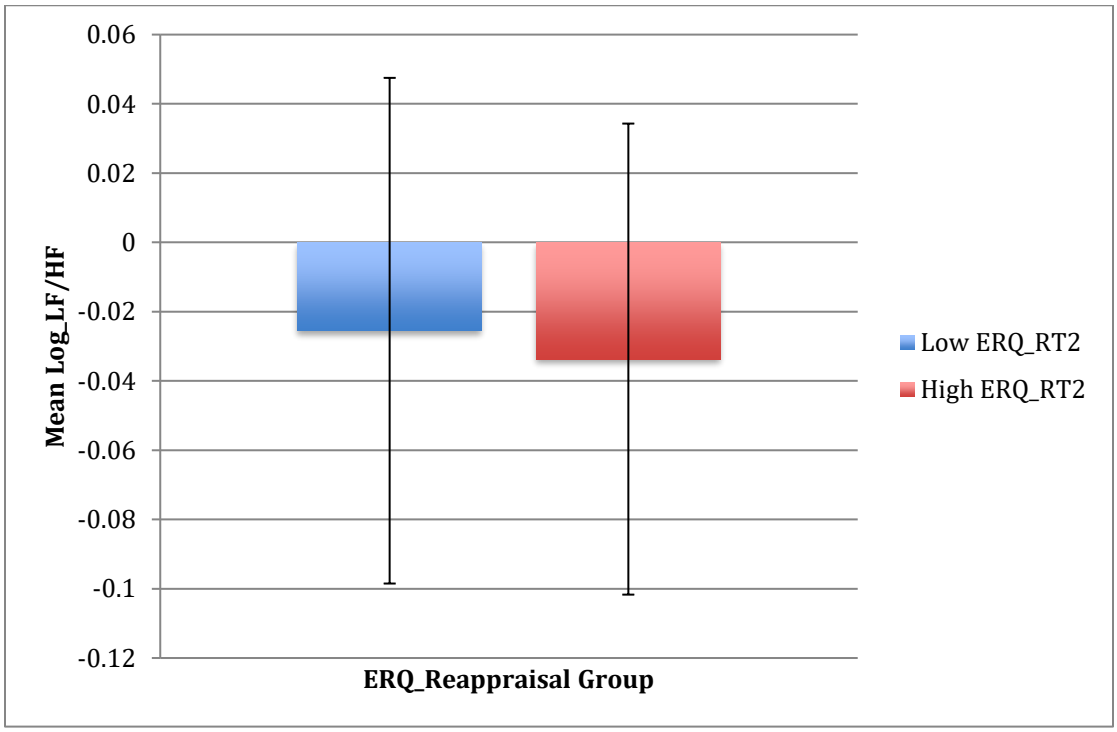

Figure 4c. Mean Log_LFHF Ratios for Low and High ERQ Reappraisal Groups. Error bars represent 1 SE.

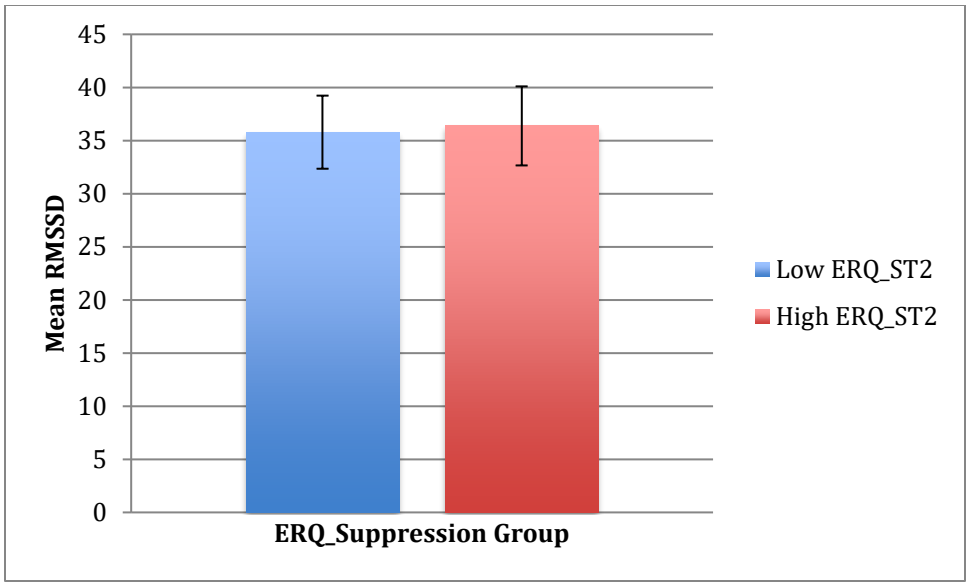

Figure 5a. Mean RMSSD for Low and High ERQ Suppression Groups. Error bars represent 1 SE.

