IDENTIFYING A CROSS-CORRELATION BETWEEN HEART RATE VARIABILITY AND SKIN CONDUCTANCE USING PAIN INTENSITY ON HEALTHY COLLEGE STUDENTS

By
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Chronic pain affects approximately 100 million Americans annually. Heart rate variability and skin conductance have been used separately as measures of pain intensity. Current methods of assessing pain intensity have some limitations as they completely rely on subjective pain scales, require the patient's cooperation, and completely fail in unconscious patients. Therefore, there is a need for an objective method of measuring pain to improve the quality of pain management. Understanding the relationship between heart rate variability and skin conductance can be beneficial for non-pharmacological treatments of pain such as biofeedback training, as combining both signals can be used to create a more powerful tool to measure pain. To identify a relationship between skin conductance and heart rate variability, we propose a cross-correlation analysis. Such approach necessitates collection of baseline data on healthy college students, administration of a thermal stimuli, and collection of data during and after the stimuli.

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Chapter 1: Introduction

1.1 Overview

The most important factors in successful pain management are accurately measuring and reporting pain levels. Many health care professionals rely on subjective measures of pain. Generally, pain is self-reported through a pain scale – ranking pain on a scale from 1 to 10 – as well as observing physical and behavioral cues. However, pain scales rely completely on the subject's cooperation and their own understanding of pain which can lead to either understating or overstating pain levels.[1] Furthermore, pain scales completely fail in unconscious, uncooperative, or other incapacitated subjects.[2]

It has been established that pain increases sympathetic tone, leading to a higher firing rate in sympathetic post-ganglionic cholinergic neurons.[2–4] Such increase in activity of the sympathetic nervous system includes the activation of palmar sweat glands. Recent studies have linked skin conductance variability – numbers of skin conductance fluctuations – to pain levels.[1, 2] Other studies have utilized heart rate variability coherent biofeedback (HRVB) – a tool to determine pain and stress management.[5–7]

1.2 Aim

Several studies have challenged the accuracy of popular pain scales such as the Behavioral Pain Scale (BPS) and the Critical-Care Pain Observation Tool which resulted in 72.04% and 70.8% accuracies, respectively.[8] As a result, there is a need for an objective, quantifiable, subject-independent assessment of pain.[2,9] Therefore, this study aims to combine two different measurements that have been used to assess pain levels: skin conductance (SC) [2,3,9–12] and heart rate variability (HRV) [6,10,11,13] via a cross-correlation analysis. Specifically, the cross-correlation analysis will be performed on the two portions of the signals that are believed to be more closely correlated: the low frequency and high frequency components of HRV in the frequency domain and the phasic and tonic components of skin conductance found via non-negative deconvolution.

1.3 Hypothesis

It is believed that the high frequency components of HRV will be more closely correlated to the phasic components of skin conductance since this is where stimuli are more likely to be expressed, given that high frequency components are related to parasympathetic activity and tonic components are related to stimuli responses. Therefore, it is hypothesized that the cross-correlation between heart rate variability and skin conductance increases as pain level increases. The purpose of the proposed study is to combine HRV and skin conductance measurements to: (i) identify changes in HRV and skin conductance between baseline measurements and painful stimuli measurements, and (ii) identify a relationship between heart rate variability and skin conductance, using a cross-correlation analysis. It is expected that high frequency HRV cross-correlated with Phasic SC components will have a large correlation coefficient, while low frequency HRV cross-correlated with Tonic SC components will have a small correlation coefficient due to the larger expression of the stimuli in the high frequency and phasic component.

Chapter 2: Background

2.1 Autonomic Nervous System

It is widely accepted that autonomic imbalance physiologically characterizes multiple medical and psychiatric disorders [15]. The autonomic nervous system is divided into two main categories: the parasympathetic and the sympathetic nervous system. The parasympathetic nervous system is known as the “rest and digest” division that innervates many visceral organs as well as involuntary responses. The sympathetic nervous system is recognized as the “fight or flight” division that controls voluntary movement, including mass activation. Typically, introducing a stressor will increase the sympathetic response, while inducing relaxation will increase parasympathetic activity.[7,14]

One measure of the autonomic nervous system is heart rate variability (HRV). Via spectral analysis, heart rate variability provides an index of sympathetic and parasympathetic activity[15]. Sweating is another measure of the peripheral autonomic nervous system. Normal sweat gland function requires sympathetic and parasympathetic innervation. Thus, by quantifying sweating via skin conductance measurements, we can explore another index of parasympathetic and sympathetic activity[16,17].

2.2 Heart Rate Variability

Heart rate variability (HRV) has been identified as one of the best non-invasive tools to measure real-time autonomic activity.[18] However, measuring heart rate variability can be difficult. Multiple external and internal factors can contribute to variations in heart rate such as breathing, movement, stress and even lack of sleep.

HRV has been described as the fluctuation between intervals in both consecutive and instantaneous heart beats.[19] Both divisions of the nervous system work to establish the rhythmic nature of the cardiac cycle. The parasympathetic decreases heart rate, while the sympathetic increases it. Since 1981, power spectral analysis has been utilized to quantify heartbeat oscillation (R-R) intervals. Additionally, statistically determined differences between R-R intervals suggest that there is some correlation to frequency fluctuations.[18,19] HRV is an indicator of sympathetic and parasympathetic

activity via a power spectral analysis through three main frequency components: (1) low frequency (LF), high frequency (HF) and (3) very low frequency (VLF). High frequency (HF) values indicate parasympathetic activity (0.15-0.4 Hz), while low frequency values (0.4-0.15 Hz) indicate sympathetic activity, specifically when expressed in normalized units[15]. Figure 1 shows the low frequency and high frequency components of heart rate with its corresponding ranges for sympathetic and parasympathetic activity.[20] Very low frequency values (<0.04 Hz) are believed to signify sympathetic activation[15]. However, in this study, we will focus on low frequency and high frequency components.

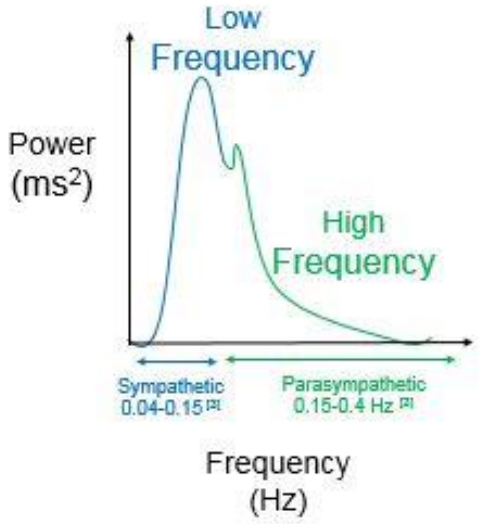


Figure 1. Low and high frequency components of HRV

2.3 Photo-plethysmography

Photo-plethysmography (PPG) is a non-invasive tool that utilizes optical based technology to measure the rate of blood flow generated by the heart's pumping mechanism. PPG utilizes low-intensity infrared light to create the PPG waveform that occurs when light travels through biological tissues and is absorbed by venous and arterial blood. One component of the PPG waveform is a pulsatile AC physiological component, typically at around 1 Hz, attributed to cardiac synchronous changes in blood volume with each heartbeat. Such waveform is superimposed on a slowly varying "quasi-DC" baseline with various low frequency components associated with respiration, sympathetic activity, and thermoregulation.[21] Although a DC component does not

normally vary, in the PPG waveform, there are slow changes present due to respiration, vasomotor activity, vasoconstriction waves, and thermoregulation[21].

Moreover, the AC component has smaller amplitude than the “quasi-DC” component. The absolute maximum of the AC component is associated with systolic blood pressure, while the relative maximum is associated with diastolic blood pressure. Systolic blood pressure is related to the contraction of the heart with each heartbeat that forces blood out through the arteries to the entire body. Diastolic blood pressure refers to the pressure created when the heart is at rest between heartbeats. During this process, the heart is filled with blood.[22] The instantaneous heart rate is the time difference between two consecutive systolic peaks. In this study, PPG is used to measure heart rate variability – the variation in the beat-to-beat interval.

2.4 HRV Live Software

HRV Live! is a software developed by Biocom technologies that relies on photo-plethysmography (PPG) to measure heart rate variability. It allows for the measurement of parasympathetic and sympathetic activity in real time as well as calcuating root mean squared standard deviation (RMSSD) and standard deviation from normal to normal (SDNN). This software automatically transforms the PPG signal to heart rate in beats per minutes using an algorithm that measures the pulse wave to derive beat-by-beat intervals (P-P). Then, it performs a power spectral analysis using a Fast Fourier Transform (FFT) to extract data from the power spectrum (i.e. the low frequency and high frequency values associated with parasympathetic and sympathetic inputs, respectively) as well as very low frequency, total power, and the LF/HF ratio[23].

2.5 Anatomy, Physiology, and Properties of the Skin

The interpretation of skin conductance requires a basic understanding about the structure of tissues and the electrical properties of the skin. Skin can be broken down into three main layers: the epidermis, the dermis, and subcutaneous tissue. The outermost layer, the epidermis, is composed of the stratum corneum, the stratum lucidum, the granular layer, the prickle cell layer, and the basal (germinating) layer. The epidermis is a renewing layer that contains derivative structures including finger and toe nail. The dermis is the layer of skin between the epidermis and the subcutaneous

tissue that contains blood vessels, capillaries, nerve endings, and eccrine sweat glands. Sweat production by the eccrine glands is stimulated via cholinergic fibers from the sympathetic nervous system. The eccrine sweat glands secrete a hypotonic solution to plasma with varied amounts of electrolytes such as sodium, chloride, and potassium; therefore, sweat is a relatively good conductor, considered to be equivalent in conductance to 0.3% NaCl salt solution[24]. As sweat production increases, the excretory ducts of the eccrine sweat glands composed of epithelial cells fill.[17]

2.6 Electrodermal Activity

Electrodermal activity (EDA) is an umbrella term that refers to autonomic changes in the electrical properties of the skin.[25] One property, skin conductance, can be quantified by applying an electrical potential between two points of skin contact and measuring the current flow between them. Skin conductance data is composed of a sequence of overlapping phasic responses over a tonic component. Thus, the EDA complex can be distinguished between background tonic skin conductance level (SCL) and rapid phasic components, known as skin conductance responses (SCR) that result from sympathetic activity.[24,25] Figure 2 contains an overview explaining electrodermal activity, its tonic and phasic components, and the information that can be extracted from each.

In addition, electrodermal activity can be divided into two types of measurements: *exosomatic*, which refers to current that is introduced from the outside, and *endosomatic*, which refers to an internal voltage source.

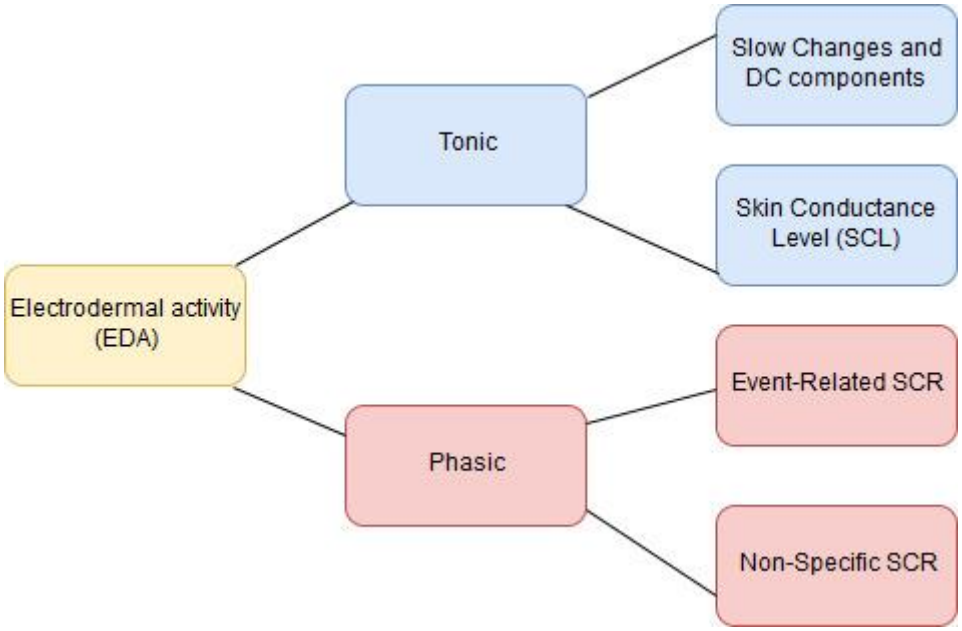


Figure 2.Breakdown of electrodermal activity including its tonic and phasic components

Electrodermal activity is commonly measured at palmar sites using Ag/AgCl electrodes with specific placement sites. Each electrode contains a half-cell potential; therefore, if the potentials are similar and contain the same chloride concentrations, their effects are equal and cancel. Thus, to prevent this, it is best to use an electrode paste with the same salt concentration of sweat such as 0.3% NaCl. Abrasion of the sites reduces resistance and noise, thus providing a clear waveform.[24] Moreover, since this is a reversible type of electrode, polarization and bias potential are minimized.

To measure *exosomatic* conditions, two different conditions can be used: either a constant current or a constant voltage. For constant-current conditions, Equation 1 is used to measure skin conductance as a function of time (SC (t)), where E_b = battery voltage, R_A= series resistance, and V_s = voltage source.

$$SC(t) = \frac{E_b}{R_A V_s(t)} \qquad \textit{Equation 1}$$

For constant-voltage conditions, Equation 2 is used to measure skin resistance as a function of time (SR (t)), where R_A = series resistance and it is small compared to R_S = resistance of skin, and voltage V_A = voltage measured across the resistance.

$$SR(t) = \frac{E_b R_A}{V_A} \qquad \textit{Equation 2}$$

2.7 Skin Conductance

Sudomotor function testing measures the function of sweat gland innervation. It evaluates the peripheral sympathetic nervous system but relies mainly on cholinergic post-ganglionic neurotransmission due to the innervation with the secretory portion of the sweat glands. Through this process, the sweat is released into the sweat duct leading through the dermis and epidermis, and concluding in a pore located on the skin's surface. One skin conductance response (SCR) corresponds to a single sudomotor burst. The skin conductance signal is composed of slow varying tonic levels superimposed by separate phasic skin conductance responses[16,26].

2.7.1 Consensys Software

Consensys software interfaces with the Shimmer 3 Galvanic Skin Response + Unit (Dublin, Ireland) to collect skin conductance data. It allows for live data collection, data processing (e.g. digital filters), and mathematical algorithms.

2.7.2 Shimmer 3 Galvanic Skin Response + Unit

The Shimmer 3 Galvanic Skin Response (GSR)+ Unit contains an internal resistor network which works as a potential divider, thus providing a voltage that can be converted by an internal analog-to-digital converter (ADC) to a 12-bit number. This number represents the external skin conductance. Using the values obtained from the 12-bit ADC, the Shimmer 3 reports values from 0 to 4095 which are proportional to skin conductance. Then, each full-scale range setting is mapped to a linear function used to calculate the skin conductance value per Equation 3, where x equals the ADC output, y equals skin conductance (μS), and p_1 and p_2 are parameters specific to the range setting determined by the two most significant bits of the Shimmer output. These parameters are shown in Table 1.[27]

$$y = p_1 x + p_2 \qquad \textit{Equation 3}$$

Typically, conductance value output is measured in Siemens, thus resistance in ohms is determined by Equation 4. Tables 2 and 3 contain the typical physiologic skin conductance values on healthy adults as well as the range of the Shimmer 3 GSR+ Unit.

$$Resistance\ (\Omega) = \frac{1\times10^6}{Conductance} \qquad \textit{Equation 4}$$

Table 1. Coefficients for ADC value to skin conductance conversion.

Setting	Full Scale Range		Linear Coefficients
	Resistance	Conductance	
0	10 kΩ - 56 kΩ	100 µS – 17.9 µS	$p_1 = 0.0373$ $p_2 = -24.9915$
1	56 kΩ - 220 kΩ	17.9 µS – 4.5 µS	$p_1 = 0.0054$ $p_2 = -3.5194$
2	220 kΩ - 680 kΩ	4.5 µS – 1.5 µS	$p_1 = 0.0015$ $p_2 = -1.0163$
3	680 kΩ - 4.7 MΩ	1.5 µS – 0.2 µS	$p_1 = 4.558\times10^{-04}$ $p_2 = -0.3014$

Table 2. Skin resistance physiologic values and detection range from the Shimmer 3 GSR+ Unit.[27]

Skin Resistance Values	
Typical Physiologic Resistance Range	47 kΩ – 1 MΩ
Shimmer's Resistance Detection Range	10 kΩ – 4.7 MΩ

Table 3. Skin conductance physiologic values and detection range from the Shimmer 3 GSR+ Unit.[27]

Skin Conductance Values	
Typical Physiologic Conductivity Range	21 µS – 1 µS
Shimmer's Conductivity Detection Range	100 µS – 0.2 µS

2.7.3 Skin Conductance Signal Decomposition

The decomposition of skin conductance data by means of deconvolution was proposed by Alexander et al, in which he argued that the skin conductance data was a result of a convolution process of the activity of sudomotor nerves which corresponds to a driver function as well as an impulse response shaped similar to a biexponential function. It was proposed that deconvolving skin conductance data by the response function, conforms to a sequence of discrete bursts. Then, peak detection was performed on the drivef runction and time segments can be extracted from this. Lastly, isolated skin conductance responses (SCRs) can be extracted from the original skin conductance data with a reconstructed signal, for which the respcted segment is set to baseline. After isolation of the skin conductance responses, then phasic parameters can be computed from each single, non-overlapped SCR [34].

LEDALAB is a MATLAB-based software for the analysis of skin conductance, specifically its decomposition into phasic and tonic components. Decomposition of skin

conductance data requires a two-compartment diffusion model to describe the shape of the skin conductance responses based on sweat diffusion as well as a method of non-negative deconvolution to decompose the data into its tonic and phasic components. LEDALAB performs “event-related analysis” – analysis in which stimuli is applied – and returns various parameters of phasic and tonic activity via continuous decomposition analysis (CDA), a method in which skin conductance data is decomposed into continuous signals of phasic and tonic activity.

Skin Conductance Responses (SCRs) are described by the following biexponential function:

$$f(t) = g \cdot \left(e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}} \right) \quad \textit{Equation 5}$$

However, biexponential functions can be derived directly from models of the dynamics of the concentration of sweat in the corneum. This can be modeled by a two-compartment model in which the sweat is released to compartment A – the sweat duct – then travels to compartment B – the corneum – and is evaporated from compartment B. In this model, it is assumed that diffusion and evaporation occur in a unidirectional manner at a speed proportional to the concentration in its respective compartment. It is also assumed that compartment B is much larger than compartment B so that unidirectional diffusion can occur. Such dynamics are derived from two coupled first-order differential equations describing the concentration of sweat in the compartments A and B:

$$\frac{da}{dt} = -\frac{a(t)}{\tau_1}, \frac{db}{dt} = \frac{a(t)}{\tau_1} - \frac{b(t)}{\tau_2} \qquad \textit{Equation 6}$$

Since it is assumed that diffusion can only occur unidirectional (forward) this grants a stepwise solution, entering the solution of the previous compartment in the equation for the next compartment[26]. Furthermore, using the biexponential function, the skin conductance time-series was modeled:

$$q(t) = (\tau_0 \tau_1)\frac{d^2y}{dt^2} + (\tau_0 + \tau_1)\frac{dy}{dt} + y(t) \qquad \textit{Equation 7}$$

In this equation, $\tau_0 \; and \; \tau_1$ are time-constants, while y (t) = skin conductance, and q (t) = the driver function. An impulse spike in the driver at t = 0, results in the Bateman Function[28]:

$$b(t) = e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}}$$ *Equation 8*

The Bateman function is described by a steep onset (τ_1) and a slow recovery (τ_2). Thus, the skin conductance model equation defines the signal y (t) as the convolution of the driver function q(t) with a biexponential function. Therefore, by deconvolving the signal, the driver function can be acquired, allowing the isolation of the individual peaks. After the peaks have been isolated, the peaks can then be deconvolved with the biexponential function to reconstruct individual skin conductance responses, thus giving rise to the phasic and tonic components of the signal.

Since the standard deconvolution requires the assumption of a standard SCR shape (impulse response), this means that it cannot account for different SCR shapes as they may result from the conditional process of pore opening. Therefore, the deconvolution method used in LEDALAB, deconvolves the data by a fixed response function which is the Bateman function. However, this does allow for the detection of departures from the SCR shape.

LEDALAB performs the non-negative deconvolution based on literature that assumes that skin conductance can be viewed as a result of a driver function – the activity of sweat glands or sudomotor neurons – which triggers an impulse response – skin conductance increases due to perfusion by the sweat. Since sudomotor neurons are supposed to be either active or inactive, then the driver function representing such activity, should be non-negative: either producing positive impulses or staying at zero. Since the signal is divided by the impulse response which generates the driver function, then it must also be a condition that all the values in the quotient must be non-negative. This can be achieved only if the entire quotient is considered where such is calculated per digit and the overall minimum is taken. Thus, non-negativity can be achieved while still performing the convolution.

In summary, the decomposition of the signal is completed in four steps: “estimation of the tonic component, non-negative deconvolution of phasic skin conductance data, segmentation of driver and remainder, and reconstruction of skin conductance data”[26].