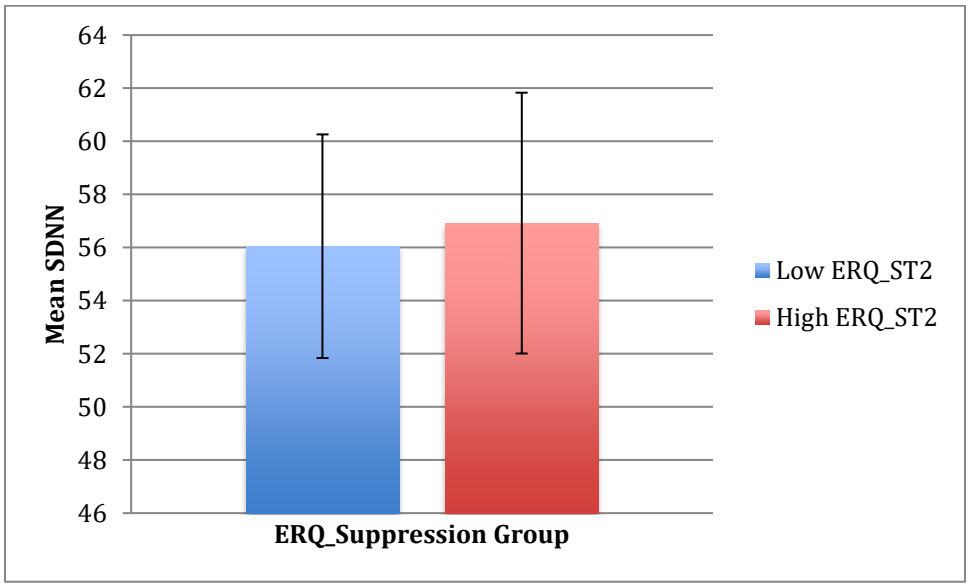

Figure 5b. Mean SDNN for Low and High ERQ Suppression Groups. Error bars represent 1 SE.

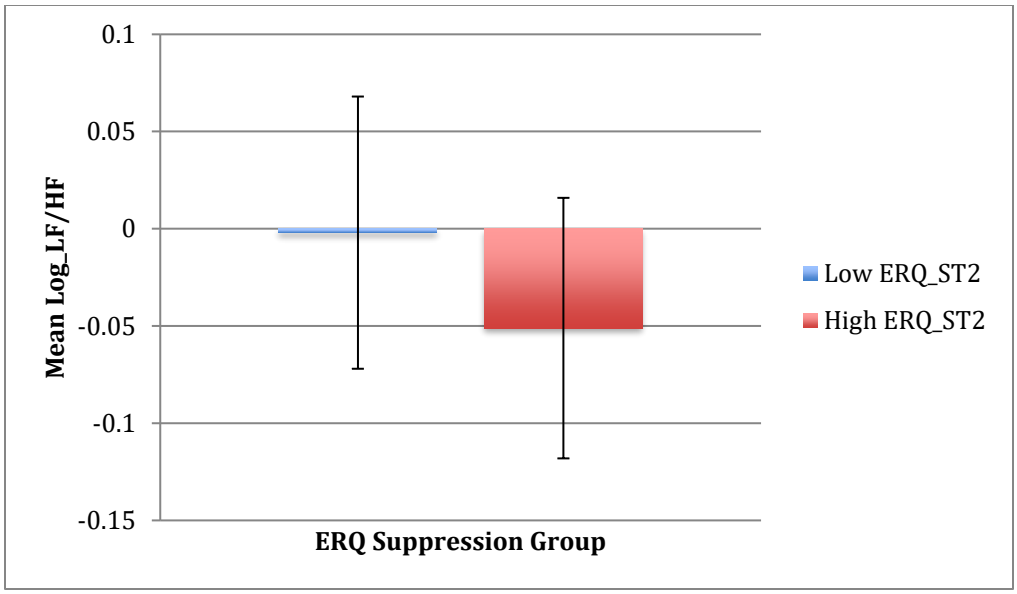

Figure 5c. Mean Log_LFHF Ratios for Low and High ERQ Suppression Groups. Error bars represent 1 SE.