2.8 Quantitative Sensory Testing

The PATWHAYS CHEPS model, which is the instrument that was used in this study to apply a cold stimuli to subjects relies on quantitative sensory testing (QST). QST is a non-invasive method for diagnosing peripheral nervous system disorders including chronic pain and pain-related diseases such as diabetes. QST determines the sensation and pain thresholds for cold and warm temperatures [33]. Quantitative sensory testing is the most frequently used method to assess and quantify somatosensory function of the whole somatosensory system, from the receptors to the cerebral cortex.[29,30,31] QST measures detection thresholds for thermal stimuli, both hot and cold as well as mechanical stimuli.[29,30] However, for this study, only cold-thermal stimuli was used.

The German Research Network of Neuropathic Pain (DFNS) has developed a standardized QST battery that consists of 7 tests measuring 13 parameters including: thermal detection thresholds for the perception of cold and warm sensations, thermal pain thresholds for cold and hot stimuli, mechanical detection threshold for touch and vibration, mechanical pain sensitivity such as thresholds for pinprick and blunt pressure, and pain summation of repetitive pinprick stimuli. However, this study would only adopt part of the standardized protocol developed by the DFNS, specifically the portion of the protocol regarding pain thresholds using thermal and pain detection.[32–34]

The protocol established age- and gender-matched absolute and relative reference values from 180 healthy subjects by assessing bilateral stimuli over three distinct regions: face, hand, and foot. Per DFNS studies, QST parameters were region specific and age dependent. Pain thresholds were statistically lower in females than in males ($p<0.01$); however, thermal detection thresholds (cold and warm detection) demonstrated significant differences in gender, when classified by placement location of the thermode. In women, the higher temperature sensitivity was only significant in the lower limbs. Heat pain had the largest gender differences, followed by cold pain. No differences were found for bilateral comparisons of stimuli. For all QST parameters, sensitivity was higher in the face than in the foot, while the hand exhibited medium sensitivity.[32]

2.9 QST Pathway CHEPS/ATS Model

The Pathway CHEPS/ATS Model has been approved by the FDA under 510(k), 041908. The device summary and indications for use are included in Appendix A. The proposed study falls under the following indications for use for this device: "evaluating the functionality of human pain reception and transmission of sensory pathways."

Therefore, the PATWAY model CHEPS/ATS will be used to create contact cold-evoked potentials or small fiber-evoked potentials, in accordance with its indications for use. This system can be used as a tool for the assessment of objective pain perception via contact cold-evoked potentials and evaluate the changes in pain sensation due to pain stimuli, in compliance with UL-2601-1:94 which is a standard that covers the safety requirements for medical electrical systems to provide protection for patients and operators.[35]

The ATS technology allows for the delivery of fast, heat stimuli with predetermined temperatures that can be used to activate distinct sensory fiber groups with a temperature repeatability of ± 0.1 °C and absolute accuracy of 0.3°C. Table 4 shows the specific parameters used for the ATS model, including temperature range of the contact area.

Table 4. PATHWAY Model ATS Specifications[35].

PATHWAY Model ATS Specifications			
Max Temperature	**Min Temperature**	**Max Heating Rate**	**Max Cooling Rate**
55°C	-10°C	8°C/s	8°C/s

Chapter 3: Literature Review

3.1 Heart Rate Variability

A study titled “Non-pharmacological Intervention for Chronic Pain in Veterans: A Pilot Study of Heart Rate Variability Biofeedback,” by Berry et al., demonstrated that biofeedback training decreased subject pain scores when compared to a control group[6]. This study utilized 14 veterans, 8 that were in the treatment group, and 6 in the control group[6]. All study participants were diagnosed with chronic pain. The 14 participants were randomly assigned to a treatment and a control group. The treatment group received instruction a self-regulation technique that is known to increase HRV coherence in conjunction with a computer-based heart rate variability biofeedback (HRVB) plus standard of care for chronic pain, whereas the control group received standard care only. Subjects were excluded if they indicated regular use of medications known to affect pain perception or the autonomic nervous system two weeks prior to study participation. In addition, subjects that reported suffering from rheumatism, diabetes, traumatic musculoskeletal system damage, chronic, neurologic, and endocrinology syndromes as well as hypertension, coronary artery disease, substance abuse or obesity were not recruited. All study participants received pre-training baseline assessments of perceived pain levels using the Brief Pain Inventory (BPI) which is another pain rating scale that rates pain from 0 to 10 and asks a series of questions to better understand the nature of pain such as pain location. Stress levels were measured for all subjects using the Perceived Stress Scale (PSS) and baseline HRV assessments were also completed for all subjects. For the treatment group, the Quick Coherence self-regulation technique was explained and instructions were given on how to perform it. This technique involves controlled breathing and self-induction of positive or neutral emotional state. This technique was practiced during four biofeedback training sessions and followed a post-training assessment of pain, stress, and HRV using the brief pain inventory. It was found that the subjects in the treatment group showed significant increases over the baseline in coherence ratio as well as a significant reduction in pain ratings, stress, negative emotions, and limitation of physical activity via one-tailed t-tests with a significance of $p<0.001$. Using analysis of covariance (ANCOVA), treatment

effects were analyzed of the post-scores by group, using the pre-scores as covariate. This revealed that the treatment group was significantly lower than the control group for all measures of post HRVCB with a significance of $p<0.05$ [6].

Another study by Kang et al, entitled “Heart Rate Variability for Quantification of Autonomic Dysfunction in Fibromyalgia”, studied the ratio of SDNN and RMSSD as a parameter for autonomic nervous system function to potentially quantify subjective autonomic symptoms in patients with fibromyalgia[18]. In this study, 16 patients diagnosed with fibromyalgia (12 women, 4 men, ages 37-60) were recruited along with 16 healthy, gender and age-matched controls. All subjects in the control group reported no pain at the time of testing and were not taking medications such as anti-inflammatory drugs that may affect the results. Subjects in the treatment group were asked to fill out a Fibromyalgia Impact Questionnaire (FIQ) as well as a Numeric Pain Intensity Score (NPIS) which ranges from 0 (no pain) to 100 (most intense pain). A second visit was requested for patients to visit the hospital in the afternoon and to refrain from alcohol, caffeine, and strenuous physical activity in which HRV was recorded using a three-lead electrocardiogram (ECG). It was found that patients with fibromyalgia possessed significantly higher SDNN/RMSSD values under both normal quiet breathing and rate controlled breathings when compared to controls. Moreover, the difference between the longest and shortest R-R intervals were significantly lower in patients with fibromyalgia than in healthy controls[18].

Another study by Appelhans et al. entitled “Heart Rate Variability and Pain: Associations of two interrelated homeostatic processes” aims to better understand pain and pain sensitivity[10]. This study hypothesized that greater resting parasympathetically mediated HRV would predict reduced sensitivity to thermal pain in young, healthy adults. Fifty-nine right handed participants (37 women, 22 men) were recruited for this study and were excluded if they were taking any medications that may influence the data or suffered from chronic pain, were asked to refrain from smoking, alcohol, energy drinks, and caffeine 2 hours prior the study. Thermal stimuli were applied to these subjects on their non-dominant plate using a 14 cm × 33 cm cold plate with an integrated temperature controller (-10 and 70°C with an accuracy of ± 0.1°C). Baseline ECG measurements were collected for a 5 minute period, then the stimuli was applied

using the cold plate set at 4°C for 4.5 mins until they could no longer tolerate the pain. However, all participants were able to complete the 4.5 mins exposure. Upon completion, participants were asked to rate their pain (unpleasantness) using 101-point numerical rating scale in which 0 (no pain), 50 (moderate pain), and 100 (intense pain). In this study, the Acqknowledge software Biopac Systems Inc. was used to process the ECG data and automatically identify and calculate the RR interval series. Using an HRV analysis software for Windows, HRV measures were calculated including the power spectrum of HRV and its respective low and high frequency components. Regression models were completed for low frequency and high frequency HRV with the pain ratings. It was found that greater correlation for LF was associated with lower temperatures (higher thresholds) at which participants first identified noticeable pain. Greater LF predicted lower temperature (higher thresholds) for the onset of moderate pain. However, HF was not statistically significantly associated with thresholds for noticeable or moderate pain. Although LF and HF HRV were highly correlated in this sample ($p<0.001$), it was found that commonly employed indices fell well below conventional criteria[10].

3.2 Skin Conductance

A study by Ledowski et al. entitled “The assessment of postoperative pain by monitoring skin conductance: Results of a prospective study,” demonstrated a correlation between fluctuations of skin conductance and subjective pain intensity using a numeric 0–10 rating scale, with zero being no pain and 10 ‘the worst pain imaginable’[2]. Table 5 shows the mean number of skin conductance fluctuations per second (NSCF) measured in 75 post-operative patients that underwent general, plastic, or orthopedic surgery.[2] In this study, patients that reported a score of ≤ 3, the rating was repeated after 10 minutes, whereas patients with a score > 3, fentanyl – a synthetic opioid analgesic was administered intravenously, then every 3 minutes, the rating score was repeated until a score of ≤ 3 was achieved. A conductance (MEDSTORM AS 2005, manufacturer) monitor was used to measure the palmar skin conductance of these subjects. The mean skin conductance was calculated in microsiemens (µS) for every 5 seconds with a refreshing rate of 15 s. Any fluctuation with an amplitude greater than 0.02 µS was automatically counted. The number of fluctuations of skin conductance

was determined with a sampling rate of 1 Hz. At the same time that skin conductance was being measured, systolic blood pressure and heart rate were recorded. In addition, any data points were exclude from analysis if the patients were actively vomiting, shivering, or had nausea symptoms as this would cause artifacts of movement and false readings. In this study, at least 150 readings per group of patients with either none or mild pain, moderate, or severe pain. Statistically analysis were used such as the Spearman's correlation coefficient (p) to describe the correlation between the number of skin conductance fluctuations and pain scores. However, it is important to note that the calculation of p does not account for variation in the number of assessments per patient. Pain scores were categorized as follows: none (0), mild (1-3), moderate (4-5), and severe (>5). Table 5 contains the results of this study in which 73 patients (30 female, 43 male, ages 19-81, were included in this study. Two patients were not included because they previously received intra-operative anticholinergic drugs[2].

Table 5. Mean number of skin conductance fluctuations per second (NCSF) based on self-reported pain levels on 73 post-operational subjects (*p<0.001).[2]

Pain Level	**NSCF per second**
None	0.07
Mild	0.16
Moderate	0.28
Severe	0.33

Although, the study did find differences in the number of NCSFs, the location of the pain on the tested population was varied. Data included 42 orthopedic, 16 plastic, and 15 general surgical cases which was collected after 8.5 minutes (on average) of being in the recovery room.[2]

Such variations in the type of surgery and differences in procedures may have impacted the data collected. Other factors that may influence the data include the extent of surgery, the reason for surgery, and the amount of anesthesia. After only 8.5 minutes in the recovery room, subjects may still be under the influence of anesthesia and may not be completely coherent, leading to inaccurate self-reported pain levels. Moreover,

the study failed to collect any demographic data on subjects such as weight, height, race as well as any history of medical diseases which may or may not influence the readings. It may also be the case that subjects with dry skin or sunburnt skin may have had different variations in skin conductance, which in turn can alter the readings. Even though this publication demonstrated differences in pain levels, it seemed to be limited by the lack of inclusion of several important factors that may affect the data.

Another study by Gunther et al. entitled “Palmar skin conductance variability and the relation to stimulation, pain and the motor activity assessment scale in intensive care unit patients” as sympathetically mediated palmar skin conductance variability is related to emotionally induced perspiration and correlates with pain levels in the perioperative setting but had not being studied in ICU patients[9]. This study recruited 40 critically-ill patients above 17 years of age, where half of the patients were intubated and the other half were not. Patients were excluded if they suffered from any neuro- or myopathy disorders, if they were on neuromuscular blocking agents or if they were treated with atropine or glycopyrrolate on the same day of testing as any of these could affect sweat gland receptor activity. Skin conductance variability was measured for a period of 1 hour using the MED-STORM Pain Monitoring System® on the subjects’ non-dominant hand. Similarly to the study by Ledowski et al., any skin conductance readings with an amplitude greater than 0.02 µS was considered a skin conductance fluctuation. The mean NCSF value was calculated every 15 seconds. The refreshing time (the time a new window was analyzed) was one second. For patients that were awake, their pain level was measured using an 11-point numeric rating scale (0-10). However, for patients that were unable to communicate, the patient’s behavior (i.e. physical cues) at rest vs. during the procedures, were observed. In this study, observation of pain was done during the following procedures: needle stick, turning of the patient, suction of the mouth, unsynchronized breathing pattern with ventilator or abnormal breathing, and dressing of wounds. High pain were considered to be a score greater than 3; however, if a patient was unable to communicate, the following physical cues were considered: facial grimacing, moaning or groaning, withdrawing from touch or resisting potentially painful movement or procedure. In addition to collecting skin conductance data, patient’s arousal or agitation levels were measured using a Motor Activity Assessment

Scale (MAAS). MAAS contains a description of the person's behavior which the researcher makes an observation that matches with that person's behavior and scores them accordingly. For example, a score of 0 means that the patient is unresponsive and does not move with noxious stimuli, whereas a score of 6 means that the patient is dangerously agitated or uncooperative. Since intubated patients could not speak and more often received sedatives or opioids, the intubated patients and the non-intubated patients were analyzed separately. It was found that non-intubated patients displayed higher levels of stimulation/pain were associated with higher number of skin conductance fluctuations per second for all MAAS levels, except MAAS 2. In contrast, for intubated patients, increasing stimulation/pain was also associated with higher number of skin conductance fluctuations per second for all MAAS levels. It was found that in critically ill patients, the number of skin conductance fluctuations per second may be more useful to determine emotional distress than just level of pain[9].

Another study by Loggia et al, entitled "Autonomic responses to heat pain: Heart rate, skin conductance, and their relation to verbal rating and stimulus intensity" to assess the pain subjects are experiencing in an effort to quantify pain in a more subjective manner[36]. In this study, a total of 39 male subjects between the ages of 19 and 34 were recruited. Stimuli were applied using the CHEPS PATHWAYS Model in which all subjects received a 12 heat stimuli (4 temperatures: 42 °C, 44 °C, 46.5 °C, and 48 °C; 3 repetitions per temperature), which were pseudo-randomly applied on three regions of the left volar forearm. Each stimuli lasted 6 seconds and was applied 34 s after the previous one. Four seconds after the end of each stimulus, the thermode was removed from the skin, and subjects were asked to numerically rate the heat intensity and unpleasantness using a 200-mm Visual Analogue Scale (VAS) as a reference. Pain was ranked as 0 (no pain) and most intense pain tolerable (200). Skin conductance was recorded in micro-Siemens (μS) and at a sampling rate 32 Hz using 2 circular electrodes. Heart rate was also measured in beats per minutes (BPM) using an electrode placed under each clavicle and 1 electrode below the sternum at a sampling rate of 4 Hz. The coefficients of the within-subjects correlations between the intensity ratings and autonomic responses were calculated. A paired sample t-tests within-subjects revealed that the coefficients for the correlations between intensity ratings and

%SC were significantly higher than those for the correlations with %HR when all stimuli were analyzed. Although a few subjects exhibited negative correlations between pain ratings and heart rate, none reached statistical significance. In a few subjects, correlations with %HR or %SC were negative (statistically significant in 1 subject for SC, $P < .01$, and trending toward significance in another subject for HR, $P = .08$). Repeated-measures ANOVA on the coefficient of variations were completed for temperature × SC and temperature × Heart Rate, which yielded statistically significant results for both. . Post hoc pairwise comparisons revealed that the correlation variation for %HR were not statistically different across temperatures. However, for %SC at the 2 highest temperatures were statistically smaller than both those at the 2 lowest temperatures than those of %HR at all temperatures. It was found that graded intensities of painful cutaneous heat stimuli evoke graded increases in both heart rate and skin conductance. Within-subject analyses revealed higher and less scattered R values for the correlations with skin conductance, suggesting that SC is more sensitive to relative changes in perception. Despite the stronger within-subject correlations, at the group level SC did not significantly correlate with each subject's pain rating, suggesting that this measure does not predict the absolute level of pain reported by the subject. However, the heart rate data showed the exact opposite pattern: even though %HR did not reliably predict verbal responses to pain stimuli on a trial-by-trial basis, it did at the group level. The researchers argue that the incongruity between within- and between subjects analyses suggests that HR, although genuinely affected by pain perception (between-subject analyses), is a very noisy measure, requiring averaging over several stimulations in order to yield reliable responses[36]. In this study, both heart rate and skin conductance were significantly increased during pain which confirms a wide range of previous studies that have observed this relationship with either heart rate, skin conductance, or both, using experimental heat pain[37],[38],[39],[40],[41].

However, some studies have examined both skin conductance and heart rate in response to pain, and results of these studies are variable. Some found greater increases in skin conductance, others found stronger effects for heart rate and some find similar changes for both measures; however, most studies did not include pain ratings.

3.3 Cross-Correlation

A study titled “Nonlinear relationship between electrodermal activity and heart rate variability in patients with acute schizophrenia” by Rachow et al.[17], found a non-linear relationship between electrodermal activity and heart rate variability in patients with acute schizophrenia. This study aimed to test the hypothesis that heart rate modulation and electrodermal activity (EDA) is more closely interrelated in patients with schizophrenia as compared to healthy controls. Eighteen patients with paranoid schizophrenia were recruited along with matched controls (age, sex, weight, smoking habits, and education level). Patients were excluded if they suffered from any other psychiatric or somatic diseases and if they were on any medication that could affect the readings. Psychotic symptoms were quantified using the Scale for the Assessment of Positive Symptoms (SAPS), the Scale for the Assessment Negative Symptoms (SANS), and the Positive and Negative Symptom Scale (PANSS). To measure the interrelations between heart rate variability and skin conductance level (time series), HRV and skin conductance level (SCL) were being recorded at the same time using the same device (LifeShirt System™ – a garment with embedded sensors that continuously collects information on a range of cardiopulmonary parameters, including HRV, GSR, temperature etc.) Both HRV and SCL were measured for 30 mins after subjects had rested in a supine position for 10 minutes. This device automatically extracted beat-to-beat intervals using PPG and SCL was measured using seat-isotonic records placed on the palm of subjects. RMSSD, HF Norm and LF Norm were measured for HRV, whereas skin conductance level was measured for skin conductance. Using a Multivariate Analysis of Variance (MANOVA), it was revealed that there was a significant difference overall between patients and controls for heart rate, RMSSD, LF Norm, HF Norm, and SCL.

Although other cross-correlation studies have been done, to my knowledge, this is the only study that has cross-correlated heart rate variability with skin conductance. Even though in this study electrodermal activity and heart rate variability were correlated, there was no pain stimulus included as part of the study Therefore, this study did not rely on pain scales, and instead, positive and negative symptoms were measured on patients with schizophrenia. It was hypothesized that un-medicated

patients with schizophrenia contain more interrelation in comparison to controls (no schizophrenia), due to reduced parasympathetic cardiovascular regulation.[11] However, some limitations of this study include: a small sample size, uncontrolled breathing rates, and using two different devices to assess skin conductance. Nevertheless, this study strengthens the proposed hypothesis that there is a relationship between heart rate variability and skin conductance, using a pain stimulus on the area

Chapter 4: METHODS

4.1 Objective

The overall objective of this research is to identify a relationship between two established measures of pain: heart rate variability and skin conductance, using a cross-correlation analysis when pain stimuli are applied to healthy college students. To perform the cross-correlation analysis, the skin conductance data must be decomposed into its tonic and phasic components via the non-negative deconvolution. Once the phasic and tonic components were extracted from the skin conductance signal, they were cross-correlated with the high frequency and low frequency components of the heart rate variability signal, respectively.

Identifying a relationship between these two signals can have potential uses such as creating a more powerful tool used to treat chronic pain non-pharmacologically, through biofeedback training as well as improving the accuracy of pain reporting techniques.

4.2 Subject Inclusion and Exclusion Criteria

Data were collected from nineteen male and female college students, ages 19-32. Only data for 17 subjects were used because one file was corrupted, and one subject's data was too noisy to use. The subjects acted as self-controls with readings taken before and after the stimuli. The study subjects were selected based on the absence of previous known chronic pain diseases. All subjects were physically healthy and had no known symptoms of chronic pain. All subjects were proficient in the English language. The principal investigator assessed such criteria for inclusion; all students invited to participate met the specified criteria. No special populations were considered for this study.

4.3 Subject Recruitment and Consent

The study subjects were recruited from East Carolina University in Greenville, NC. A consent form was provided to each participant (see Appendix B). The study subjects were identified and recruited by the principal investigator and/or the co-investigator through the following avenues: verbal, email, or flyer invitation. A detailed consent form

was provided upon agreement to participate in the study stating that participation in this study was voluntary, confidential and that all results will be kept in a locked cabinet in Austin Hall, Room 321 for at least three years. All subjects were rewarded with $15 gift cards for their participation.

4.4 Study Location

Subjects participated in this research study in Rose Hall 2150. Subjects were exposed to the same environment and the same equipment. While at the study location, subjects were not exposed to any type of audio-visual stimuli that may had influenced their heart rate or skin conductance. Approximately 4- 6 hours before the study, subjects were asked not to consume energy drinks, caffeine, or consume medications that may induce tachycardia. Subjects were exposed to the same environmental stimuli or no stimuli at all (e.g. room temperature, visual or audio stimuli etc.)

4.5 Procedure

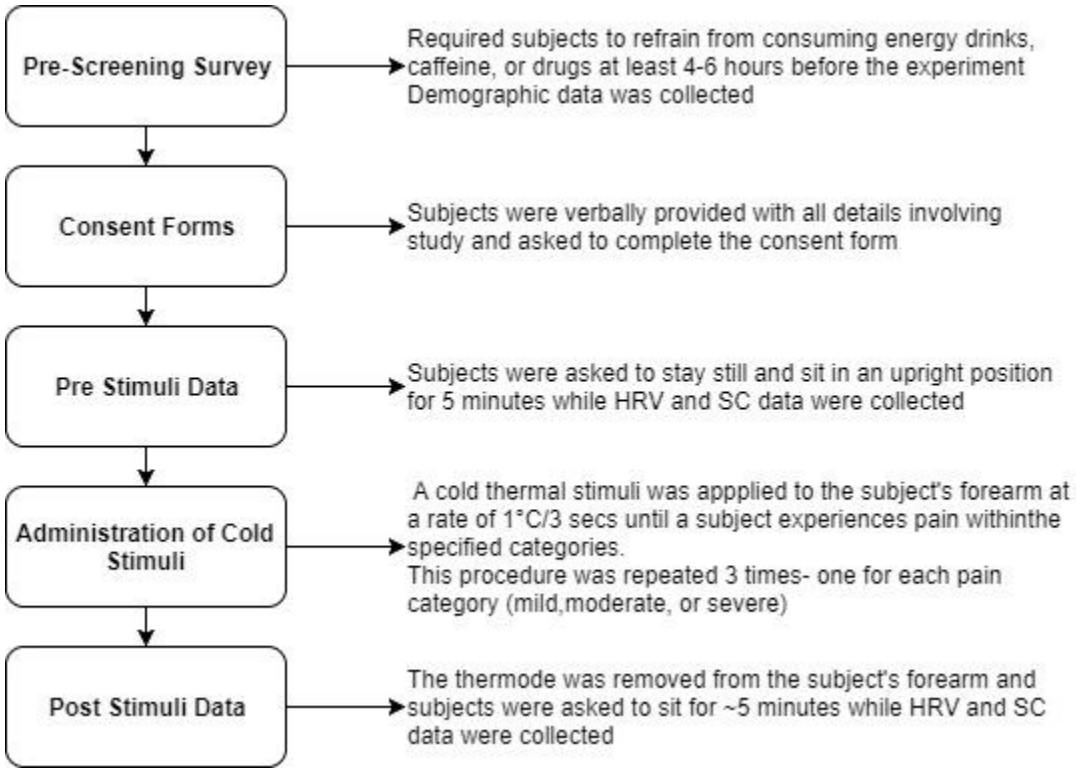


Figure 3. Procedure Overview

4.5.1 Cleaning and Disinfecting

Since the same room and equipment were used for data collection, the hardware was wiped down with alcohol wipes before and after each subject. The chair were subjects were sitting was wiped with Cavi Wipes™ disinfecting towelettes and a plastic chair cover was changed after every use. The principal investigator changed gloves after every subject and wiped down counter areas where their hands or personal belongings were placed using isopropyl alcohol (IPA).

4.5.2 Pre-Screening Survey

An initial screening survey was done to collect demographic information (see Appendix C), screen participants, and to verify that the subjects did not suffer from any chronic pain and meet age criteria. We did not screen for acute pain as this study only pertains to chronic pain. A separate post-test survey (see Appendix D) was administered to identify their pain intensity after the stimulus, using the defense and veteran's pain rating scale (DVPRS). The DVPRS was used for two reasons: first, it is a pain assessment tool that combines a numerical rating scale, word descriptions, color coding, and pictorial facial expressions all matched to pain levels which appeal to a wide variety of individuals. Second, the DVPRS has shown to be consistent and reliable.[42]

The principal investigator provided the subject with all the necessary information regarding the study, including disclosure of risks. Upon agreement to take part in the study, the subject was provided with a consent form and the consent form was reviewed and stored by the principal investigator. A copy of the consent form was given to each participant for their records. Each subject's identifiable information was kept confidential. A feasibility study was done in which only baseline data was collected under UMCIRB 17-000602. The purpose of this feasibility study was to test out the procedures and equipment so that any adjustments regarding data collection mechanisms could be made. Data from the feasibility study was not included in this document. Data for this study were collected under UMCIRB 17-001152 (Appendix C).

4.5.3 Data Collection

First, nineteen college students were pre-screened to verify that they do not experience any type of chronic pain. Second, the subjects were asked to sit in an upright position on a chair and to try to minimize movement. Then, the principal investigator placed the HRV monitor (Biocom pulse wave sensor HRM-02, Poulsbo, WA) on the subject's right earlobe. Figure 4 shows the correct placement of the ear lobe sensor. The GSR hardware (SHIMMER 3 GSR + Unit, Dublin, Ireland) consists of two sensors that are fastened with Velcro to the subject's index and middle fingers. Figure 5 shows the correct placement of the GSR hardware.

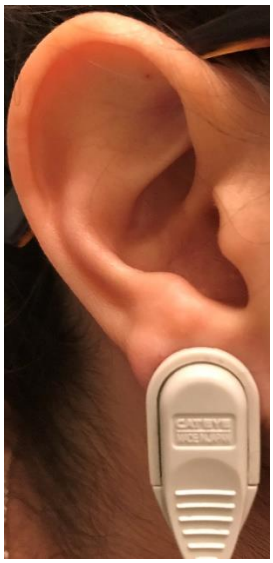


Figure 4. Ear lobe sensor positioning for optical pulse measurements

Figure 5. Correct GSR electrode positioning

To obtain baseline measurements, data were collected for five minutes on each subject. Pain was not measured at baseline as no pain stimuli were induced during this time. After baseline readings for heart rate and skin conductance were established, stimuli were applied using the MEDOC PATHWAY CHEPS Model. Subjects were informed in the consent form of the temperature limits of the probe to avoid any type of fear of injury during testing.

The thermode of the MEDOC PATHWAY CHEPS model was placed on the subjects' forearms, in accordance with the German Research Network of Neuropathic Pain (DFNS) protocol. For this experiment, we used cold stimuli, starting at 37°C, which is normal physiologic temperature, and decreased the temperature at a rate of 0.33°C/s, until the subject experienced pain or the probe reached 0°C. Subjects were provided with a reset button on their contralateral hand and were instructed to press the button as soon as they perceived any pain within the specified categories (mild, moderate, or severe pain). At reset, the probe temperature returned to 37°C. The average temperature that all subjects experienced overall for all categories was 25.7 (± 3.6). A secondary safety mechanism was established in case the button failed which involved the temperature to be reset in the software itself by the test operator; however, this was not used in data collection as the reset button did not fail. Tests for pain intensities were

repeated 3 times, one for each pain category — mild, moderate, or severe, during an approximate 6-minute period.

Meanwhile, heart rate variability and skin conductance were collected continuously at a sampling rate of 1 Hz; after the baseline was established, during the stimuli, and after the stimuli for a total of approximately 17 minutes per subject, during a one-time visit. Figure 6 contains the correct placement of all hardware. Then, the principal investigator removed all hardware from the subject's body. During data collection, the subjects were asked to complete the Defense and Veterans Pain Rating Scale (DVPRS) by telling the principal investigator the pain number they were currently experiencing.[43]

Figure 6.Correct placement of all hardware on subject

4.6 Risks

There were only minimal risks associated with participation in this research. The Shimmer™ GSR + Unit and the PPG optical sensor utilize non-invasive techniques to assess electrodermal activity and heart rate variability, respectively. Minimal side effects may be associated with using thermal testing, including goosebumps and temporary skin redness. The PATHWAY CHEPS/ATS model has built-in safety features that do

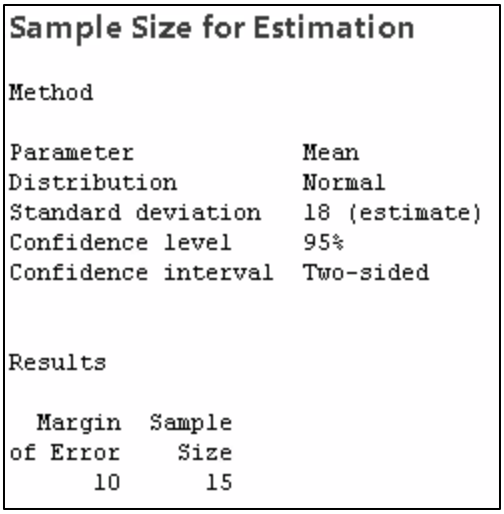
not allow for the maximum temperature to go over 55 °C or its minimum temperature to fall below -10°C. However, none of the subjects reported experiencing any side effects. Subjects were told prior to the study that they may stop participating at any time.

4.7 Confidentiality

The records of this study were kept confidential. The principal investigator did not include the name of any participant involved in this research in any scientific reports. Research records were kept in a locked file in Austin Hall, Room 321 at East Carolina University. The principal investigator and the co-investigator will be the only persons who will have access to these records.

4.8 Sample Size Calculation

Sample size was calculated with Minitab® Statistical Software, using the 'sample size for estimation' method. Data from Gunther et al. was used to calculate this sample size estimation for skin conductance, specifically, the results from "Table 2: Patient demographics" which include 60 intubated patients with a standard deviation of 16 and 55 non-intubated patients with a standard deviation of 18.[2] The sample size for estimation was calculated with the largest sample size based on literature which was 18, an assumed margin of error of 10, and a two-sided confidence level of 95% which resulted in a sample size of 15 subjects. Figure 7 contains the sample size estimation for skin conductance from Minitab® Statistical Software. Similarly, the sample size needed for heart rate variability was calculated using the same method with the data from Appelhans et al., specifically, the 4°C pain intensity mean of 52.36 with a standard deviation of 19.65 in a pool of 59 subjects.[10] This data was used since this study utilized a similar procedure in which pain was induced to subjects via the cold pressor test, while collecting HRV data. Figure 8 contains the sample size estimation for heart rate variability from Minitab® Statistical Software. As a result, the proposed sample size for this study is a minimum of 18 subjects.



Sample Size for Estimation

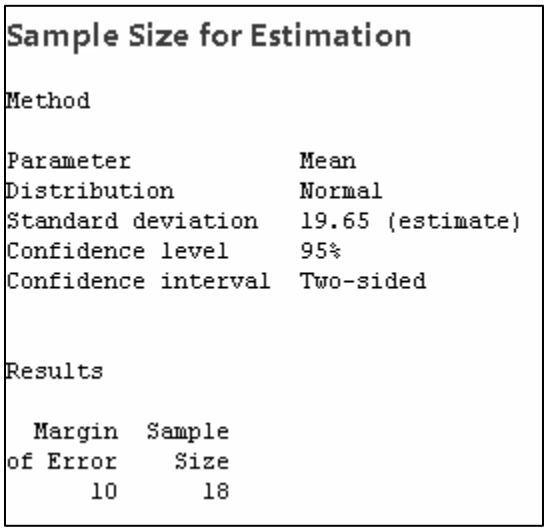
Method

Parameter	Mean
Distribution	Normal
Standard deviation	18 (estimate)
Confidence level	95%
Confidence interval	Two-sided

Results

Margin of Error	Sample Size
10	15

Figure 7. Sample Size Estimation for Skin Conductance using Minitab Statistical Software. A margin error of 10 was assumed for this calculation.



Sample Size for Estimation

Method

Parameter	Mean
Distribution	Normal
Standard deviation	19.65 (estimate)
Confidence level	95%
Confidence interval	Two-sided

Results

Margin of Error	Sample Size
10	18

Figure 8. Sample Size Estimation for heart rate variability using Minitab Statistical Software. A margin error of 10 was assumed for this calculation.

Chapter 5: Data Processing and Analysis

5.1 HRV in Time domain

The common measures of heart rate variability were compared such as SDNN (standard deviation of NN intervals) and RMSSD (root mean squared standard deviation of consecutive NN intervals).

5.2 HRV in Frequency Domain

The low frequency (LF norm) and high frequency (HF Norm) normalized values were extracted from the *HRV Live!* Software. These values were then graphed in MATLAB for both pre- and post- stimuli as a function of time for all subjects.

Table 6. Data Groups and Conditions

Group	Condition
LF Norm pre	Low frequency values of HRV at rest (before the cold stimuli)
LF Norm post 1	Low frequency values of HRV during the first cold stimuli range (mild pain).
LF Norm post 2	Low frequency values of HRV during the second cold stimuli range (moderate pain).
LF Norm post 3	Low frequency values of HRV during the third cold stimuli range (severe pain).
HF Norm pre	High frequency values of HRV at rest (before the cold stimuli)
HF Norm post 1	High frequency values of HRV during the first cold stimuli range (mild pain).
HF Norm post 2	High frequency values of HRV during the second cold stimuli range (moderate pain).
HF Norm post 3	High frequency values of HRV during the third cold stimuli range (severe pain).
SC tonic pre	Skin conductance tonic component at rest (before the cold stimuli)
SC phasic pre	Skin conductance phasic component during the first cold stimuli range
SC tonic post	Skin conductance tonic component during the second cold stimuli range
SC phasic post	Skin conductance phasic component during the third cold stimuli range

*Note: All data groups were collected for all subjects individually, yielding 12 variables per person, for a total of 204.

5.3 Skin Conductance Data

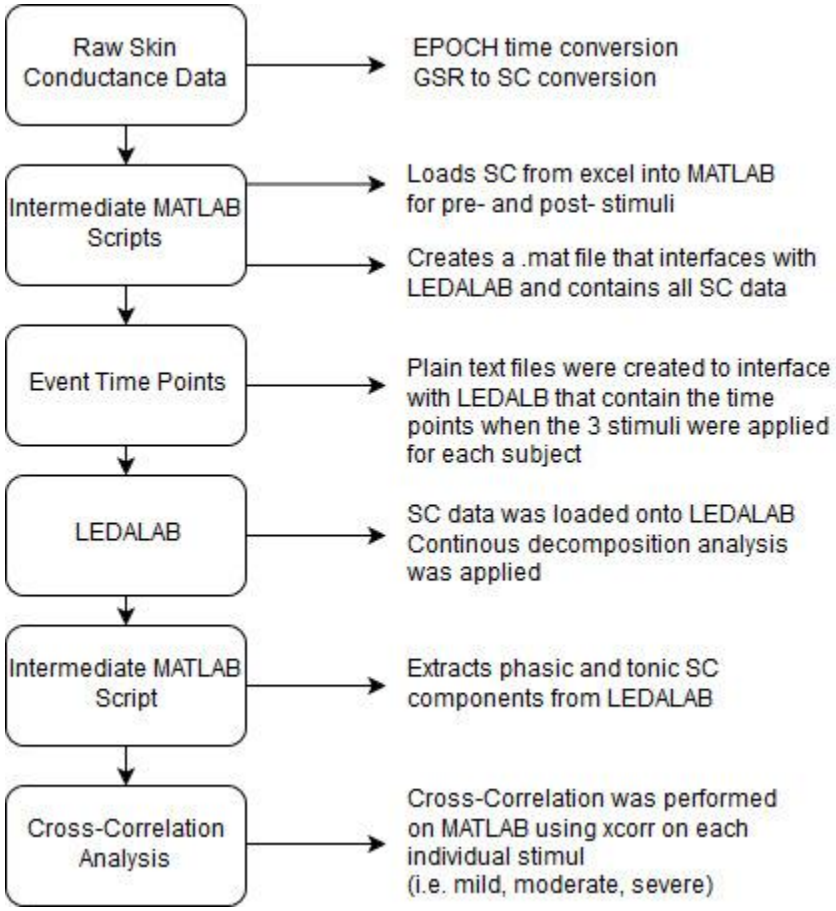


Figure 9. Skin Conductance Data Analysis Overview

Figure 9 contains an overview of the data processing procedure used. After data collection, all pre- and post- stimuli skin conductance data were modified to convert from EPOCH time to a regular time format (i.e. dd:mm:yyyy:hh:ss.0) as well as convert GSR calibrated data to skin conductance using Equation 4. In addition, all time points were added to these files manually to reflect the (events) in which a stimulus was applied. Then, all excel data files were loaded into MATLAB using an original script in which pre- and post- stimuli data were separated. This MATLAB original script was then used to interface with LEDALAB to separate the tonic and phasic components of the skin conductance signal.

5.3.1 Event Detection

LEDALAB necessitates the user to input the time points in seconds in which the stimuli were applied for each subject. Therefore, plain text files that contained the time

in seconds in which the stimuli were applied (referred to as events) along with the event ID (i.e. 1, 2, 3) were created for all subjects. Each plain text file was imported into MATLAB along with the corresponding excel file that contained the skin conductance data for each subject. Due to the nature of event time collection which consisted of writing down the time relative to the start of data collection when a subject pressed the reset button, the exact time may or may not be correct. Each person's reaction time needs to be accounted for as well as the reaction time of the principal investigator; thus, some time events were off by just a few seconds. Thus, the principal investigator visually inspected the signals to ensure that the time event was at the peak of the signal, if not, then the event time was altered to accommodate such.

5.3.2 Separation of Phasic and Tonic Components

Upon event detection, the data was optimized to improve the goodness of fit of the model as the decomposition procedure is initially implemented with predefined parameters for τ_1 and τ_2 ($\tau_1 = 0.75, \tau_1 = 0.20$). Optimization of data re-runs all four steps of decomposition (i.e. i) estimation of the tonic component, ii) non-negative deconvolution of phasic skin conductance data, iii) segmentation of driver and remainder, and iv) reconstruction of skin conductance data[26]) with the new parameters. To decompose the signal into its tonic and phasic components, a standard deconvolution is applied to the signal using the Bateman function. As the impulse response is computed, it concludes with an estimation of the driver function that is not non-negative, producing only a tonic skin conductance component. Via a convolution, the resulting driver function was smoothed with a Gaussian window since deconvolution amplifies noise. Once the driver function was smoothed, the peaks were detected to identify individual impulses. Peak detection was computed by finding zeros in the first time-derivative of the smoothed driver function. Local maxima and minima were found. An impulse is defined by the section between the local maxima and minima and a significant peak is defined as having a difference of $\delta \geq 0.2\ \mu S$. Lastly, "tonic activity is estimated using a time grid with 100 s spacing by averaging the driver function of inter-impulse sections within the range of half of the grid spacing before and after the grid points". Upon tonic signal estimation, the signal was subtracted from the raw skin conductance data which yields the phasic data[26]. Figure 10 shows a sample LEDALAB

screenshot of subject 4, during optimization, smoothing, continuous decomposition analysis, and peak detection. Figure 11 shows the resulting plot after applying the continuous decomposition analysis seen on Figure 10 which yields the phasic (blue) and tonic (gray) skin conductance components in an interactive plot.