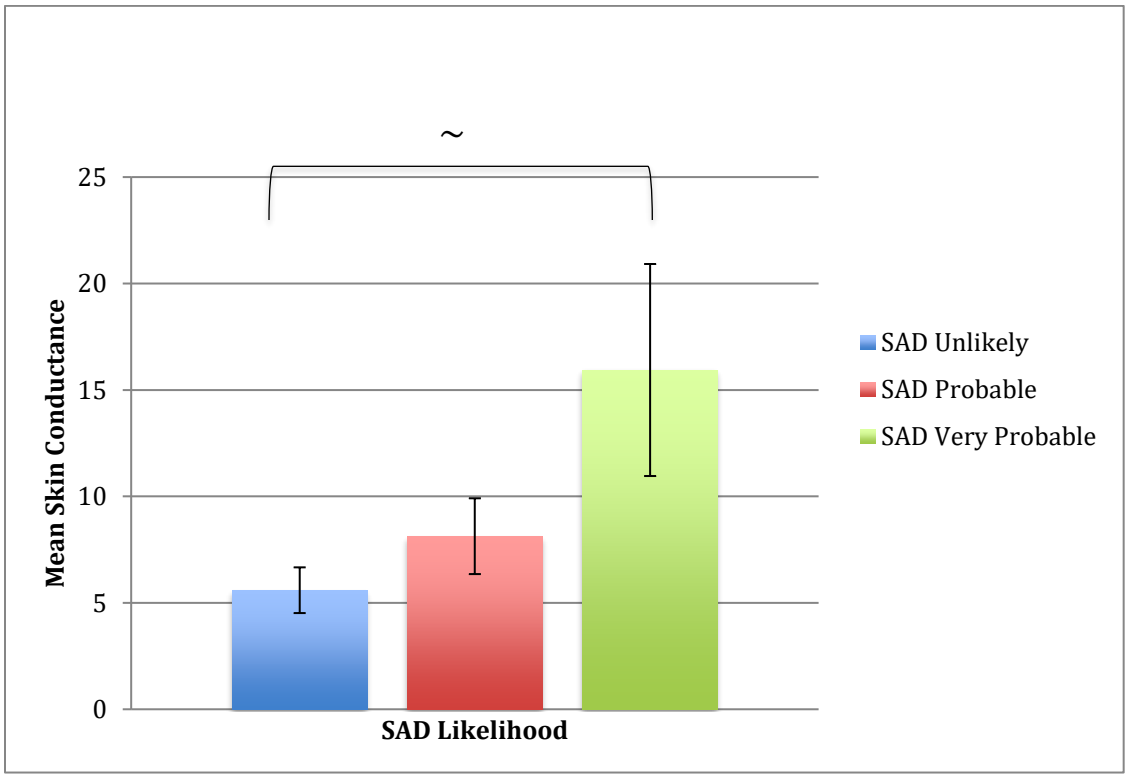

Figure 6. Mean Skin Conductance for SAD Likelihood Groups. Error bars represent 1 SE. There was a trend towards a significant difference in mean skin conductance between the SAD unlikely and the SAD very probable groups (two-tailed, $p < 0.084$).