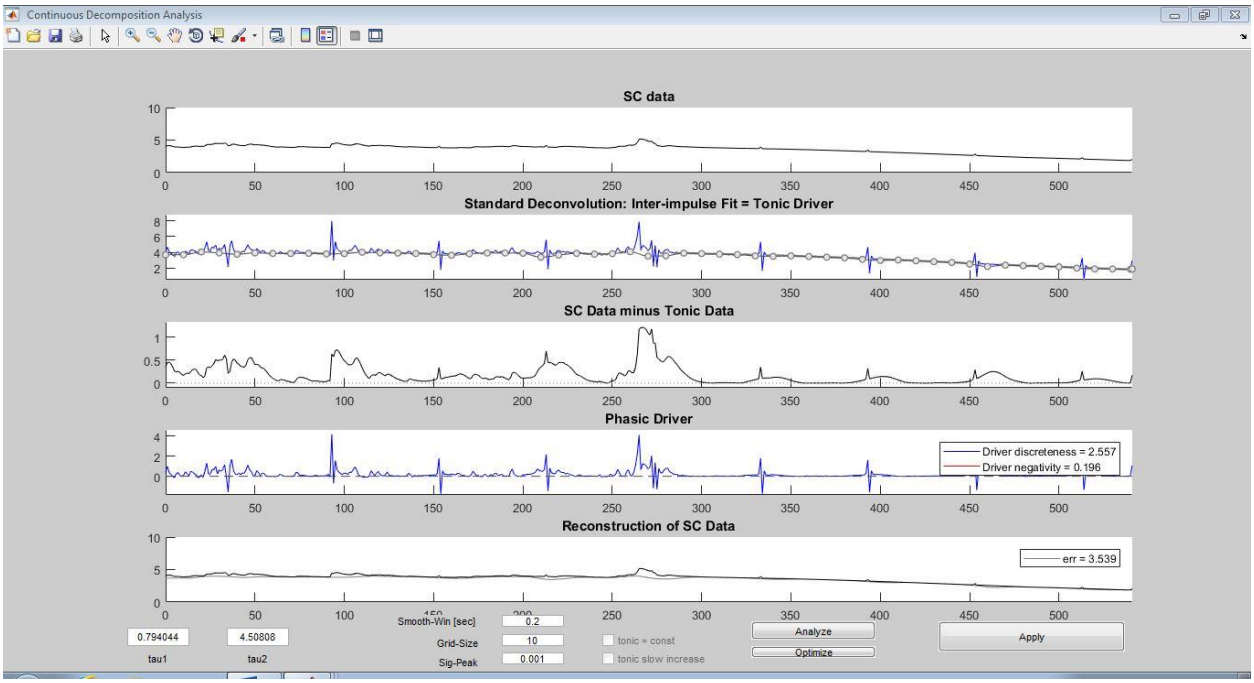


Figure 10. Continuous Decomposition Analysis in LEDALAB

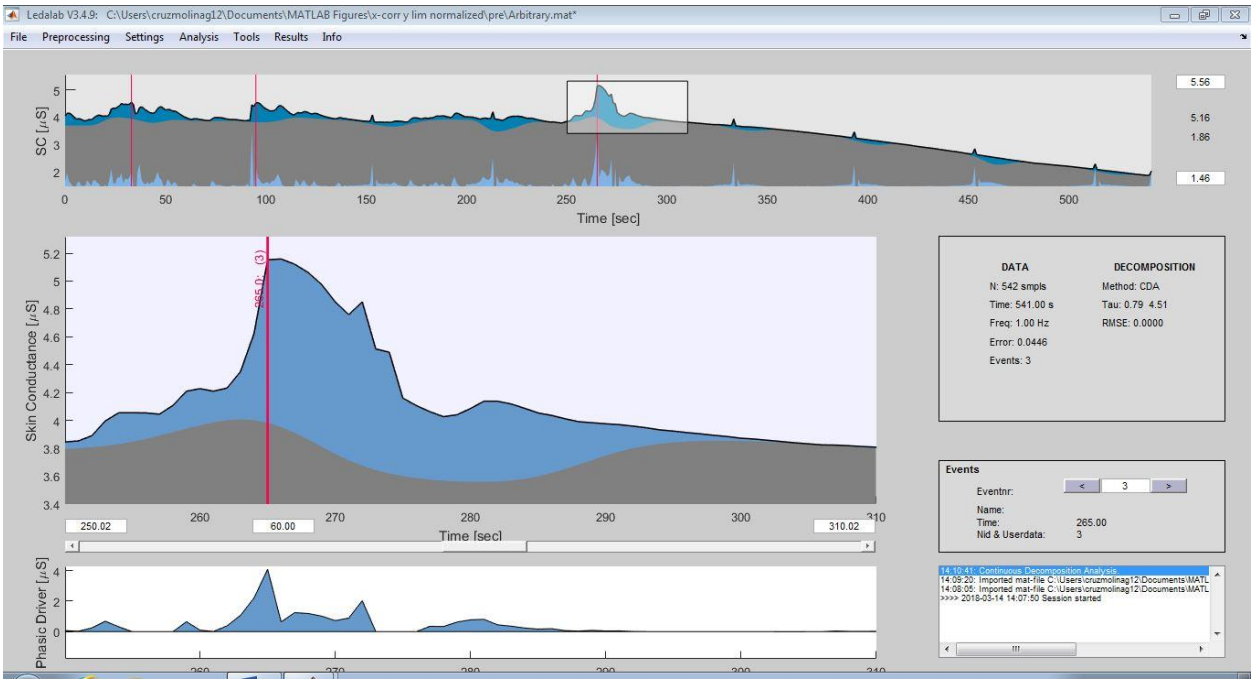


Figure 11.Decomposed Skin Conductance Signal in its tonic (gray) and phasic (blue) components

After the phasic and tonic activity were extracted from the time domain signal of skin conductance, the values were extracted from LEDALAB and plotted using an original MATLAB script. However, it was observed that the signals would just drop off after a certain point. It was found that the plots had two zero values at the end that would greatly influence the correlation; therefore, these values were removed and only array values with a numerical value greater than zero were used. These zero values were on every subject's last two data points and were attributed to taking off the hardware (i.e. the PPG sensor and the SHIMMER 3 GSR+ Unit) from each subject before stopping data logging. Figure 12 shows the phasic and tonic values from subject 2 with the zeros, whereas Figure 13 shows the phasic and tonic values without the zeros.

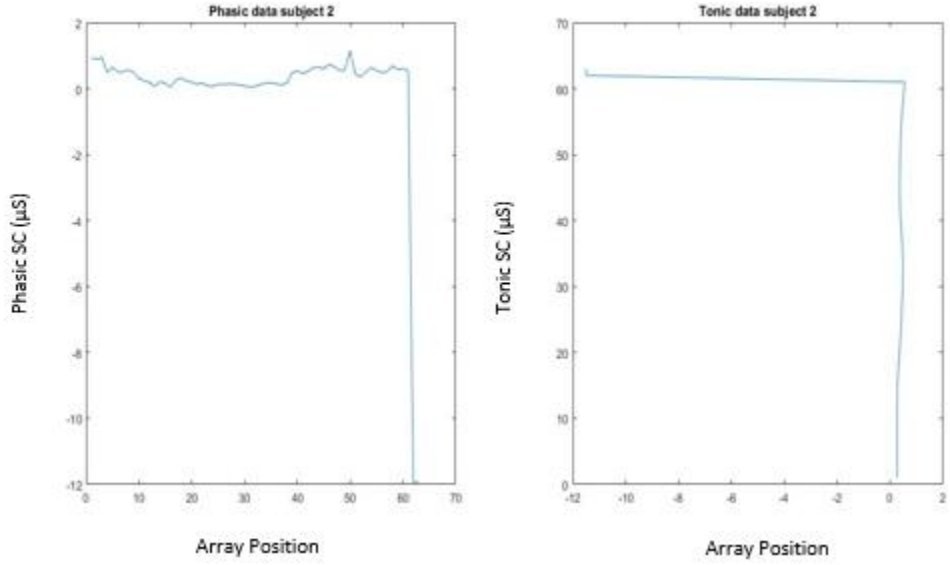


Figure 12. Sample Decomposed Skin Conductance Signal in its Phasic and Tonic Components with the zero values.

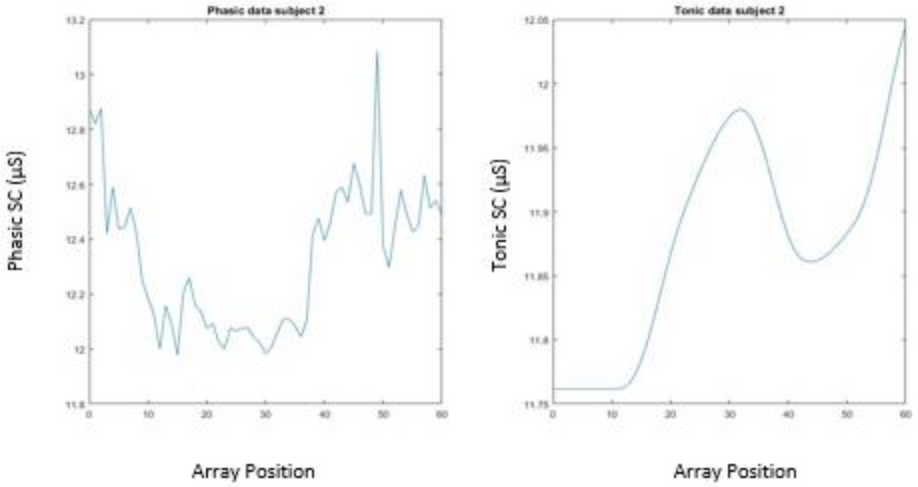


Figure 13. Sample Decomposed Skin Conductance Signal in its Phasic and Tonic Components without the zero values.

5.4. Cross-Correlation Analysis

First, all conditions (HF Norm pre, HF post- stimuli 1,2, and 3, LF Norm pre, LF post- stimuli 1,2, and 3, tonic pre- and post- stimuli, phasic pre- and post- stimuli) were normalized by subtracting their mean away from each other and dividing by its corresponding standard deviation. Second, the cross-correlation of heart rate variability and skin conductance was done for each condition using the *xcorr* function on an original MATLAB script. Specifically, high frequency values of HRV (HF Norm) were cross-correlated with phasic values of skin conductance, whereas low frequency values of HRV (LF Norm) were correlated with tonic values of skin conductance. Equation 9 shows the *xcorr* command, where r = correlation coefficient, x = signal 1, y = signal 2. Equation 10 is a sample normalized cross-correlation mathematical function applied to all subjects.

$$r = xcorr(x, y) \quad \textit{Equation 9}$$

$$r = xcorr\left(\frac{LF\ Norm - mean\ (LF\ Norm)}{std(LF\ Norm)}, \frac{tonic\ post - mean(tonic\ post)}{std(tonic\ post)}\right) \quad \textit{Equation 10}$$

The cross-correlation for each condition (for example, the cross-correlation of HF Norm pre and tonic pre) were plotted using an original MATLAB script. Then, the absolute maximum or minimum were found to determine the highest degree of correlation for each condition. Everything before the zero time mark was ignored and only regarded a peak as a maximum value after zero to be significant. Figures 14 and 15 show a sample cross-correlation of LF and HF, respectively.

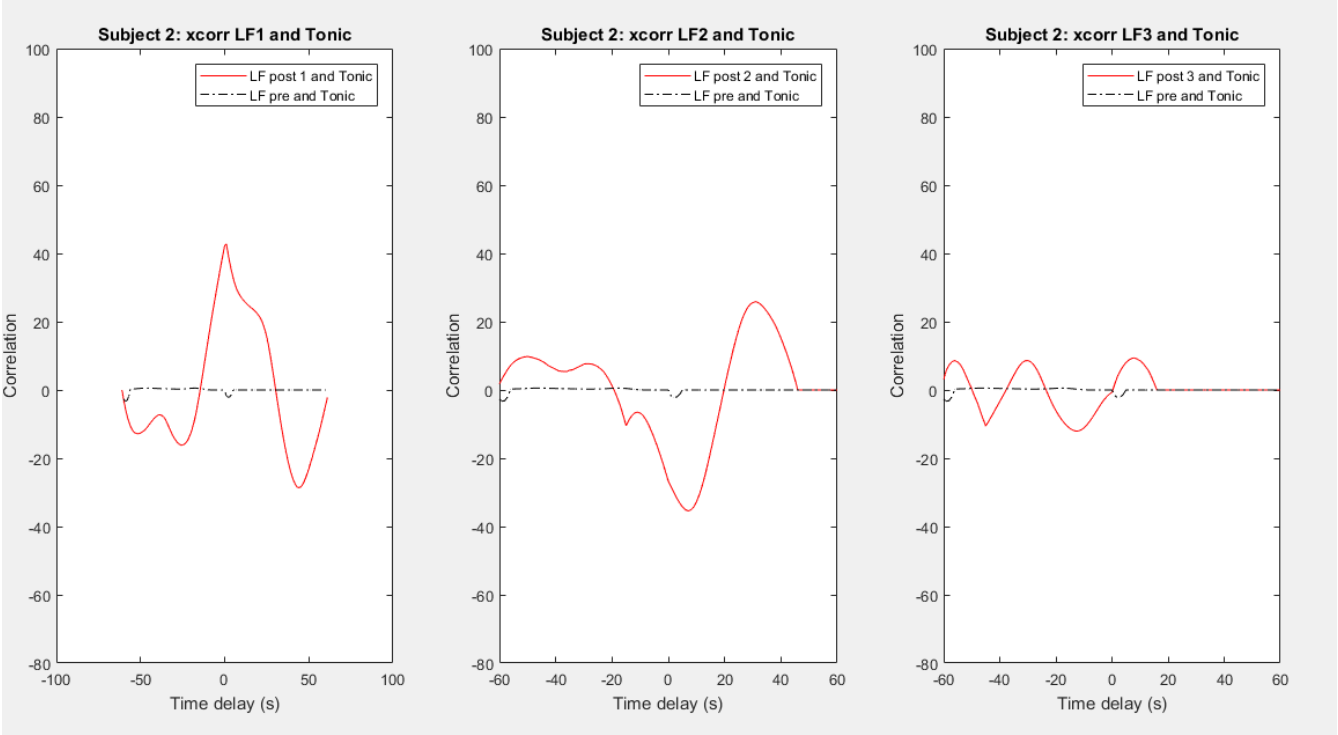


Figure 14. Sample Cross-Correlation of LF Norm and Tonic Values

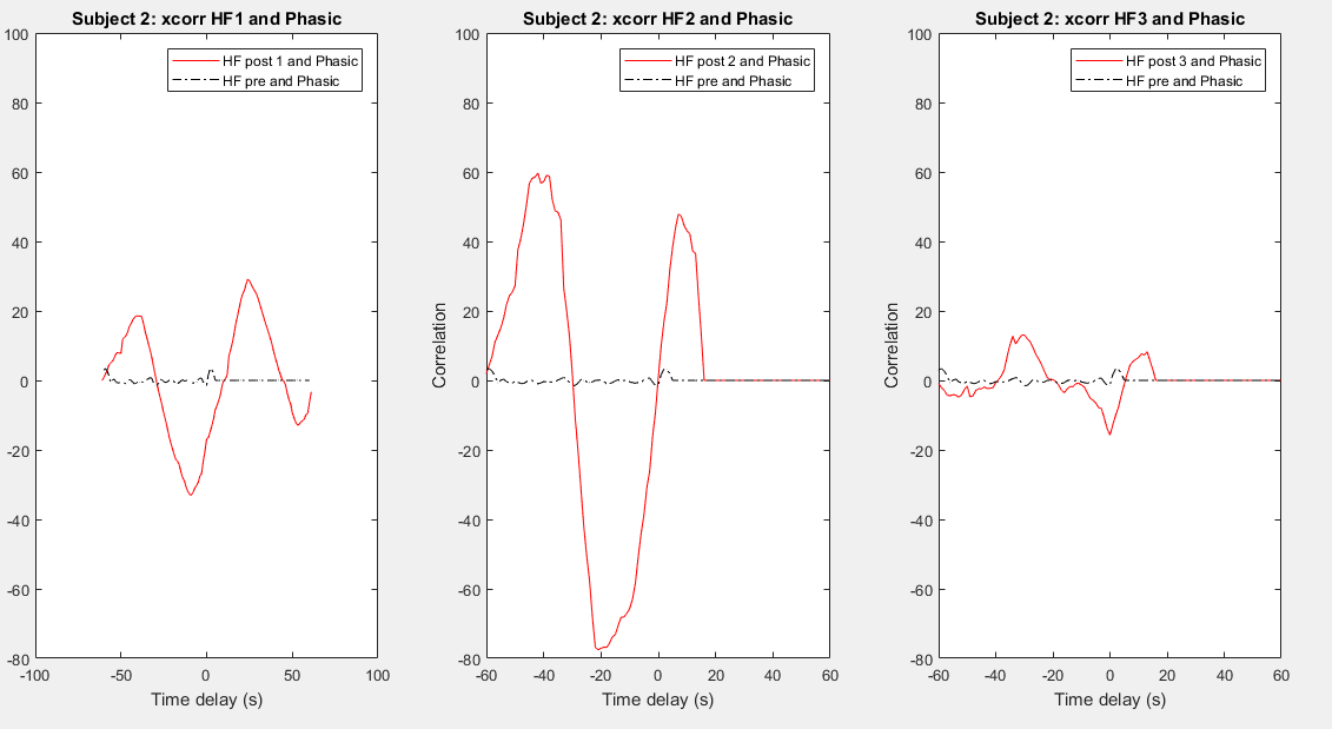


Figure 15. Sample Cross-Correlation of HF Norm and Phasic Values

Chapter 6: Results

6.1 Descriptive Statistics

Data for subject 8 were unused due to a software issue that caused the skin conductance file to be corrupt and unable to access. Data for subject 1 were unused because it was too noisy and could not get any good readings out of it. Thus, all data analysis was done on 17 subjects, ages 19-23. Table 7 contains the descriptive statistics. Table 8 contains the mean pain scores of 17 subjects using the Defense and Veterans Pain Rating Scale.

Table 7. Descriptive Statistics for Subjects used in Data Analysis

Group	Amount	Age
All	17	21.3 (±1.4)
Females	12	21.1 (±1.1)
Males	5	21.8 (±1.9)

Table 8. Descriptive Statistics for Pain Scores

Group	Mild	Moderate	Severe
All	2.29 (±0.85)	5.28 (±1.09)	7.29 (±1.57)
Female	2.42 (±0.90)	5.54 (±0.66)	7.83 (±0.83)
Male	2.33 (±1.03)	4.40 (±1.52)	6.00 (±2.24)

*Mean pain scores for subjects during stimuli, includes subject 12 whose pain score did not change from moderate to severe.

6.2 Repeated Measures ANOVA's

For a repeated measures ANOVA to be successful, an important assumption must be made: the relationship between pairs of experimental conditions is similar meaning that it is assumed that the variances are roughly equal. If the condition of sphericity is violated, then the effect is a loss of power (an increased probability of a Type II error) and a test statistic (F-statisic) that cannot be compared to the tabulated values of the F-distrubiton. However, there are corrections that can be made to the data including the Greenhouse-Gessier and the Hyunh-Feldt correction to adjust the degrees of freedom which makes the F-statistic more conservative. The Greenhouse-Geisser correction should be applied when $\varepsilon < 0.75$ and the Hyunh-Feldt correction should be applied when $\varepsilon > 0.75$. Maulchy's test of sphericity revealed that there are significant

differences, between the variances of the variables, LF and HF; therefore, the condition for sphericity is not met (χ^2 (5) = 31.744, p = 0.000). Since, ε <0.75, the Greenhouse-Geisser correction must be applied to adjust the degrees of freedom[44].

Several repeated measures ANOVA with the Bonferroni adjustment were completed in SPSS 24 to determine the differences between the following:

- Heart Rate (HRT) pre, HRT 1, HRT 2, HRT 3
- LF pre, LF Norm 1, LF Norm 3, and LF Norm 3
- HF pre, HF Norm 1, HF Norm 2, and HF Norm 3
- VLF pre, VLF 1, VLF 2, VLF3
- TP pre, TP 1, TP 2, TP 3
- RMSSD pre, RMSDD 1, RMSSD 2, RMSSD 3
- SDNN pre, SDNN 1, SDNN 2, SDNN 3
- LF/HF pre, LF/HF 1, LF/HF 2, LF/HF
- SC pre, SC post 1, SC post 2, SC post 3

6.2.1 Heart Rate Variability

The mean value for each group (i.e. pre-stimuli, post-stimuli 1, post-stimuli 2, post-stimuli 3) for all subjects and all variables (i.e. HRT, HF Norm, LF Norm, LF/HF, Total Power, VLF, SDNN, RMSSD, SDNN/RMSSD) were calculated in Microsoft Excel®. Repeated measures ANOVA were completed in SPSS for all variable groups. Table 9 shows these results for all subjects. Heart Rate is in beats per minutes, RMSSD and SDNN are in milliseconds, Total Power and Very Low Frequency (VLF) are in ms*2/Hz, HF norm and LF norm are both in normalized units, whereas LF/HF and SDNN/RMSSD are unitless ratios.

Table 9. Multivariate tests of resting (pre) and post measures (post 1, post 2, post 3) with means (sd) for HRV. Repeated measures ANOVA show F-values, P-values, effect size (n^2) for interaction effects, and observed power.

Measure	**Pre**	**Post 1**	**Post 2**	**Post 3**	**ANOVA (group x time)**			
					F	**p**	n^2	**Power**
HRT (bpm)	74.5 (14.9)	76.8 (14.3)	75.8 (13.9)	75.6 (13.3)	6.857	0.005	0.595	0.925
LF Norm (n.u.)	53.4 (19.6)	60.0 (14.2)	64.4 (12.6)	62.2 (11.6)	5.401	0.011	0.536	0.847
HF Norm (n.u.)	46.6 (19.6)	40.2 (14.0)	35.3 (12.9)	37.8 (11.6)	4.241	0.010	0.210	0.602
LF/HF	1.7 (1.5)	1.9 (1.5)	2.3 (1.5)	2.0 (1.2)	5.769	0.009	0.553	0.871
TP (ms*2/Hz)	2434.8 (3870.3)	2032.2 (1371.2)	2494.2 (2283.2)	2594.8 (3518.9)	0.614	0.617	0.116	0.146
VLF (ms*2/Hz)	594.4 (580.3)	990.4 (834.4)	862.9 (834.2)	760.0 (674.0)	2.611	0.093	0.359	0.514
RMSSD (ms)	62.3 (28.8)	67.26 (40.3)	72.8 (51.9)	73.5 (61.4)	3.337	0.050	0.417	0.628
SDNN (ms)	74.0 (37.6)	84.9 (31.8)	83.8 (37.6)	84.7 (46.1)	3.991	0.030	0.461	0.714
SDNN/RMSSD	0.860 (0.209)	0.771 (0.186)	0.818 (0.227)	0.812 (0.231)	1.895	0.177	0.289	0.386

However, only the HRV variables relevant to the cross-correlation were further tested with more repeated measures ANOVA's to determine sphericity, the differences between-subjects and within-subjects for pre, post 1, post 2, post 3 In addition, if statistical significance was found, then post-hoc tests with Bonferroni corrections were completed.

Table 10 contains the results for Maulchy's test of sphericity for LF Norm and HF Norm. Maulchy's test of sphericity for LF and HF revealed that there are significant differences between the variances of the variables; therefore, the condition for sphericity is not met for LF (χ^2 (5) = 31.744, p = 0.000) and HF (χ^2 (5) = 33.331, p = 0.000). Since, ε <0.75 for both, the Greenhouse-Geisser correction must be applied to adjust the degrees of freedom.