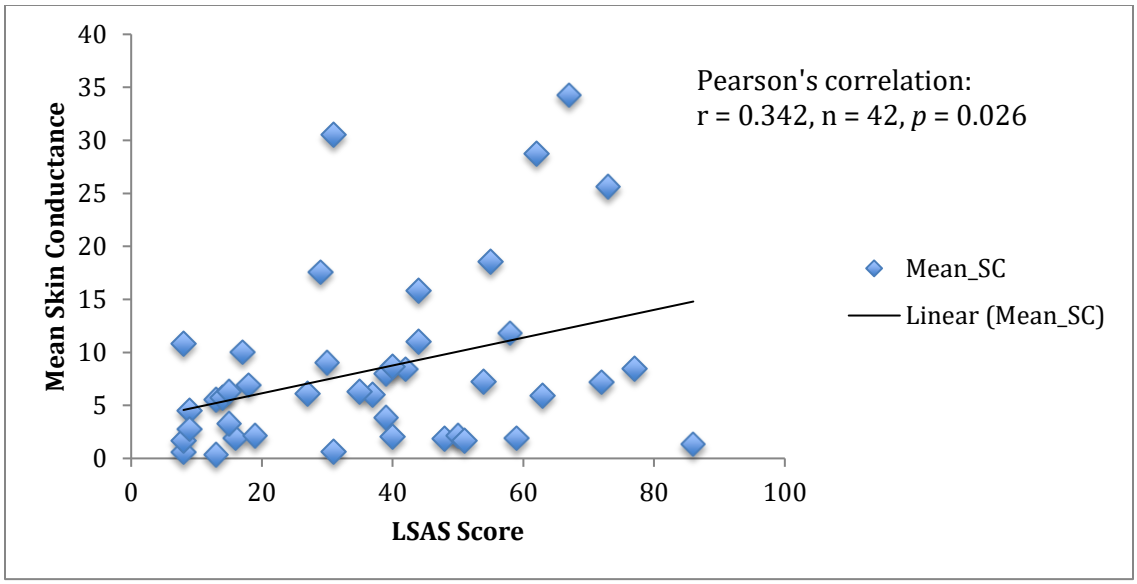

Figure 7. Relationship Between Mean Skin Conductance (Mean_SC) and LSAS.

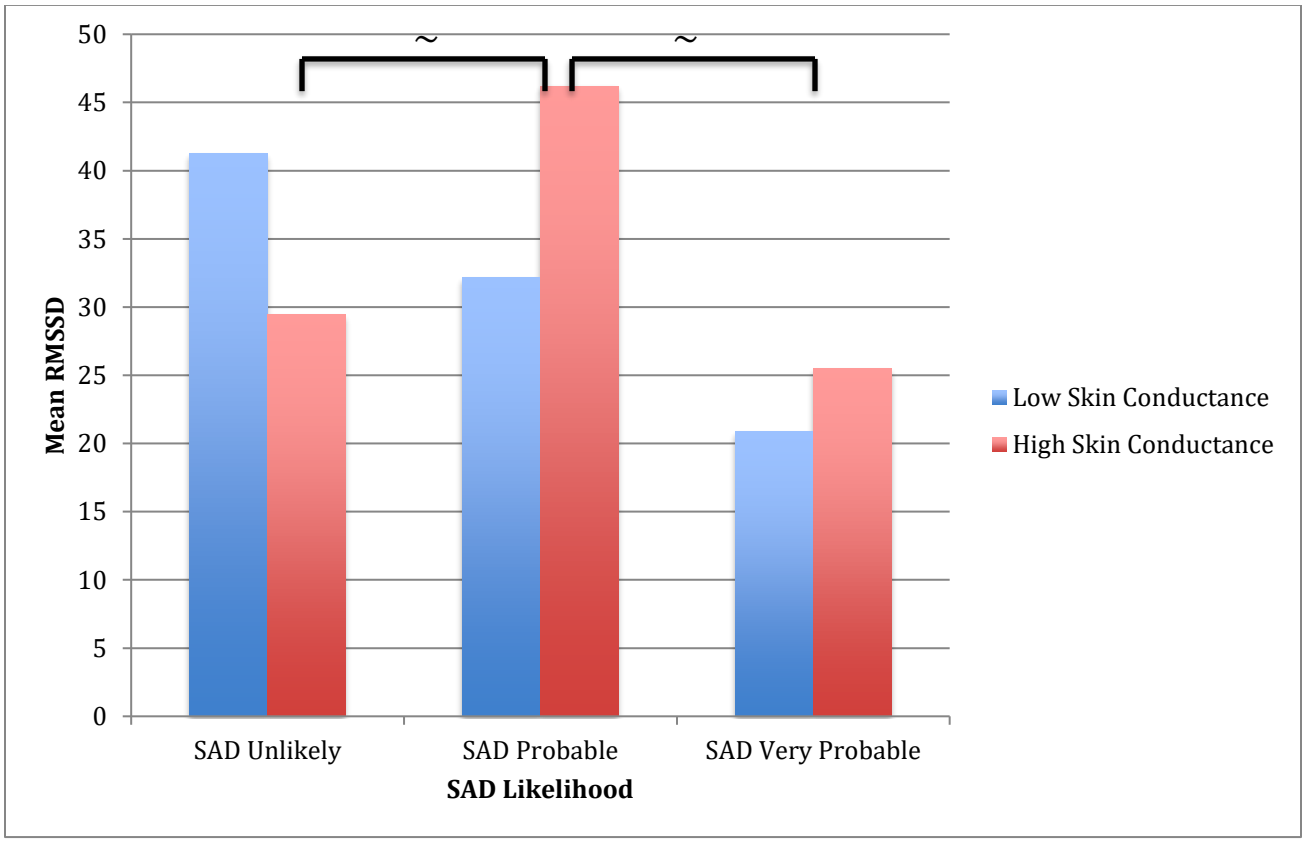

Figure 8. Difference in Mean RMSSD Based on Low and High Skin Conductance (Low_SC and High_SC, respectively) Across SAD Groups Using *t*-test for Equality of Means.
~. In the high skin conductance group, there was a trend towards a significant difference in mean RMSSD between the SAD probable and the SAD very probable groups ($t(9) = 2.381$, $p = 0.041$), and also between the SAD unlikely and the SAD probable groups ($t(12) = -2.014$, $p = 0.067$).

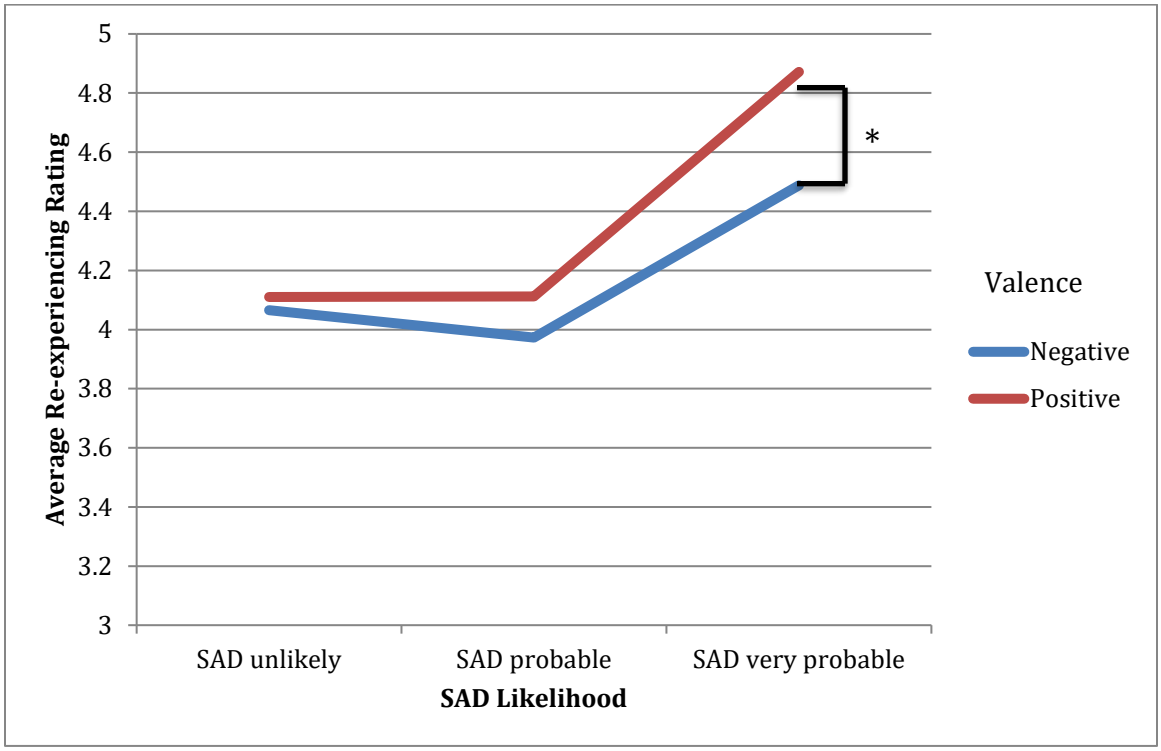

Figure 9. Effect of Average Re-experiencing of Positive or Negative Autobiographical Memories on SAD Group (SAD unlikely, SAD probable, and SAD very probable) (Scale was 1-7).

*. There was a significant main effect of valence for average re-experiencing ratings ($F(1, 38) = 5.144$, $p = 0.029$).