Table 10. Mauchly's[a] Test of Sphericity

Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
						Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	LF	.116	31.744	5	.000	.496	.535	.333
	HF	.104	33.331	5	.000	.491	.528	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table

Table 11 shows the results of the repeated measures ANOVA for within-subjects effects for both LF and HF. Since the results were statistically significant for LF and HF ($p < 0.05$), post-hoc tests with Bonferroni corrections were done for the pairwise comparisons which is shown on Table 12.

Table 11. Tests of within-subjects effects for LF Norm and HF Norm

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	LF	**Greenhouse-Geisser**	1157.786	1.487	778.692	4.107	.040	.204	6.106	.590
	HF	Greenhouse-Geisser	1199.295	1.473	814.441	4.241	.037	.210	6.245	.602
Error (Time)	LF	Greenhouse-Geisser	4510.998	23.789	189.622					
	HF	Greenhouse-Geisser	4524.314	3.561	192.029					

Table 12. Pairwise Comparisons for LF Norm and HF Norm

Measure	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
LF	1	2	-6.621	4.371	.896	-19.771	6.528
		3	-11.039	4.285	.122	-23.931	1.853
		4	-8.800	4.364	.365	-21.929	4.329
	2	1	6.621	4.371	.896	-6.528	19.771
		3	**-4.418***	**1.446**	**.045**	**-8.767**	**-.069**
		4	-2.178	2.338	1.000	-9.213	4.856
	3	1	11.039	4.285	.122	-1.853	23.931
		2	4.418*	1.446	.045	.069	8.767
		4	2.239	1.504	.937	-2.287	6.765
	4	1	8.800	4.364	.365	-4.329	21.929
		2	2.178	2.338	1.000	-4.856	9.213
		3	-2.239	1.504	.937	-6.765	2.287
HF	1	2	6.418	4.263	.910	-6.406	19.241
		3	11.303	4.422	.127	-2.000	24.606
		4	8.800	4.364	.365	-4.329	21.929
	2	1	-6.418	4.263	.910	-19.241	6.406
		3	**4.885***	**1.432**	**.021**	**.578**	**9.193**
		4	2.382	2.335	1.000	-4.643	9.408
	3	1	-11.303	4.422	.127	-24.606	2.000
		2	-4.885*	1.432	.021	-9.193	-.578
		4	-2.503	1.503	.692	-7.025	2.019
	4	1	-8.800	4.364	.365	-21.929	4.329
		2	-2.382	2.335	1.000	-9.408	4.643
		3	2.503	1.503	.692	-2.019	7.025

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Table 13 contains the results for Maulchy's test of sphericity for the ratio of LF Norm and HF Norm. Maulchy's test of sphericity revealed that there are significant differences between the variances of the variables; therefore, the condition for sphericity

is not met (χ^2 (5) = 32.766, p = 0.000). Since, ε <0.75, the Greenhouse-Geisser correction must be applied to adjust the degrees of freedom.

Table 13. Maulchy's [a] Test of Sphericity for LF Norm/HF Norm

Measure: LF Norm /HF Norm

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Time	.108	32.766	5	.000	.543	.596	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 14 shows the results of the repeated measures ANOVA for within-subjects effects for the ratio of LF Norm and HF Norm. Since the results were not statistically significant for LF Norm/HF Norm (p≠< 0.05), post-hoc tests with Bonferroni corrections were not done.

Table 14. Tests of within subjects Effects for LF Norm/HF Norm

Measure: LF Norm /HF Norm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Time	Greenhouse-Geisser	3.687	1.629	2.263	1.436	.254	.082	2.340	.256
Error (Time)	Greenhouse-Geisser	41.067	26.062	1.576					

6.2.2 Skin Conductance

The mean value for each SC group (i.e. pre-stimuli, post-stimuli 1, post-stimuli 2, post-stimuli 3) for all subjects were calculated in Microsoft Excel®. Repeated measures

ANOVA were applied to these values to test the differences between them over time. Table 15 contains these results.

Table 15. Multivariate tests of resting (pre) and post measures (post 1, post 2, post 3) with means (sd) for skin conductance. Repeated measures ANOVA show F-values, P-values, effect size (n^2) for interaction effects, and observed power.

Measure	**Pre**	**Post 1**	**Post 2**	**Post 3**	**ANOVA (group x time)**			
					F	**p**	n^2	**Power**
SC (uS)	1.43 (1.60)	3.64 (2.97)	3.69 (3.17)	3.60 (3.27)	10.2	0.001	0.685	0.988

Table 16 shows the Maulchy's test of sphericity results for skin conductance. Maulchy's test of sphericity revealed that there are significant differences between the variances of the variables; therefore, the condition for sphericity is not met (χ^2 (5) = 74.994, p = 0.000). Since, ε <0.75, the Greenhouse-Geisser correction must be applied to adjust the degrees of freedom.

Table 16. Maulchy's [a] Test of Sphericity for Skin Conductance

Measure: SC

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
time	.006	74.994	5	.000	.390	.402	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Table 17 shows the results of the repeated measures ANOVA for between-subjects effects for skin conductance. Since the results were not statistically significant for SC (p< 0.05), post-hoc tests with Bonferroni corrections were done which is shown on table 18.

Table 17. Tests of between-subject effects for skin conductance

Measure: SC

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	649.469	1	649.469	22.082	.000	.580	22.082	.993
Error	470.577	16	29.411					

a. Computed using alpha = .05

Table 18. Pairwise Comparisons for Skin Conductance

Measure: SC

(I) time	(J) time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-2.217*	.394	.000	-3.404	-1.031
	3	-2.263*	.444	.001	-3.600	-.926
	4	-2.178*	.472	.002	-3.597	-.760
2	1	2.217*	.394	.000	1.031	3.404
	3	-.045	.106	1.000	-.365	.274
	4	.039	.174	1.000	-.485	.563
3	1	2.263*	.444	.001	.926	3.600
	2	.045	.106	1.000	-.274	.365
	4	.084	.079	1.000	-.152	.321
4	1	2.178*	.472	.002	.760	3.597
	2	-.039	.174	1.000	-.563	.485
	3	-.084	.079	1.000	-.321	.152

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

6.3 Cross-Correlation Coefficient Results

The cross-correlation coefficient found by determining the peaks of the cross-correlation plots between HF Norm and Phasic, LF Norm and Tonic were graphed in boxplots on SPSS to show the differences in correlation between these variables. Table

19 shows the descriptive statistics that were calculated for each. Figure 18 shows the correlation coefficient (r) between HF Norm and Phasic. Figure 19 shows the time delay between Norm and Phasic. Figure 20 shows the correlation coefficient (r) between LF Norm and Tonic. Figure 21 shows the time delay between LF Norm and Tonic.

Table 19. Descriptive statistics for the cross-correlation coefficients

Group	**Mean**	**Median**	**S.E.** (σ^2)	**Max.**	**Min.**	**95% CI**	**IQR**
HF pre and Phasic	3.31 (14.3)	3.03	3.46	52.20	-16.60	(-4.03, 10.65)	8.95
HF Norm 1 and Phasic	11.58 (17.3)	4.21	17.35	45.38	-17.06	(2.66, 20.50)	25.66
HF Norm 2 and Phasic	28.47 (43.80)	35.16	10.63	98.07	-73.83	(5.95, 51.00)	48.66
HF Norm 3 and Phasic	20.27 (15.24)	23.50	3.70	56.94	61.24	(12.43, 28.11)	22.24
TD HF Norm pre and Phasic	5.00 (8.57)	2.00	2.08	37.00	0.00	(0.5921, 9.41)	5.00
TD HF Norm 1 and Phasic	33.82 (28.61)	27.00	6.94	109.00	0.00	(19.11, 48.53)	14.00
TD HF Norm 2 and Phasic	64.65 (38.45)	53.00	9.33	130.00	7.00	(44.88, 84.42)	69.50
TD HF Norm 3 and Phasic	52.65 (37.89)	48.00	9.18	130.00	1	(33.18, 72.11)	49.00
LF Norm Pre and Tonic	2.28 (8.32)	0.1	2.02	26.60	-6.40	(-2.00, 6.56)	6.95
LF Norm 1 and Tonic	16.54 (15.12)	17.98	3.66	42.78	-14.77	(8.76, 24.31)	57.55
LF Norm 2 and Tonic	19.47 (12.19)	16.77	2.96	45.70	3.68	(13.20, 25.74)	17.49
LF Norm 3 and Tonic	19.33 (13.53)	17.50	3.28	42.00	-5.43	(12.38, 26.29)	21.74
TD LF Norm Pre and Tonic	7.12 (10.31)	3.00	2.50	34	33	(1.82, 12.42)	4.50
TD LF Norm 1 and Tonic	32.47 (26.41)	30.00	6.41	94	0.00	(18.89, 46.05)	38
TD LF Norm 2 and Tonic	47.06 (36.70)	33.00	8.90	131	0.00	(28.19, 65.92)	37.50
TDLF Norm 3 and Tonic	61.82 (40.88)	33.00	9.92	147	8.00	(40.80, 82.84)	66.50

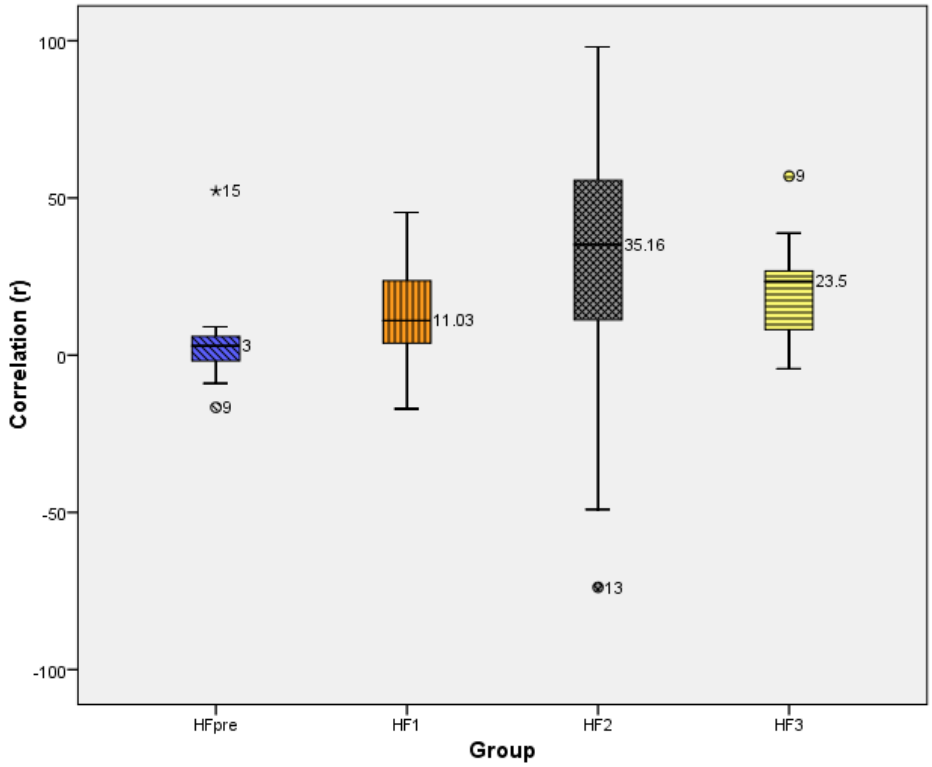


Figure 16. Correlation Coefficient for HF Norm and Phasic

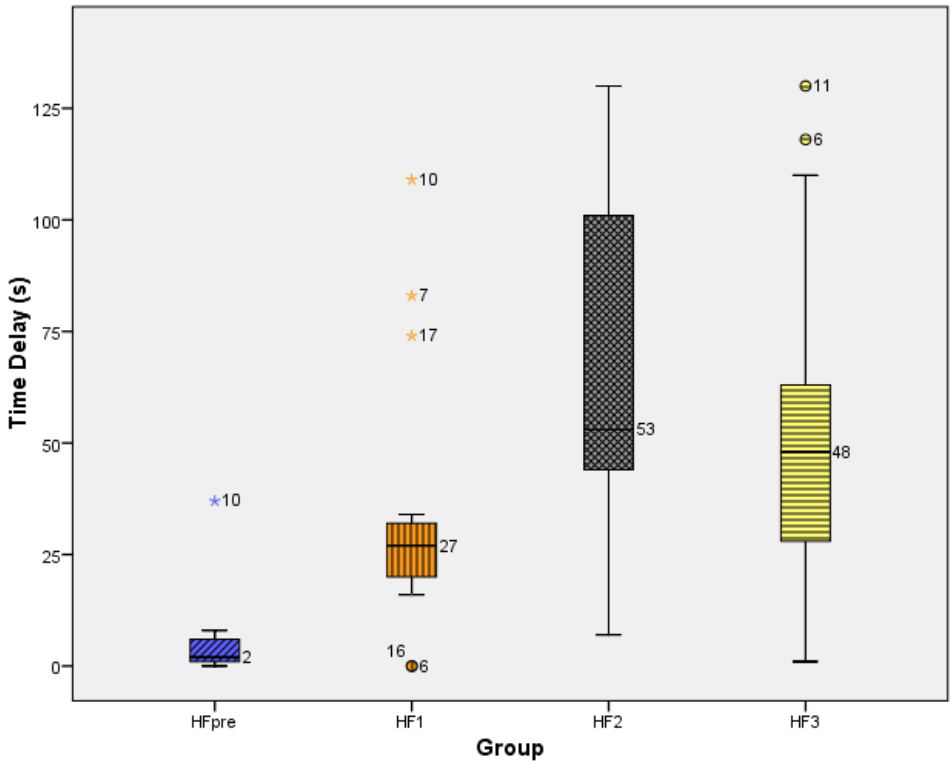


Figure 17. Time Delay between HF Norm and Phasic

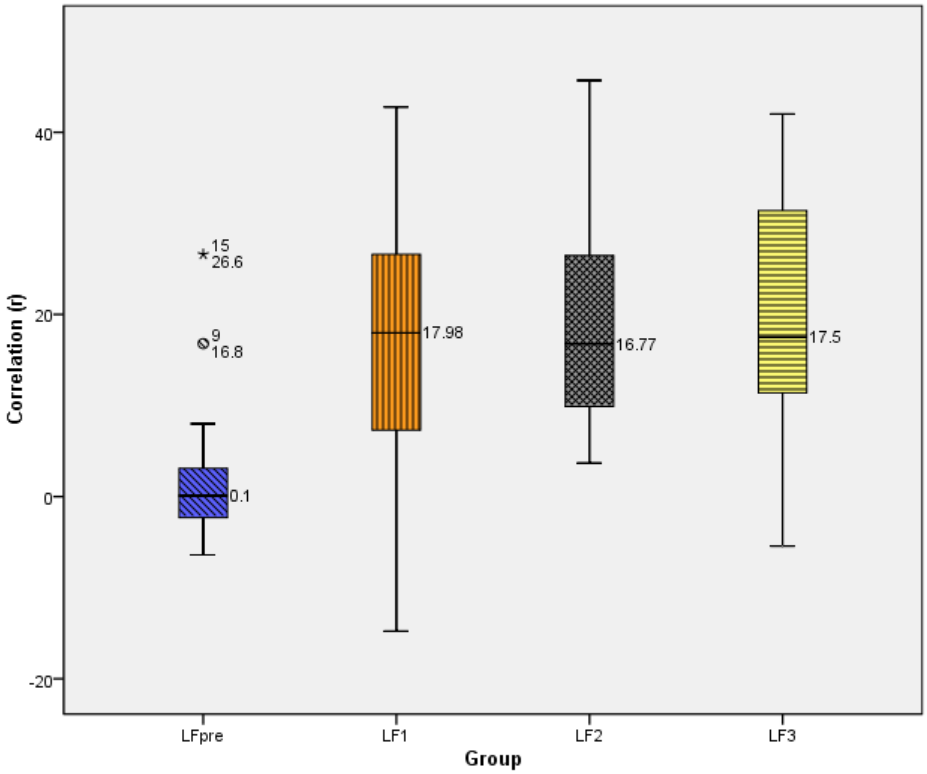


Figure 18. Correlation Coefficient for LF Norm and Tonic

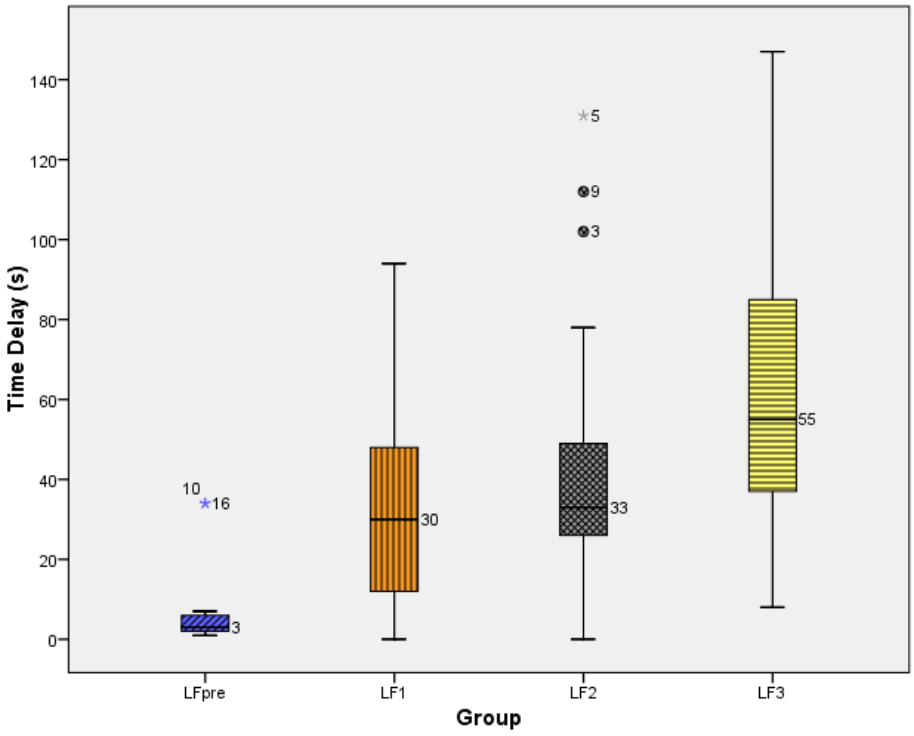


Figure 19. Time delay for LF Norm and Tonic

Chapter 7: Discussion

Analysis of Variance (ANOVA) (group x time) were done on the following measures: Heart Rate (HRT), LF Norm, HF Norm, LF/HF,TP, VLF, RMSSD, SDNN, and SDNN/RMSSD shown on Table 9 to determine if the application of the stimuli had an impact on these readings over time. Table 9 shows that heart rate increased on average when comparing pre-stimuli to post-stimuli measures. Such increase was statistically signficant (p=0.005) as shown in Table 9. It also shows that there was an increase on average in LF Norm values that was statistically significant (p=0.011), whereas the average HF Norm decreased which was also statistically signifcant (p=0.010). Since HF and LF are measures of parasympathetic and sympahtetic activity that work together to regulate the body, it is a good measure to look at the ratio of LF to HF which is shown on Table 9. On average, the LF/HF ratio increased as the stimuli were applied wich was statistically signficant (p=0.009). On average, VLF increased; however, it was not statistically signficant (p=0.093). Total Power (TP) increased on average but this was not statistically significant (p=0.617). Total Power is a sum of all activity a subject is experiencing (High Frequency + Low Frequency + Very Low Frequency). Root Mean Squared Standard Deviation (RMSSD) increased on average but this was not statistically significant (0.05), whereas SDNN also increased on average but it was statisticaly significant (p=0.030). Finally, the ratio of SDNN to RMSSD decreased; however, this was not statistically significant.

Similarly, an ANOVA (group x time) was done on skin conductance to determine if the application of the stimuli had an impact on these readings over time. Table 15 shows these results which determined that skin conductance increased as the stimuli were applied which was statistically signficant (p=0.001).

Moreover, a repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean the low frequency components of heart rate variability after the application of cold stimuli differed statistically siginificantly within-subjects ($F(3, 1.487) = 4.107$, $p = 0.040 < 0.05$). Post hoc tests using the Bonferroni correction revealed that only the first stimuli (LF Norm post 1) was statistically significantly different from the

second stimuli (LF Norm post 2) ($p = 0.045 < 0.05$). Therefore, we can conclude that the application of cold stimuli elicits a statistically significant decrease in low frequency values of heart rate variability but only when comparing the first to the second stimuli. No other pairwise comparisons were statistically significant within-subjects. It also revealed that the application of cold stimuli was statistically significant for mean LF Norm between-subjects ($F(1,6) = 377.227$, $p = 0.000 < 0.001$).

Similarly, another repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean high frequency components of heart rate variability after the application of the cold stimuli differed statistically siginificantly within-subjects($F(3, 1.473) = 4.241$, $p = 0.037 < 0.05$). Post hoc tests using the Bonferroni correction revealed that only the first cold stimuli (HF Norm post 1) was statistically significantly different to the second cold stimuli (HF Norm post 2) ($p = 0.021 < 0.05$). Therefore, we can conclude that the application of cold stimuli elicits a statistically significant increase in low frequency values of heart rate variability but only when comparing the first to the second stimuli. No other pairwise comparisons were statistically significant within-subjects. It also revealed that the cold stimuli was statistically significant for mean HF Norm between-subjects ($F(1,6) = 167.177$, $p = 0.000 < 0.001$).

To determine if there would be a statistically significant difference when cold stimuli were applied on the ratio between LF Norm and HF Norm, a repeated measures ANOVA with a Greenhouse-Geisser correction was applied. It determined that the application of cold stimulli was not statistically signifcant ($F(3, 1.629) = 1.436$, $p = 0.254$) within-subjects. Therefore, we cannot conclude that the application of cold stimuli had an overall statistically significant difference on the ratio between low frequency and high frequency normalized components of heart rate variability. Since it was not statistically signficant, no post hoc tests were done.

To determine if there would be a statistically significant difference when cold stimuli were applied on skin conductance, another repeated measures ANOVA with a Greenhouse-Geisser correction was applied. It determined that the application of cold stimuli was statistically signifcant within-subjects ($F(3, 1.170) = 23.733$, $p = 0.000 < 0.05$). Post hoc tests using the Bonferroni correction revealed that application of cold

stimuli were statistically significant between skin conductance between the following: SC pre and SC post 1 ($p = 0.000 < 0.05$), SC pre and SC post 2 ($p = 0.001 < 0.05$), and SC pre and SC post 3 ($p = 0.002 < 0.05$). No other pairwise correlations were statistically significant.Therefore, it can be concluded that the application of cold stimuli elicits a statistically significant increase in skin conductance only from pre-stimuli to post-stimuli (1, 2, and 3) but not from stimuli to stimuli.

Figure 16 shows the correlation coefficient (r) between HF Norm and Phasic. Table 19 contains the descriptive statistics for the high frequency components cross correlated with Phasic. HF pre and Phasic contains one outlier which is its minimum value (-16.60). It also contains one extreme outlier which is 52.20, a cross-correlation value found on subject 15. It is assumed that this extreme outlier exists for subject 15 because the normalized cross-correlation result for its highest peak was higher than other subjects which can be attributed to subject variability. The subject may have been nervous before the application of the stimuli or may have already been stressed out by other factors not controlled in a lab setting. A low median value for HF Norm pre- is desirable because it can be confirmed that the subject was not experiencing significant stress and was in fact at rest before the stimuli were applied. Therefore, the application of a cold stimuli had an increasing effect on the cross-correlation between normalized high frequency heart rate variability values and phasic components of skin conductance.

As shown on Figure 16, HF Norm 1 does not contain any outliers or extreme values, indicating that all subjects had a similar response to the first cold stimuli. An increase of 8.03 is shown (Figure 16) between median values of HF Norm pre- and HF Norm 1; however, it shows a larger spread described by a higher interquartile range. Since there is a clear increase between medians and quantiles, it can be concluded that the application of the first cold stimuli had an increasing effect on the normalized cross-correlation between HF Norm and phasic values.

HF Norm 2 contains one outlier (0.10) for subject 13. From the data, we can conclude that the correlation between HF Norm and phasic was not high for subject 13 because the average difference between HF Norm 1 (62.7) and HF Norm 2 (61.8) was only 0.9. Such a small difference between the application of the first and second cold stimuli is negligible, thus it makes sense that this subject’s normalized correlation

coefficient would be an outlier. HF Norm 2 has a higher median than both HF Norm 1 and HF Norm pre- but it has a much larger spread than both variables.

HF Norm 3 contains one outlier at 31.90 for subject 9 which is the same subject that had an outlier for HF pre. However, HF Norm 3 had a lower median than HF Norm 2 but still higher than both HF Norm 1 and HF Norm pre. Such decrease could be attributed to the desensitization of subjects after two consecutive cold stimuli were applied. Subjects may have already become accustomed to the feeling which caused the 11.66 decrease between the two.

Overall, Figure 16 and Table 19 show that the normalized correlation coefficient found for HF pre- has a lower median value (3.00) than all other variables HF1 (11.03), HF2 (35.16), and HF3 (23.50); however, HF 2 has the highest median but it has a greater spread. Therefore, it can be concluded that the strongest correlation between heart rate variability and skin conductance was found at HF2 which represents the normalized cross-correlation between HF and phasic values when the second cold stimuli were applied to subjects. Moreover, to determine if the normalized cross-correlation between HF Norm and Phasic values were statistically significant, another repeated measures ANOVA with a Greenhouse-Geisser correction was applied to all values of the correlation (HF Norm 1 and Phasic 1, HF Norm 2 and Phasic 2, and HF Norm 3 and Phasic 3). It determined that the cross-correlation between HF Norm and Phasic was not statistically signifcant within-subjects ($F(3, 1.628) = 3.079$, $p = 0.072$). Since it was not statistically significant, post hoc tests were not applied. However, it revealed that the normalized cross-correlation between HF Norm and Phasic was statistically significant between-subjects ($F(1,16) = 24.564$, $p = 0.000 < 0.05$).

Figure 17 shows the time delay between HF Norm and Phasic and Table 19 shows the descriptive statistics. TD HF Norm pre- contains one extreme outlier at a value of 37 for subject 9. TD HF Norm pre- has a lower median value (2.00) than the rest of the variables: TD HF Norm 1 (27), TD HF Norm 2 (53), and TD HF Norm 3 (48). A low median value for TD HF Norm pre- is desirable because it can be confirmed that the subject was not experiencing significant stress and was in fact at rest before the stimuli were applied. Since the median TD HF Norm pre- value is lower than all variables, it can be concluded that the application of a cold stimuli had an increasing

effect on the time delay between the normalized high frequency values and phasic skin conductance components. TD HF Norm pre- has a small spread with an interquartile range of 5 which means that all subjects (except the extreme outlier) were at a similar relaxed state before the application of the cold stimuli.

TD HF Norm 1 contains three extreme outliers which were 74 s (subject 16), 83 s (subject 9), and 109 s (subject 6). It also has one outlier at a value of 16 for subject 17. It is unclear why the time delay between the high frequency signal and phasic skin conductance signal was extremely high for these subjects since the mean value was 33.82 s. TD HF Norm 1 had a larger spread than HF pre but the difference between their interquartile ranges was only 9; however, there was a 25 second increase in the time delay between the high frequency values and phasic signal before the stimuli and after the application of the first cold stimuli as seen on Figure 16.

TD HF Norm 2 contains no outliers but has a very large spread among all subjects represented by the interquartile range of 69.50. Such variation may be attributed to the differences in gender and race between these subjects. However, TD HF2 contains the largest median, 25^{th} and 75^{th} percentiles which is consistent with the findings of the normalized cross-correlation result seen on Figure 16. Therefore, it can be concluded that the group with the highest correlation (HF 2) also had the largest time delay in seconds than any of the other groups. Thus, the greater the correlation between high frequency heart rate variability and phasic components of skin conductance, the higher the time delay between these two signals.

TD HF Norm 3 contains two outliers with values 118 s (subject 6) and 130 s (subject 11). TD HF Norm 3 (48) had a lower median value than TD HF Norm 2 (53). Such 5 second decrease could be attributed to the desensitization of subjects after two consecutive cold stimuli were applied which is consistent with the results from the normalized cross-correlation between HF and phasic values as shown on Figure 16.

Overall, Figure 17 shows that there is an increase in the time delay between the high frequency heart rate variability and the phasic components of skin conductance when cold stimuli were applied to the subjects. To determine if the time delay between HF Norm and Phasic were statistically significant when the normalized cross-correlation was applied, another repeated measures ANOVA with a Greenhouse-Geisser

correction was applied to all values of TDHF (TDHF Norm 1, TDHF Norm 2, and TDHF Norm 3). It determined that the time delay between TDHF Norm and TD Phasic was statistically signifcant within-subjects ($F(3, 1.776) = 13.741$, $p = 0.000<0.05$). Post hoc tests with the Bonferroni correction were applied to the pairwise comparisons which revealed that the differences between TDHF Pre and TDHF 1 ($p=0.001$), TDHF Pre and TDHF 2 ($p=0.000$), TDHF Pre and TD HF 3 ($p = 0.001$) were all statistically significant. However, it revealed that there was no statistical significance between TDHF 1 and TDHF 2, TDHF 1 and TDHF 3, and TDHF 2 and TDHF 3. Nonetheless, it revealed that the normalized cross-correlatin between TDHF Norm and TD Phasic was statistically significant between-subjects ($F(1,16) = 79.944$, $p = 0.000 < 0.05$).

Figure 18 shows the correlation coefficient (r) between LF Norm and Tonic and Table 19 shows the descriptive statistics. LF Norm Pre- has one extreme outlier at a value of 26.6 (subject 15), and another outlier at a value of 16.8 (subject 9). These outliers may have been caused by the anticipation of the stimuli for these subjects as these subjects also contain outliers on the correlation between high frequency values and phasic (Figure 18). However, LF Norm Pre- has a very small median (0.1) and a small spread with an interquartile range of 6.95. These low values are desirable for LF Norm Pre- because it means that on average all subjects (except subjects 15 and 19) were at a similar relaxed state before the application of the cold stimuli.

LF Norm 1 has a higher median (17.96) than LF Norm pre (0.1) which means that the application of the first cold stimuli had a 17.86 increasing effect on the normalized cross-correlation between the low frequency signal of heart rate variability and the low frequency components of skin conductance. However, the spread of LF Norm 1 was much larger than the spread for LF Norm Pre- among all subjects with a difference of 50.6. Such variation may be attributed to the differences in gender and race between these subjects. Nonetheless, LF Norm 1 has a much larger median, mean, and 25^{th} and 75^{th} percentiles than LF Norm Pre- as shown in Figure 18

Although the median of LF Norm 2 is higher than for LF Norm Pre- by 16.67, it is smaller than the median value for LF Norm 1. Since there is only a 1.21 decrease between the first cold stimulus and the second cold stimulus, then it is not clear if the stimuli itself had a decreasing effect on the normalized cross-correlation between these

two variables as this decrease was not statistically significant according to the repeated measures ANOVA with a Greenhouse-Geisser Correction.

Although the median of LF Norm 3 is higher than for LF Norm Pre- by 17.4, it is smaller than the median for LF Norm 1 (17.98) and higher than the median of LF Norm 2 (16.77). There is only a 0.73 increase between LF 2 Norm and LF Norm 3 that is not statistically significant according to a repeated measures ANOVA with a Greenhouse-Geisser correction.

Even though there is a difference between the median of all three, a repeated measures ANOVA with a Greenhouse-Geisser correction revealed that the pairwise comparisons between LF Norm 1, LF Norm 2, and LF Norm 3 were not statistically significant. However, the repeated measures ANOVA revealed that there was a statistically significant difference ($p<0.005$) for the pairwise comparisons between LF Norm Pre- and LF Norm 1, LF Norm Pre- and LF Norm 2, and LF Norm Pre and LF Norm 3. Therefore, it can be concluded that there is a statistically significant difference between the normalized cross-correlation of low frequency heart rate variability and components and phasic skin conductance components between rest and the application of any of the three cold stimuli. However, on average the normalized cross-correlation of low frequency HRV and tonic SC were lower than the cross-correlation of high frequency HRV and phasic SC. Such result was hypothesized as it was believed that the application of stimuli would increase the sympathetic nervous system response which in turn would increase the high frequency components of heart rate variability as well as increase the phasic response of skin conductance.

Figure 19 shows the time delay (TD) between LF Norm and Tonic. TDLF Norm Pre- as two extreme outliers (subjects 16 and 11) at a value of 34 s. TDLF Norm Pre- has a very low median value (3s) and a small spread denoted by its interquartile range (4.50). These low values are desirable for TDLF Norm Pre- because it means that on average all subjects (except subjects 16 and 11) were at a similar relaxed state before the application of the cold stimuli.

TDLF Norm 1 contains a higher median than TDLF Norm Pre- which means that there was an average increase in the time delay between the two signals when the first cold stimulus was applied to all subjects. However, the time delay between LF Norm 1

and Tonic contains a large spread among all subjects with denoted by its interquartile range of 38 which is an increase in variability of 33.50. TDLF Norm 1 contains no outliers.

TDLF Norm 2 contains a higher median (33s) than TDLF Norm 1 and TDLF Norm Pre; however, the difference was only an average of 3 seconds among subjects. The spread for TDLF Norm 2 was smaller by 4 seconds. TDLF Norm 2 contains two outliers and one extreme outliers with values 102 (subject 2), 112 (subject 10), and 131 (subject 5), respectively.

TDLF Norm 3 contains a higher median (55s) than TDLF Norm 2, TDLF Norm 1, and TDLF Norm Pre. There was a larger increase of (22 seconds) in the median between TDLF Norm 3 and TDLF Norm 2. However, the spread of TDLF Norm 3 was almost double than TDLF Norm 2. TDLF Norm 3 contains no outliers. To determine if the time delay between LF Norm and Tonic signals were statistically significant (when the normalized cross-correlation was applied), another repeated measures ANOVA with a Greenhouse-Geisser correction was applied to all values of TDLF (TDLF Norm 1, TDLF Norm 2, and TDLF Norm 3). It determined that the time delay between TDLF Norm and TD Tonic was statistically signifcant within-subjects ($F(3, 2.513) = 12.379$, $p = 0.000<0.05$). Post hoc tests with the Bonferroni correction were applied to the pairwise comparisons which revealed that the differences between TDLF Pre and TDLF 1 ($p=0.000$), TDLF Pre and TDLF 2 ($p=0.004$), TDLF Pre and TD LF 3 ($p = 0.001$), and TDLF 2 and TDLF 3 ($p=0.034$) were all statistically significant. However, it revealed that there was no statistical significance between TDLF 1 and TDLF 2, and TDLF 2 and TDLF 3. Nonetheless, it revealed that the normalized cross-correlation between TDLF Norm and TD Tonic was statistically significant between-subjects ($F(1,16) = 59.193$, $p = 0.000 < 0.05$).

Chapter 8: Conclusions

Currently, heart rate variability and skin conductance are used as two different measures of sympathetic activity. While we cannot measure pain directly, we can use skin conductance and heart rate variability as an indirect measure of pain. Therefore, this study serves as a pilot study in which future applications include improving the accuracy of pain reporting by utilizing two measures of sympathetic activity instead of just one by identifying the cross-correlation between these signals. Heart rate variability and skin conductance were evaluated in this work, specifically, the high and low frequency components of the power spectrum of HRV and the phasic and tonic components of skin conductance. HRV Live! is a software used to measure heart rate variability using a PPG sensor that contains the capabilities via algorithms to obtain HRT, SDNN, RMSSD, LF, HF, VLF, and TP for each subject. Consensys is another software used to measure skin conductance via a GSR. LEDALAB, a MATLAB-based software was used to separate the tonic and phasic components of skin conductance. A data processing code was developed in MATLAB to perform the normalized cross-correlation between HF and phasic and LF and tonic.

The findings of this study show that on average heart rate and low frequency increased as the stimuli got colder, whereas high frequency decreased. Skin conductance activity also increased with application of cold stimuli. An increase in heart rate and skin conductance during pain confirms previous literature that have observed this relationship with either variable or both on a wide range of pain studies including cold pain[45],[46],[47] electric shock[48],[49], evoked back pain[50], evoked muscle pain[51], evoked esophageal pain[52], and post-operative pain[53]. Other studies have also observed greater low frequency values with lower temperatures at which subjects first identified pain[10].

In this study, it was found that on average there is a strong cross-correlation between HRV and SC only when stimuli is applied, when no stimuli is applied the cross-correlation is small. For high frequency and phasic, HF Norm 2 and Phasic have the highest cross-correlation (35.16) and time delay (53 s). It is believed that the higher correlation for the second cold stimuli is because by the third stimuli, the subjects were already desensitized to the cold. The time delay signifies which signal responds first, in

this case, high frequency heart rate variability responded first rather than phasic skin conductance level. LF 1 and Tonic have the highest cross correlation coefficient but LF 2 and Tonic has the highest time delay (55 s) for its group. Overall, the low frequency normalized cross-correlation with tonic were lower than the high frequency normalized cross-correlation with phasic which is expected as tonic skin conductance components do not reflect stimuli spikes, rather the signal is just a background steady signal.

Future work would require performing a linear mixed model to determine if there is a correlation between heart rate variability and skin conductance to numerical pain levels. This study should be done on a larger scale with healthy populations that include those older than college age and with a more even number of males and females. If those results yield statistical significance, another study should be conducted with populations suffering from chronic pain to determine if this model could be used to improve the accuracy of pain reporting.

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Appendix A – Product Summary and Survey Forms

K041908 1/2

SUMMARY AND CERTIFICATION

FEB 2 5 2005

A. 510(k) Summary

Submitter:	Medoc Ltd. Advanced Medical Systems
Contact Person:	Alquest, Inc Tracy Gray RN, BS, RAC Sr. Consultant and Consultant to Medoc 4050 Olson Memorial Hwy Suite 350 Minneapolis, MN 55422.
Date Prepared:	February 2, 2005
Trade Name:	Contact Heat-Evoked Potential Stimulator (CHEPS)
Classification, Name and Number:	Class II No assigned classification number, as with the predicate devices 21 CFR 882
Product Code:	LQW/LLN
Predicate Device(s):	The subject device is substantially equivalent to the following device(s): • GSA Genito Sensory Analyzer (K010981), manufactured by Medoc Ltd. Advanced Medical Systems. • TSA-2001 Thermal Sensory Analyzer (K922052), manufactured by Medoc Ltd. Advanced Medical Systems.
Device Description:	The Contact Heat-Evoked Potential Stimulator (CHEPS) is a computerized thermal stimulator that produces a heating stimulation in rate of 70°C/sec, enabling delivery of painful stimuli from a baseline to 55°C in 250 milliseconds. The system consists of the CHEPS control unit, external cooling unit, 27mm diameter thermode probe, thermode cables, and software. The software program requires the use of an IBM compatible notebook or desktop computer, which is not supplied. Also, the following are optional components: MRI-safe thermode and cables and cart.

K041908 2/2

Intended Use:	The Contact Heat-Evoked Potential Stimulator (CHEPS) is indicated for the use in evaluating the functionality of human pain reception and transmission of sensory pathways.
Functional and Safety Testing:	The device underwent mechanical, physical, and biocompatibility testing as described in **Section 6** and **Section 7** of this submission. The results of testing were successful. The device performed as designed and met, or exceed, all product specifications.
Conclusion:	Medoc Ltd. Advanced Medical Systems considers the Contact Heat-Evoked Potential Stimulator (CHEPS) equivalent to the predicate devices listed above. This conclusion is based upon the devices' similarities in function, design, materials, and indication for use.

Figure 20. 510(K) for the CHEPS Device

East Carolina University

Informed Consent to Participate in Research
Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Identifying a cross-correlation between heart rate variability and skin conductance using pain intensity on healthy college students.
Principal Investigator: Genesis Cruz-Molina
Institution, Department or Division: College of Engineering
Address: Slay 208, Greenville, NC 27858
Telephone #: (252) 737-4652

Researchers at East Carolina University (ECU) study issues related to society, health problems, environmental problems, behavior problems and the human condition. To do this, we need the help of volunteers who are willing to take part in research.

Why am I being invited to take part in this research?
The purpose of this research is to collect heart rate variability and skin conductance data from healthy volunteers. You are being invited to take part in this research because you are a healthy volunteer that fits the age range for this study. The decision to take part in this research is yours to make. By doing this research, we hope to learn if there is a mathematical relationship between heart rate variability and skin conductance on healthy volunteers.

If you volunteer to take part in this research, you will be one of 18 people to do so.

Are there reasons I should not take part in this research?
I understand I should not volunteer for this study if I am, under 18 years of age, I suffer from a chronic pain illness, or take medicine that may affect my heart rate.

What other choices do I have if I do not take part in this research?
You can choose not to participate.

Where is the research going to take place and how long will it last?
The research will be conducted in Ross Hall 2150. You will need to come to Ross Hall 2150, one time during the study. The total amount of time you will be asked to volunteer for this study is 30 minutes.

What will I be asked to do?
You will be asked to do the following:

First, you will be asked to fill out a quick pre-screening survey used to assess your eligibility in this study as well as collect demographic information. We encourage you to ask questions if any part of the survey is not clear. For data collection, you will be asked to sit in an upright position and asked to breathe normally. You will be asked to refrain from talking or moving your hands and/or feet as this may cause the data to skew. Then, the researchers will place a clip on your right earlobe and two electrodes that are fastened with Velcro to your two middle fingers. The earlobe clip is used to measure your heart rate, and the electrodes on your hand are used to measure your skin conductance. You will sit for five minutes in this position. After baseline data collection, a Thermode will be placed on your

Figure 21. Consent Form

forearm and a reset button will be given to you to hold on the other hand. This Thermode is used to provide cold thermal stimuli to your forearm. The temperature will be decreased at a rate of 1°C/ 3 seconds, until you feel pain that coincides with the respective category – mild, moderate, or severe. At this time, you will press the reset button given to you, which will cause the temperature to immediately revert back to normal physiologic temperature which is 37°C. This procedure will be repeated three times to accommodate for the different pain levels (mild, moderate. or severe) in a span of approximately 6 minutes. Then, the Thermode will be removed from your forearm and you will be asked to stay in the same position while we collect heart rate and skin conductance data for another 5 minutes. After this, you may move and talk while all the hardware will be removed from you.