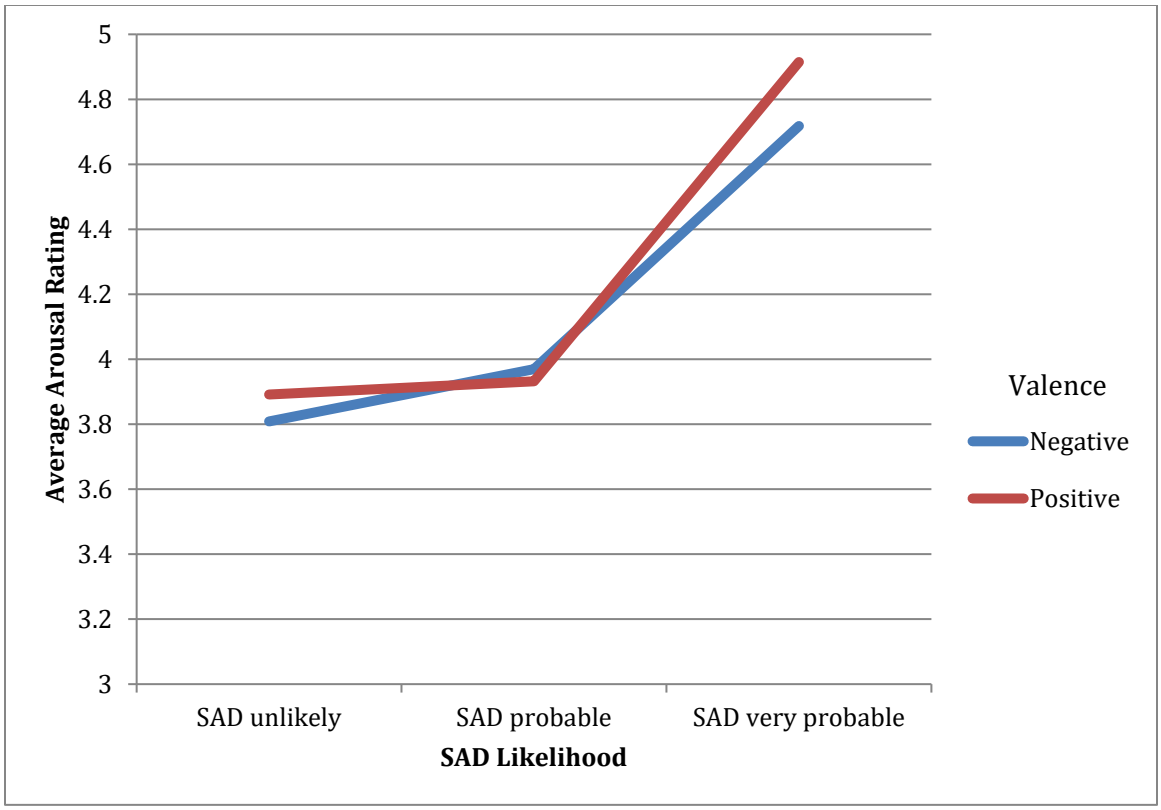

Figure 10. Effect of Average Arousal of Positive or Negative Autobiographical Memories on SAD Group (SAD unlikely, SAD probable, and SAD very probable) (Scale was 1-7).

Table 4. Differences in the Average Arousal and Re-experiencing Ratings for Negative and Positive Autobiographical Memories Across SAD Groups Using *t*-test for Equality of Means.

Average Memory Ratings	**SAD unlikely M (SD)**	**SAD probable M (SD)**	**SAD very probable M (SD)**
***Negative* Arousal** **Re-experiencing**	3.81 (0.93)~ 4.07 (0.84)	3.97 (0.92) 3.97 (1.15)	4.72 (1.11)~ 4.49 (0.89)
***Positive* Arousal** **Re-experiencing**	3.89 (0.97)~ 4.11 (1.02)	3.93 (0.93)~ 4.11 (1.21)	4.91 (1.03)~ 4.87 (1.18)

~. There was a trend towards a significant difference in average arousal ratings of negative autobiographical memories between the SAD unlikely and the SAD very probable groups ($t(22) = -2.063$, $p = 0.051$). There was also a trend towards a significant difference in average arousal ratings of positive autobiographical memories between the SAD unlikely and the SAD very probable groups ($t(22) = -2.303$, $p = 0.031$), as well as between the SAD probable and the SAD very probable groups ($t(22) = -2.279$, $p = 0.033$)

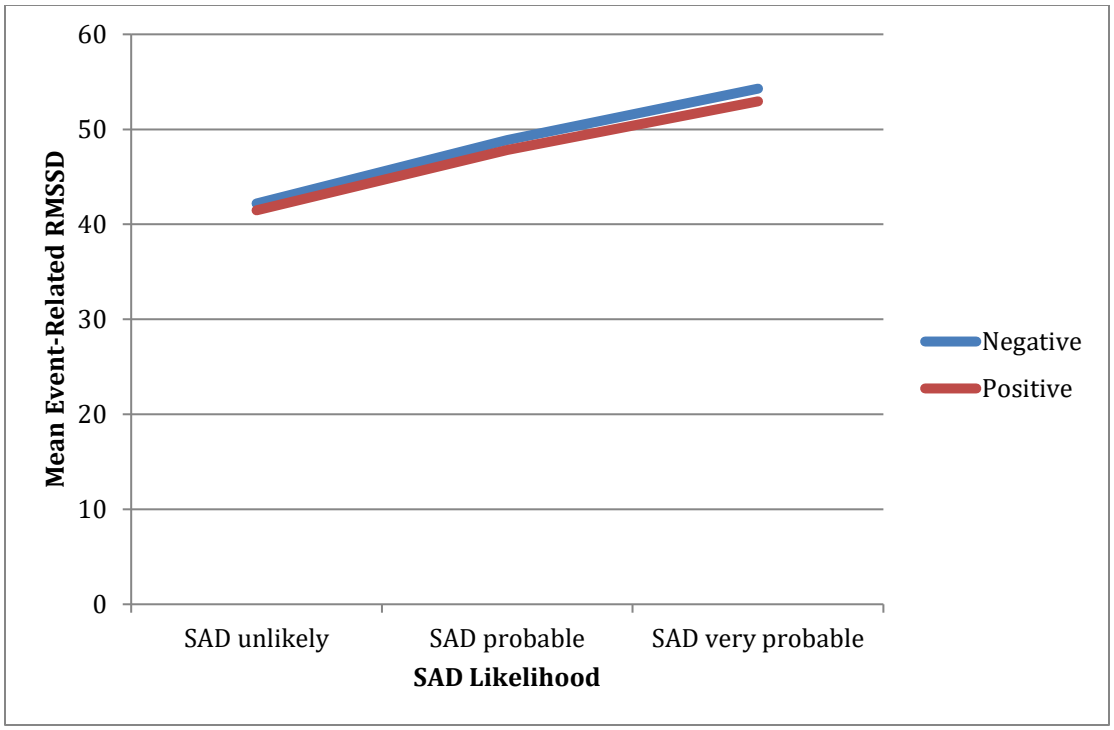

Figure 11. Effect of Mean Event-Related RMSSD on SAD Group (SAD unlikely, SAD probable, SAD very probable).