What might I experience if I take part in the research?
We don't know of any risks (the chance of harm) associated with this research. Any risks that may occur with this research are no more than what you would experience in everyday life. We don't know if you will benefit from taking part in this study. There may not be any personal benefit to you but the information gained by doing this research may help others in the future.

Will I be paid for taking part in this research?
We will be able to pay you for the time you volunteer while being in this study with a $15 gift card.

Will it cost me to take part in this research?
It will not cost you any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?
ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- The University & Medical Center Institutional Review Board (UMCIRB) and its staff have responsibility for overseeing your welfare during this research and may need to see research records that identify you.

How will you keep the information you collect about me secure? How long will you keep it?
Data information will be kept in a cabinet in Austin 324. Your name will not be displayed on any of this data. The data will be kept for 3 years.

What if I decide I don't want to continue in this research?
You can stop at any time after it has already started. There will be no consequences if you stop and you will not be criticized. You will not lose any benefits that you normally receive.

Who should I contact if I have questions?
The people conducting this study will be able to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at (919) 610-5303 between 10-7 pm.

If you have questions about your rights as someone taking part in research, you may call the Office of Research Integrity & Compliance (ORIC) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If you would like to report a complaint or concern about this research study, you may call the Director of the ORIC, at 252-744-1971.

Are there any Conflicts of Interest I should know about?
The Principal Investigator (or the sub-investigator, research staff member, or family member) do not have any conflict of interests.

Consent Version # or Date:

Title of Study: Identifying the cross-correlation between heart rate variability and skin conductance.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

Participant's Name (PRINT)	Signature	Date

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

Person Obtaining Consent (PRINT)	Signature	Date

Principal Investigator (PRINT)	Signature	Date

Figure 22. Consent form (cont.)

Pre-Screening: Heart Rate Variability and Skin Conductance Study

Please answer the following questions by following the instructions provided. You may ask for clarification in any of the following questions.

Demographic Information

1. Gender: ☐Male ☐Female

2. Age: _____

3. In which ethnic/racial group do you identify yourself in? (You may check all that apply)

☐ African-American/African/Black

☐ American Indian/Alaskan Native

☐ Asian/Pacific Islander

☐ European American/Caucasian/White

☐ Hispanic/Latino(a)

☐ Other, please list _____

Behavioral & Medical Information

4. Do you suffer from any pain-related illnesses? (chronic and non-chronic)

☐Yes ☐No

If yes, please explain and list all that apply _____

_____

_____

5. In the past 6 hours, have you consumed any energy drinks, caffeinated drinks, and/or any medication/drugs (prescribed or not) that could affect your heart rate?

Energy Drinks:

☐No, I have not consumed energy drinks.

☐ Yes, I have consumed energy drinks. Please list: _____

Caffeinated Drinks:

☐ No, I have not consumed caffeinated drinks.

☐ Yes, I have consumed caffeinated drinks. Please list: _____

Medication/Drugs

☐ No, I have not consumed any medication or drugs.

☐ Yes, I have consumed medication or drugs. Please list: _____

Figure 23. Pre-Screening Survey

Please indicate your level of pain corresponding to the applied stimulus, using the scale below.

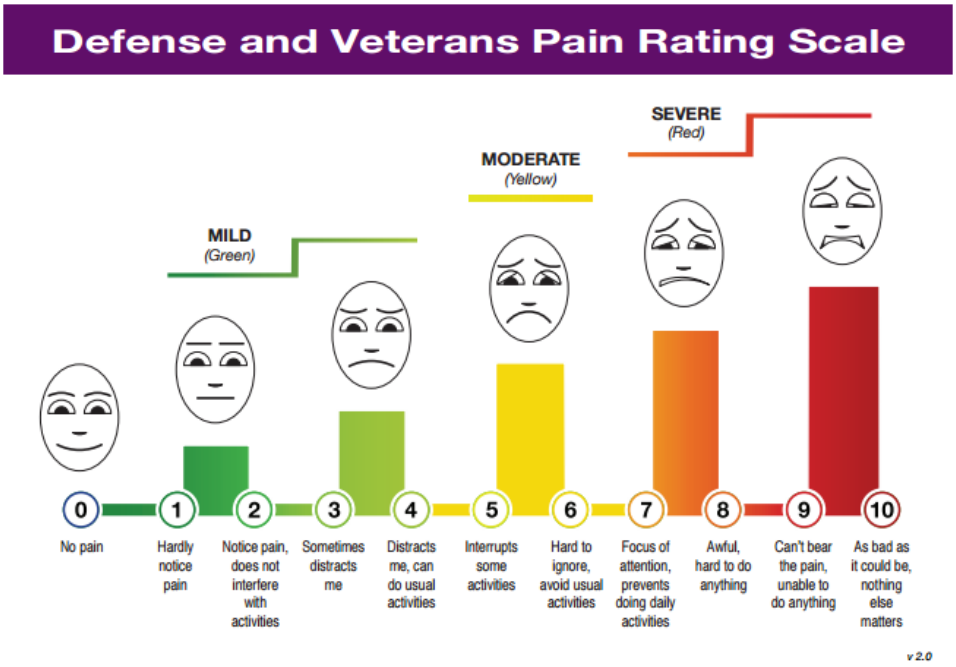

Figure 24. Pain Survey

Appendix B – MATLAB Scripts

The scripts developed in MATLAB to find the normalized cross-correlation between heart rate variability and skin conductance will be attached in this section. The first script used to export the raw skin conductance signal into MATLAB is labeled as "Skin Conductance 1". This script calls for another script labeled as "Kim" that creates a .mat file that contains the raw skin conductance values to be imported into LEDALAB. At this point, LEDALAB has to be run and the .mat file is imported as well as the plain text event file. Another script used to get the data from LEDALAB is labeled as "Get Data" and this file plots the phasic and tonic components of skin conductance. Finally, a script labeled as "Xcorr one by one" computes the normalized cross-correlation between HF and Phasic and LF and Tonic. The LEDALAB software and the xcorr function is a built in MATLAB function that can be found on the following links:

LEDALAB: http://www.ledalab.de/

Xcorr: https://www.mathworks.com/help/signal/ref/xcorr.html

```
%Skin Conductance 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%The purpose of this code is to read all of the files raw Skin Conductance
data
%for all subjects (baseline and stimuli)only so that they may be
%placed into LEDALAB for data processing, specifically separating out
%the phasic and tonic components for SC. This code calls out "kim" a
%separate code used to interface with LEDALAB. This code is meant to be
%run in sections

%% subject 1
%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session1_Shimmer_3BD6_Calibrated_PC_subj1_bas
eline';
SC = xlsread(filename, 'E3:E320');
Time = xlsread(filename, 'C3:C320');

%read excel file for SC stimuli
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session1_Shimmer_3BD6_Calibrated_SD_subject1_
stimuli plus after';
SC = xlsread(filename, 'E3:E949');
Time = xlsread(filename, 'C3:C949');
```

```
 kim; %runs the script 'kim' that interfaces with ledalab
%% subject 2

%read excel file for SC baseline
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session2_Shimmer_3BD6_Calibrated_PC_subject2_
baseline';
% SC = xlsread(filename, 'E3:E337');
% Time = xlsread(filename, 'C3:C337');

%read excel file for SC stimuli
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session3_Shimmer_3BD6_Calibrated_PC_Subject2_
stimuli';
SC = xlsread(filename, 'E3:E429');
Time = xlsread(filename, 'C3:C429');

kim; %runs the script 'kim' that interfaces with ledalab

%% subject 3
%read excel file for SC baseline
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session4_Shimmer_3BD6_Calibrated_PC_Subj3_bas
eline';
% SC = xlsread(filename, 'E3:E304');
% Time = xlsread(filename, 'C3:C304');

% %read excel file for SC stimuli
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session5_Shimmer_3BD6_Calibrated_PC_subj3_sti
muli';
SC = xlsread(filename, 'E3:E554');
Time = xlsread(filename, 'C3:C554');

kim; %runs the script 'kim' that interfaces with ledalab
%% subject 4
%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session6_Shimmer_3BD6_Calibrated_PC_subj4_bas
eline';
SC = xlsread(filename, 'E3:E310');
Time = xlsread(filename, 'C3:C310');

% %read excel file for SC stimuli
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session7_Shimmer_3BD6_Calibrated_PC_subj4_sti
muli';
SC = xlsread(filename, 'E3:E544');
Time = xlsread(filename, 'C3:C544');

kim; %runs the script 'kim' that interfaces with ledalab

%% subject 5
%read excel file for SC baseline
```

```
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session8_Shimmer_3BD6_Calibrated_PC_subj5_bas
eline';
SC = xlsread(filename, 'E3:E305');
Time = xlsread(filename, 'C3:C305');

% %read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session10_Shimmer_3BD6_Calibrated_PC_subj5_st
imuli';
% SC = xlsread(filename, 'E3:E557');
% Time = xlsread(filename, 'C3:C557');

kim; %runs the script 'kim' that interfaces with ledalab
%% subject 6

%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session12_Shimmer_3BD6_Calibrated_PC_subj6_ba
seline';
SC = xlsread(filename, 'E3:E308');
Time = xlsread(filename, 'C3:C308');

% %read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session13_Shimmer_3BD6_Calibrated_PC_Subj6_st
imuli';
% SC = xlsread(filename, 'E3:E609');
% Time = xlsread(filename, 'C3:C609');

kim; %runs the script 'kim' that interfaces with ledalab

%% subject 7
%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session14_Shimmer_3BD6_Calibrated_PC_subj7_ba
seline';
SC = xlsread(filename, 'E3:E303');
Time = xlsread(filename, 'C3:C303');

% %read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session15_Shimmer_3BD6_Calibrated_PC_subj7_st
imuli';
% SC = xlsread(filename, 'E3:E572');
% Time = xlsread(filename, 'C3:C572');

kim; %runs the script 'kim' that interfaces with ledalab
%% Subject 8
%do not have SC file due to an issue with the CONSENSYS program


%% Subject 9

%read excel file for SC baseline
```

```
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session18_Shimmer_3BD6_Calibrated_PC_subj9_ba
seline';
SC = xlsread(filename, 'E3:E303');
Time = xlsread(filename, 'C3:C303');

%read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session20_Shimmer_3BD6_Calibrated_PC_subjt9_s
timuli';
% SC = xlsread(filename, 'E3:E438');
% Time = xlsread(filename, 'C3:C438');

kim; %runs the script 'kim' that interfaces with ledalab


%% Subject 10
%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session21_Shimmer_3BD6_Calibrated_PC_subj10_b
aseline';
SC = xlsread(filename, 'E3:E302');
Time = xlsread(filename, 'C3:C302');

%read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study102617_Session22_Shimmer_3BD6_Calibrated_PC_subj10_s
timuli';
% SC = xlsread(filename, 'E3:E636');
% Time = xlsread(filename, 'C3:C636');

kim; %runs the script 'kim' that interfaces with ledalab
%% Subject 11
%read excel file for SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session1_Shimmer_3BD6_Calibrated_PC_Subj11_bas
eline.xlsx';
SC = xlsread(filename, 'E3:E310');
Time = xlsread(filename, 'C3:C310');

%read excel file for SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session2_Shimmer_3BD6_Calibrated_PC_subj11_sti
muli';
% SC = xlsread(filename, 'E3:E663');
% Time = xlsread(filename, 'C3:C663');

kim; %runs the script 'kim' that interfaces with ledalab
%% Subject 12
%SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session3_Shimmer_3BD6_Calibrated_PC_subj12_bas
eline';
SC = xlsread(filename, 'E3:E308');
Time = xlsread(filename, 'C3:C308');
```

```
%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session4_Shimmer_3BD6_Calibrated_PC_subj12_sti
muli';
% SC = xlsread(filename, 'E3:E604');
% Time = xlsread(filename, 'C3:C604');

kim;

%% Subject 13

%SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session5_Shimmer_3BD6_Calibrated_PC_subj13_bas
eline';
SC = xlsread(filename, 'E3:E326');
Time = xlsread(filename, 'C3:C326');

%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\\Skin
Conductance_TimeFix\Study11217_Session6_Shimmer_3BD6_Calibrated_PC_subj13_sti
muli';
% SC = xlsread(filename, 'E3:E426');
% Time = xlsread(filename, 'C3:C426');

kim;
%% Subject 14

%SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session7_Shimmer_3BD6_Calibrated_PC_subj14_bas
eline';
SC = xlsread(filename, 'E3:E308');
Time = xlsread(filename, 'C3:C308');

% %SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\\Skin
Conductance_TimeFix\Study11217_Session8_Shimmer_3BD6_Calibrated_PC_subj14_sti
muli';
% SC = xlsread(filename, 'E3:E484');
% Time = xlsread(filename, 'C3:C484');

kim;

%% Subject 15
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session9_Shimmer_3BD6_Calibrated_PC_subj15_bas
eline.csv';
SC = xlsread(filename, 'E3:E307');
Time = xlsread(filename, 'C3:C307');

%SC stimuli
```

```
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session10_Shimmer_3BD6_Calibrated_PC_subj15_st
imuli';
% SC = xlsread(filename, 'E3:E463');
% Time = xlsread(filename, 'C3:C463');

kim;
%% Subject 16
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session11_Shimmer_3BD6_Calibrated_PC_subj16_ba
seline';
SC = xlsread(filename, 'E3:E303');
Time = xlsread(filename, 'C3:C303');

%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session12_Shimmer_3BD6_Calibrated_PC_subj16_st
imuli';
% SC = xlsread(filename, 'E3:E542');
% Time = xlsread(filename, 'C3:C542');

kim;

%% Subject 17
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session13_Shimmer_3BD6_Calibrated_PC_subj17_ba
seline';
SC = xlsread(filename, 'E3:E362');
Time = xlsread(filename, 'C3:C362');

%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session14_Shimmer_3BD6_Calibrated_PC_subj17_st
imuli';
% SC = xlsread(filename, 'E3:E484');
% Time = xlsread(filename, 'C3:C484');

kim;
%% Subject 18

%SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session15_Shimmer_3BD6_Calibrated_PC_subj18_ba
seline';
SC = xlsread(filename, 'E3:E312');
Time = xlsread(filename, 'C3:C312');

%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session16_Shimmer_3BD6_Calibrated_PC_subj18_st
imuli';
% SC = xlsread(filename, 'E3:E543');
% Time = xlsread(filename, 'C3:C543');

kim;
```

```
%% Subject 19
%SC baseline
filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session17_Shimmer_3BD6_Calibrated_PC_subj19_ba
seline';
SC = xlsread(filename, 'E3:E302');
Time = xlsread(filename, 'C3:C302');

%SC stimuli
% filename= 'C:\Users\cruzmolinag12\Documents\Skin
Conductance_TimeFix\Study11217_Session18_Shimmer_3BD6_Calibrated_PC_subj19_st
imuli';
% SC = xlsread(filename, 'E3:E423');
% Time = xlsread(filename, 'C3:E423');

kim;

%Kim
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The purpose of this script is to interface with LEDALAB and create an
% arbitrary mat file for each subject
data.conductance = SC;
data.time        = 1:1:length(SC);
data.timeoff     = 0;

% Baseline
data.event(1).time = [];
data.event(1).nid  = [];
data.event(1).name = [];
data.event(1).userdata = [];

save('Arbitrary.mat','data');

return;


%Get Data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%The purpose of this code is to get the data from the LEDALAB interface
%%after LEDALAB separated the tonic and phasic components of SC. This code
%gets the tonic and phasic components of the signal and plots them.

clc;

handle = get(gcf); %get current figure
handleSub=get(handle.Children(43)); %get the children from array position 43

handleTonic = get(handleSub.Children(11)); %tonic data
signalTonic = handleTonic.YData;

handlePhasic = get(handleSub.Children(12)); %phasic data
signalPhasic = handlePhasic.YData;

figure(1);
hold on;
```

```
    subplot(1,2,1); plot(signalTonic,'k');
    title('Tonic data');
    subplot(1,2,2); plot(signalPhasic,'b');
    title('Phasic data');

hold off;


%Xcorr one by one
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%
%%This code is used to preform the normalized cross-correlation on each
individual
%%stimuli portion for all subjects and plot it. This code is meant to be run
in
%%sections.

%% subject 2
filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 2';

%HRV LF and HF Values subject 2
LF_Norm_B = xlsread(filename, 'N3:N7'); %LF norm for baseline
LF_Norm_S1 = xlsread(filename, 'N8:N69'); %LF norm for stimuli 1
LF_Norm_S2 = xlsread(filename,'N70:N115'); %LF norm for stimuli 2
LF_Norm_S3 = xlsread(filename,'N116:N131'); %LF norm for stimuli 3

HF_Norm_B = xlsread(filename, 'O3:O7'); %HF norm for baseline
HF_Norm_S1 = xlsread(filename, 'O8:O69'); %HF norm for stimuli 1
HF_Norm_S2 = xlsread(filename, 'O70:O115'); %HF norm for stimuli 2
HF_Norm_S3 = xlsread(filename, 'O116:O131'); %HF norm for stimuli

Time_B = xlsread(filename, 'C3:C7'); %Time for baseline
Time_S = xlsread(filename, 'C8:C131'); %Time for stimuli

%subject 2 data post
phasic =
[12.8750000004345;12.8210000004319;12.8750000004345;12.4204000007457;12.58879
99994127;12.4375999995555;12.4429999997296;12.5131999994947;12.4267999998416;
12.2486000005450;12.1838000005428;12.1244000007265;12.0001999996533;12.156799
9994196;12.0919999993910;11.9786000001523;12.2053999994820;12.2594000007492;1
2.1622000000812;12.1351999999897;12.0757999994701;12.0919999993910;12.0272000
006246;12.0001999996533;12.0757999994701;12.0649999992821;12.0757999994701;12
.0757999994701;12.0433999999345;12.0217999998372;11.9840000000556;12.00560000
05949;12.0596000004845;12.1081999993192;12.1081999993192;12.0866000002195;12.
0433999999345;12.1027999995423;12.4160000005245;12.4754000004500;12.394400000
1684;12.4591999994851;12.5725999993660;12.5887999994127;12.5348000001644;12.6
752000002665;12.5996000002216;12.4916000001581;12.4916000001581;13.0855999993
740;12.3728000005361;12.2972000006544;12.4429999997296;12.5780000001406;12.49
16000001581;12.4267999998416;12.4484000002267;12.6319999993199;12.51319999949
47;12.5402000000081;12.4862000004747];
tonic =
[11.7615288408597;11.7615288408597;11.7615288408597;11.7615288408597;11.76152
88408597;11.7615288408597;11.7615288408597;11.7615288408597;11.7615288408597;
11.7615288408597;11.7615288408597;11.7615288408597;11.7625131846233;11.766098
5964059;11.7731658178570;11.7838230890283;11.7976402040220;11.8138621516008;1
```

```
1.8315520880263;11.8496759243542;11.8671491452790;11.8828616622537;11.8965558
167210;11.9089000661050;11.9204334930567;11.9314007978625;11.9418120896034;11
.9515277568644;11.9603217236446;11.9679207352625;11.9740267424429;11.97832901
43714;11.9798216310299;11.9772736845615;11.9702728277888;11.9591728054800;11.
9448440828662;11.9284640069381;11.9113801688954;11.8950306529703;11.880900269
7705;11.8704974663327;11.8642477976400;11.8612772001507;11.8607004578841;11.8
618754167751;11.8643765743522;11.8679223053167;11.8723157837327;11.8774070251
123;11.8830708655842;11.8891949161081;11.8967826954855;11.9074872297238;11.92
20417169844;11.9402412933072;11.9612323316710;11.9837712720236;12.00639671966
79;12.0275309577996;12.0455360135361];
x =
[0;1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28
;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43;44;45;46;47;48;49;50;51;52;53;5
4;55;56;57;58;59;60];

%subject 2 data pre
tonic2 =
[5.02906226644620;5.02906226644620;5.02906226644620;5.02906226644620;5.029062
26644620;5.02906226644620;5.02906226644620;5.02906226644620;5.02906226644620;
5.02906226644620;5.02906226644620;5.02906226644620;5.02966705055061;5.0320480
8443684;5.03716858143508;5.04555941820013;5.05730939161501;5.07212741934905;5
.08941920195980;5.10835729966797;5.12793867525835;5.14702960085667;5.16478767
462449;5.18093527620974;5.19546691650776;5.20851271613192;5.22027343674481;5.
23098865996437;5.24092057723575;5.25034531281253;5.25954800832261;5.268819871
84697;5.27840332482409;5.28844525105518;5.29903077559013;5.31020351259657;5.3
2197836688633;5.33434999217983;5.34729856937082;5.36079384838333;5.3747980208
9172;5.38926778346620;5.40431037509555;5.42016198577912;5.43698170877046;5.45
479517273033;5.47349570971349;5.49286433832012;5.51259299097162;5.53230531538
533;5.55157361935854;5.56993204002528;5.58701361274046;5.60267143990376;5.616
90425548889;5.62981039530193;5.64155789679663;5.65236435166538;5.662482970656
24;5.67219272186258;5.68179127618477];
phasic2 =
[5.11519999977002;5.09899999906025;5.09899999906025;5.27180000087238;5.293399
99995861;5.27180000087238;5.14689999927820;5.22319999963270;5.21779999874147;
5.22319999963270;5.22319999963270;5.33120000034120;5.32039999993020;5.2826000
0080264;5.31499999910974;5.31499999910974;5.32039999993020;5.30419999927831;5
.28800000029613;5.35279999955079;5.42300000059599;5.40139999869621;5.41760000
131409;5.41760000131409;5.40139999869621;5.39060000012388;5.43919999880903;5.
48779999992998;5.46079999969682;5.44460000071967;5.43380000046644;5.460799999
69682;5.60119999884727;5.63899999886769;5.61200000087323;5.55800000100933;5.5
2560000092300;5.54180000131252;5.53639999910665;5.53099999890376;5.5904000000
9124;5.60119999884727;5.58500000135436;5.59579999889393;5.66059999843281;5.71
460000095834;5.70380000155064;5.67680000028339;5.67680000028339;5.69300000043
324;5.78479999997501;5.79020000080368;5.78479999997501;5.77399999995843;5.876
59999866907;5.88200000041645;5.86039999998453;5.82799999843343;5.827999998433
43;5.89819999941549;5.96300000120989];

fs= 1; %sampling frequency

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
```

```
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
figure(1);
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of LF(pre) and Tonic');

%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr LF3 and Tonic');

%HF and Phasic
```

```
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 2: xcorr HF3 and Phasic');
hold off;

%% subject 3 data
filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 3';

%HRV subject 3
Time_B = xlsread(filename, 'C3:C15'); %Time for baseline
LF_Norm_B = xlsread(filename, 'N3:N15'); %LF norm for baseline
LF_Norm_S1 = xlsread(filename, 'N16:N45');
LF_Norm_S2 = xlsread(filename, 'N46:N151');
LF_Norm_S3 = xlsread(filename, 'N152:N266');

HF_Norm_B = xlsread(filename, 'O3:O15');
HF_Norm_S1 = xlsread(filename, 'O16:O45');
HF_Norm_S2 = xlsread(filename, 'O46:O151');
HF_Norm_S3 = xlsread(filename, 'O152:O266');
Time_S = xlsread(filename, 'C16:C266'); %Time for stimuli
```

```
%SC subject 3 post
tonic =
[7.04290339881175;7.04290339881175;7.03241416639101;7.02374858607056;7.016987
20258917;7.01189999999998;7.00824869518272;7.00579500501710;7.00430064638286;
7.00352733615971];
x = [1;2;3;4;5;6;7;8;9;10];
phasic =
[12.0542000000000;12.0542000000000;12.0542000000000;12.0542000000000;12.05420
00000000;7.01189999999998;7.08619999999999;7.08619999999999;7.25359999999999;
7.28060000000000];

%SC subject 3 pre
tonic2 =
[1.76770000000000;1.76770000000000;1.76846764528491;1.77007228127684;1.772376
08626624;1.77519967179096;1.77837366514396;1.78175132261168;1.78520857831978;
1.78864064645465;1.79195819111953;1.79508395395994;1.79798829170418;1.8006912
9050466;1.80321736153479;1.80558216178885;1.80779033066947;1.80983652766025;1
.81170721752678;1.81338239161428;1.81483701273913;1.81604216708191;1.81673974
863888;1.81649315207207;1.81499315958942;1.81212251064167;1.80794470294474;1.
80267373771244;1.79664319956229;1.79027980523039;1.78408215428499;1.778604100
06314;1.77442349105579;1.77199961889420;1.77160523279390;1.77333598901605;1.7
7713967540842;1.78284645313016;1.79019482792077;1.79885254586913;1.8084329567
6125;1.81850763162407;1.82882761095408;1.83938920287304;1.85021986598228;1.86
131491305321;1.87262502010159;1.88405952138036;1.89549352985900;1.90677503381
471;1.91773091943163;1.92817179132424;1.93794167565739;1.94697176024468;1.955
25863963185;1.96284852174657;1.96982544201999;1.97630234728678;1.982414306375
10;1.98831332408740;1.99416437414990];
phasic2 =
[1.76770000000000;1.77220000000000;1.77670000000000;1.77970000000000;1.784200
00000000;1.78720000000000;1.79320000000000;1.80070000000000;1.80370000000000;
1.80520000000000;1.80670000000000;1.80820000000000;1.81120000000000;1.8127000
0000000;1.81420000000000;1.81570000000000;1.81570000000000;1.81570000000000;1
.81720000000000;1.81720000000000;1.82020000000000;1.83070000000000;1.83670000
000000;1.84120000000000;1.84270000000000;1.85770000000000;1.86820000000000;1.
86670000000000;1.86370000000000;1.86370000000000;1.87270000000000;1.880200000
00000;1.88470000000000;1.88920000000000;1.88770000000000;1.88920000000000;2.0
8580000000000;1.89820000000000;1.91470000000000;1.92820000000000;1.9327000000
0000;1.94470000000000;1.95070000000000;1.95670000000000;1.96120000000000;1.95
970000000000;1.95970000000000;1.96120000000000;1.96120000000000;1.96120000000
000;1.96720000000000;1.97320000000000;1.97620000000000;1.97920000000000;1.986
70000000000;1.98970000000000;1.98970000000000;1.99420000000000;2.021200000000
00;2.02270000000000;2.02420000000000];

fs= 1; %sampling frequency

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));
```

```
%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
figure(1);
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of LF(pre) and Tonic');

%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
```

```
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 3:  xcorr HF3 and Phasic');
hold off;

%% subject 4

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 4';

%used to plot log(LF norm) at baseline and during stimuli for subject 4
LF_Norm_B = xlsread(filename, 'N3:N8'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O8'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C8'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N9:N61');%LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N62:N126');
LF_Norm_S3 = xlsread(filename, 'N127:N217');

HF_Norm_S1 = xlsread(filename, 'O9:O61'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O62:O126');
HF_Norm_S3 = xlsread(filename, 'O127:O217');
Time_S = xlsread(filename, 'C9:C217'); %Time for stimuli

phasic =
[4.04770000000000;4.13619999999999;4.14220000000000;4.10770000000000;4.034200
00000000;3.94570000000000;3.92920000000001;3.94270000000001;3.91720000000000;
3.88120000000001;3.85420000000000;3.88870000000000;3.90970000000000;3.9007000
```

```
0000000;3.95320000000000;4.01469999999999;4.05370000000000;4.07319999999999;4
.04770000000000;4.02820000000000;4.04470000000000;4.02969999999999;4.10169999
999999;4.29220000000000;4.32670000000000;4.31769999999999;4.36420000000001;4.
40920000000000;4.49320000000000;4.46620000000001;4.47070000000000;4.461700000
00000;4.47070000000000;4.54820000000001;4.45640000000000;4.11970000000000;4.1
4670000000000;4.34020000000000;4.38069999999999;4.33420000000001;4.2607000000
0000;4.21870000000001;4.16770000000000;4.14820000000001;4.13769999999999;4.18
420000000000;4.30719999999999;4.36420000000001;4.37920000000000;4.32070000000
000;4.25920000000000;4.27720000000000;4.27870000000001;4.23820000000000;4.221
70000000001;4.21269999999999;4.16770000000000;4.11670000000001;4.064200000000
00;4.02070000000000;3.98620000000000];
x =
[0;1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28
;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43;44;45;46;47;48;49;50;51;52;53;5
4;55;56;57;58;59;60];
tonic =
[3.68836267119462;3.68836267119462;3.68836267119462;3.68836267119462;3.688362
67119462;3.68836267119462;3.68836267119462;3.68836267119462;3.68836267119462;
3.68836267119462;3.68836267119462;3.68836267119462;3.68978430280685;3.6951853
2749773;3.70640812909459;3.72426067137800;3.74859134040339;3.77844267897616;3
.81220115475517;3.84772468799922;3.88244695284192;3.91346153713053;3.93889565
965116;3.95854323532813;3.97269921759304;3.98182318241970;3.98643938424859;3.
98710481702436;3.98439728776968;3.97890973954740;3.97124680416153;3.962022352
98376;3.95143612746702;3.93928285871615;3.92545672929098;3.91005190044105;3.8
9335687604007;3.87582553174539;3.85804696633850;3.84071938076862;3.8246285945
9511;3.81063067772837;3.79980204483531;3.79313426381963;3.79115874057913;3.79
392694817803;3.80107431115832;3.81189400801638;3.82540251354803;3.84039392483
959;3.85548399683964;3.86914556418646;3.88024697931681;3.88840012349257;3.893
56454549435;3.89590792203358;3.89574467788655;3.89350102025518;3.889691120326
36;3.88489927298792;3.87976581653628];

phasic2 =
[1.55170000000000;1.54570000000000;1.53970000000000;1.53520000000000;1.529200
00000000;1.52320000000000;1.51870000000000;1.51270000000000;1.50820000000000;
1.50220000000000;1.49620000000000;1.49020000000000;1.48570000000000;1.4812000
0000000;1.47520000000000;1.46920000000000;1.46170000000000;1.45720000000000;1
.45120000000000;1.44520000000000;1.43920000000000;1.43320000000000;1.42870000
000000;1.42120000000000;1.42289140000000;1.41651020000000;1.41012900000000;1.
40374780000000;1.39782240000000;1.39098540000000;1.38414840000000;1.378223000
00000;1.37184180000000;1.36546060000000;1.35862360000000;1.35224240000000;1.3
4768440000000;1.34267060000000;1.33811260000000;1.33355460000000;1.3289966000
0000;1.32307120000000;1.32352700000000;1.33628940000000;1.34905180000000;1.35
497720000000;1.35771200000000;1.35771200000000;1.35771200000000;1.34620000000
000;1.34814020000000;1.34449380000000;1.33948000000000;1.33902420000000;1.388
70640000000;1.53319500000000;1.59970000000000;1.67320000000000;1.746700000000
00;1.86820000000000;1.98970000000000];
tonic2=
[1.45782522704076;1.46593784325856;1.47368914460558;1.48084323415202;1.487135
03671940;1.49227837731170;1.49598497941224;1.49805642655747;1.49842261061867;
1.49712892933061;1.49431221746201;1.49017802474094;1.48498231019885;1.4790175
8026842;1.47260268266911;1.46607539349482;1.45966653763131;1.45343687683890;1
.44738691308596;1.44149671631780;1.43574010514271;1.43008951801276;1.42451754
848607;1.41899732350397;1.41350250798731;1.40800720978238;1.40246252883299;1.
39681135028414;1.39102549941537;1.38511039295383;1.37910027084142;1.373051772
81229;1.36703823121170;1.36114517452175;1.35546695571384;1.35010428143077;1.3
4507611770206;1.34031135224923;1.33574917860839;1.33136379677092;1.3271646815
8871;1.32319034196947;1.31950147481305;1.31617518395475;1.31330051527389;1.31
```