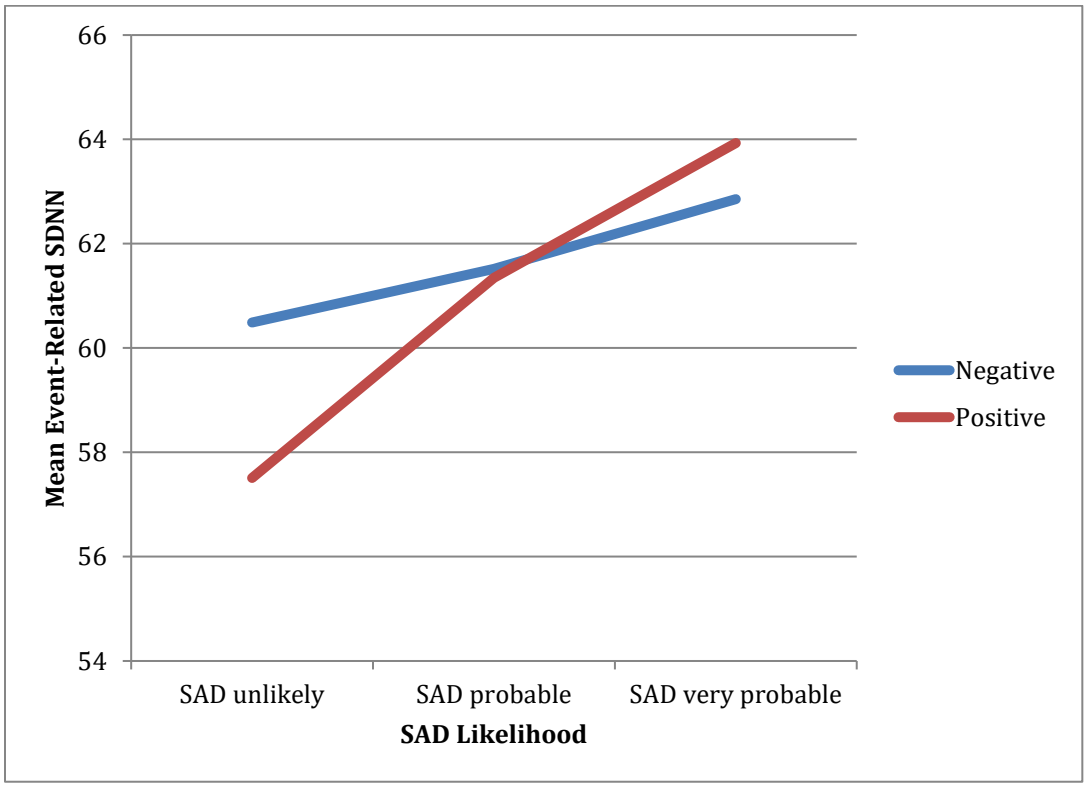

Figure 12. Effect of Mean Event-Related SDNN on SAD Group (SAD unlikely, SAD probable, SAD very probable).

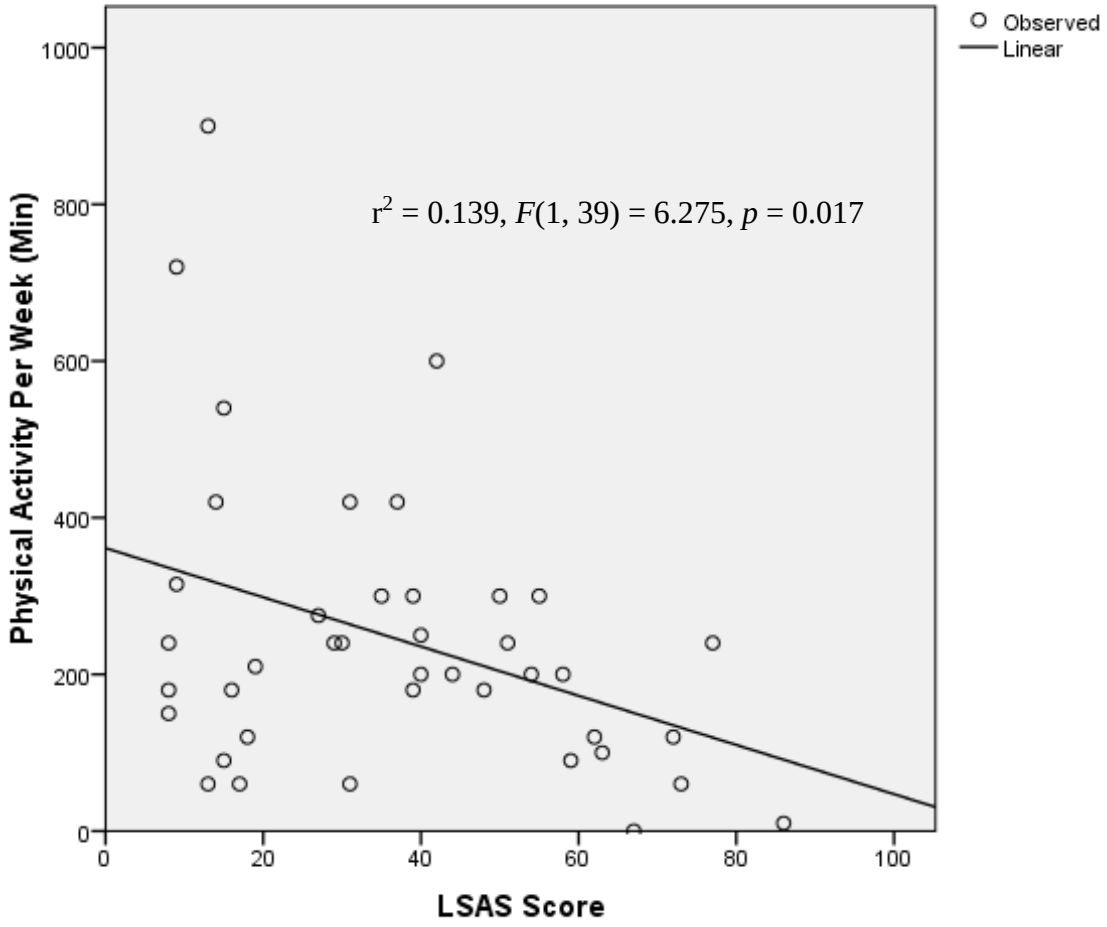

Figure 13. Relationship Between Physical Activity and LSAS.

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