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097513886794;1.30934488592916;1.30858480103203;1.30883655857924;1.31019788293
941;1.31272760965530;1.31645398470623;1.32138233332801;1.32750118978842;1.334
78692322627;1.34320713796355;1.35633996145243;1.38066796742820;1.420746286734
82;1.47826961940836;1.55233734963562];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
figure(1);
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
%plot(L1/fs,C1,'b');
%ylim([-80 100]);
% title('Subject 2: Cross-Correlation of LF(pre) and Tonic');

%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr LF1 and Tonic');

%LF post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr LF2 and Tonic');
```

```
% LF post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr HF1 and phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr HF2 and phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 4: xcorr HF3 and phasic');
hold off;

%% subject 5
filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 5';

%used to plot log(LF norm) at baseline and during stimuli for subject 5
LF_Norm_B = xlsread(filename, 'N3:N6'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O6'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C6'); %Time for baseline
```

```
LF_Norm_S1 = xlsread(filename, 'N7:N49'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N50:N188');
LF_Norm_S3 = xlsread(filename, 'N189:N248');

HF_Norm_S1 = xlsread(filename, 'O7:O49'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O50:O188');
HF_Norm_S3 = xlsread(filename, 'O189:O248');
Time_S = xlsread(filename, 'C7:C248'); %Time for stimuli

x = [41;42;43;44;45;46;47;48;49;50;51;52;53;54;55;56;57;58;59;60;61];
phasic =
[2.71120000000000;2.73220000000000;2.80420000000000;2.84470000000000;2.849200
00000000;3.00520000000000;2.96320000000000;2.85670000000000;2.80270000000000;
2.75620000000000;2.71270000000000;2.67970000000000;2.64520000000000;2.6287000
0000000;2.67070000000000;2.64520000000000;2.72770000000000;2.80420000000000;2
.86270000000000;2.85220000000000;2.76670000000000];
tonic =
[2.22342705521811;2.23703916927242;2.25285833007560;2.27135759875125;2.292534
39117150;2.31598317604846;2.34098125331780;2.36656110669367;2.39156729096775;
2.41470028429767;2.43455020899940;2.45058716422894;2.46338298354778;2.4735907
2047923;2.48175706933106;2.48831000146158;2.49357831932145;2.49781304872029;2
.50120524176997;2.50389986900254;2.50600656091745];

tonic2 =
[0.572709902345843;0.572709902345843;0.571880614781348;0.570770466241626;0.56
9592194126552;0.568435042684601;0.567342825572720;0.566342643467237;0.5654554
48682505;0.564699931676911;0.564093950818536;0.563655058366540;0.563341797924
625;0.563084654057886;0.562859474517807;0.562658809311075;0.562481352860693;0
.562328059994100;0.562200717095059;0.562101416459807;0.562032362923490;0.5619
95802722009;0.562322016645930;0.563363961035195;0.565105913578825;0.567396521
739255;0.570034537406959;0.572800356917282;0.575467623974201;0.57780749812744
4;0.579590225057460;0.580585714250978;0.580835226494330;0.580601665000504;0.5
80018909003338;0.579173378764207;0.578134035364220;0.576963417011003;0.575721
699069077;0.574468187661561;0.573261869135532;0.572161612199039;0.57117709481
8413;0.570266662187208;0.569402304669235;0.568561035922676;0.567721717572442;
0.566863891072410;0.565967347971557;0.565011971823707;0.563977680029375;0.562
844402440577;0.561569540552206;0.560121688932983;0.558505833332387;0.55674034
6523806;0.554848526091503;0.552855481356413;0.550786988140146;0.5486690674562
08;0.546527830519162];
phasic2 =
[0.603818799999999;0.596526000000000;0.594247000000000;0.592879600000002;0.59
1512200000002;0.586954200000000;0.581028800000002;0.575559200000000;0.5710012
00000001;0.566899000000000;0.565987400000001;0.573735999999999;0.574647599999
999;0.570545400000000;0.568266399999999;0.566443200000001;0.564620000000000;0
.562341000000001;0.562796799999999;0.565987400000001;0.564620000000000;0.5687
22199999999;0.569633799999999;0.579205600000000;0.569633799999999;0.582699999
999999;0.586042600000002;0.587409999999999;0.590600599999999;0.59105640000000
1;0.589688999999999;0.588777399999999;0.586498400000001;0.584219400000000;0.5
833077999999999;0.581940399999999;0.580573000000000;0.578294000000001;0.576926
600000001;0.575103399999999;0.573280200000000;0.575559200000000;0.57874980000
0001;0.578749800000001;0.576926600000001;0.575559200000000;0.575103399999999;
0.573735999999999;0.571457000000001;0.569178000000000;0.567354800000000;0.565
531599999999;0.563252600000001;0.561885200000002;0.560061999999999;0.55823880
0000002;0.555959799999999;0.554136599999999;0.551857600000001;0.5495785999999
99;0.547755400000000];
```

```
%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 5: Cross-Correlation of LF(pre) and Tonic');
fs = 1;

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5: xcorr LF2 and Tonic');

subplot(1,3,3);
```

```
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 5:  xcorr HF3 and Phasic');
hold off;

%% subject 6

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 6';

%used to plot log(LF norm) at baseline and during stimuli for subject 5
LF_Norm_B = xlsread(filename, 'N3:N8'); %LF norm for baseline
```

```
HF_Norm_B = xlsread(filename, 'O3:O8'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C8'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N9:N86');
LF_Norm_S2 = xlsread(filename, 'N87:N166');
LF_Norm_S3 = xlsread(filename, 'N167:N316');

HF_Norm_S1 = xlsread(filename, 'O9:O86'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O87:O166');
HF_Norm_S3 = xlsread(filename, 'O167:O316');
Time_S = xlsread(filename, 'C9:C316'); %Time for stimuli

%post
phasic =
[3.01120000000000;2.98720000000000;3.01120000000000;3.25220000000000;3.018700
00000000;2.98870000000000;2.97220000000000;2.96020000000000;2.96470000000000;
2.95870000000000;2.95420000000000;2.97220000000000;2.96770000000000;2.9497000
0000000;2.93920000000000;2.97970000000000;3.01870000000000;3.00220000000000;2
.98720000000000;2.99920000000000;2.98720000000000;2.96620000000000;2.95120000
000000;2.93920000000000;2.93620000000000;2.95270000000000;2.94670000000000;2.
93470000000000;2.91970000000000;2.90770000000000;2.89870000000000;2.888200000
00000;2.87770000000000;2.87020000000000;2.86720000000000;2.86870000000000;2.8
5970000000000;2.84920000000000;2.84620000000000;2.84620000000000;2.8417000000
0000;2.82970000000000;2.82220000000000;2.82070000000000;2.81920000000000;2.81
020000000000;2.81920000000000;3.00380000000000;2.78020000000000;2.77870000000
000;2.81020000000000;2.82070000000000;2.81020000000000;2.79670000000000;2.789
20000000000;2.78920000000000;2.80270000000000;2.79820000000000;2.784700000000
00;2.77720000000000;2.79520000000000];
tonic =
[2.92431221390377;2.91789918764301;2.91258675040762;2.90878219125695;2.906488
48095180;2.90532022239376;2.90499593254412;2.90531177860646;2.90611271698387;
2.90727406327849;2.90869001332826;2.91026650408732;2.91191677398201;2.9135586
0201971;2.91522462927167;2.91701415410414;2.91895122038666;2.92100866718097;2
.92312731194916;2.92522805254562;2.92721939914207;2.92900215834849;2.93047234
614530;2.93152299935458;2.93151825071260;2.92965732796257;2.92566210928779;2.
91960309034310;2.91176844169175;2.90258173341952;2.89255073804977;2.882235591
29064;2.87222899204979;2.86314388937638;2.85517059922465;2.84805026386251;2.8
4158792440454;2.83564131129660;2.83010141335561;2.82487992029155;2.8199013958
1594;2.81509840964737;2.81040851021699;2.80577234207782;2.80103860790537;2.79
606529016051;2.79084753244228;2.78547072688321;2.78007655665996;2.77484171783
207;2.76996468025646;2.76565745431470;2.76214047086165;2.75963939720865;2.758
22656401408;2.75779186262706;2.75822446360996;2.75941734811083;2.761266016697
93;2.76366754275354;2.76651997797745];
x =
[58;59;60;61;62;63;64;65;66;67;68;69;70;71;72;73;74;75;76;77;78;79;80;81;82;8
3;84;85;86;87;88;89;90;91;92;93;94;95;96;97;98;99;100;101;102;103;104;105;106
;107;108;109;110;111;112;113;114;115;116;117;118];

%pre
phasic2 =
[1.16308540000000;1.16171800000000;1.16035060000000;1.15943900000000;1.159439
00000000;1.16490860000000;1.16582020000000;1.16627600000000;1.17493620000000;
1.17858260000000;1.17721520000000;1.17493620000000;1.17265720000000;1.1717456
0000000;1.17174560000000;1.17539200000000;1.17812680000000;1.17767100000000;1
.17584780000000;1.17493620000000;1.17630360000000;1.18177320000000;1.18405220
000000;1.19727040000000;1.21322340000000;1.21641400000000;1.21140020000000;1.
20684220000000;1.20501900000000;1.21322340000000;1.22142780000000;1.223251000
```

```
00000;1.22097200000000;1.21869300000000;1.21869300000000;1.21869300000000;1.2
2142780000000;1.22963220000000;1.22142780000000;1.22620000000000;1.2309996000
0000;1.22963220000000;1.22872060000000;1.22872060000000;1.22917640000000;1.22
917640000000;1.22917640000000;1.24102720000000;1.26244980000000;1.26700780000
000;1.26244980000000;1.25789180000000;1.25470120000000;1.25880340000000;1.260
17080000000;1.25834760000000;1.25652440000000;1.25515700000000;1.255157000000
00;1.25515700000000;1.26017080000000];
tonic2 =
[1.15598648911904;1.15700317167374;1.15794349685341;1.15882759778905;1.159669
57999404;1.16047989486471;1.16126662417783;1.16203622931890;1.16279402115563;
1.16354447126852;1.16429143114269;1.16503231056479;1.16575931644335;1.1664676
9176572;1.16715800600631;1.16783617356885;1.16851272260229;1.16920191817497;1
.16992095850217;1.17068929472977;1.17152810471169;1.17251811634730;1.17378806
142569;1.17543486438230;1.17750178556952;1.17997863629624;1.18280922198831;1.
18590013548031;1.18912878137090;1.19235002693032;1.19540150006187;1.198166224
14991;1.20061218709837;1.20274775176451;1.20460142464271;1.20621242477600;1.2
0762610493778;1.20889159994410;1.21006053168353;1.21118624078403;1.2123232968
3448;1.21354912153620;1.21495079612424;1.21658886119468;1.21848907399034;1.22
064449579112;1.22302068819392;1.22556121493318;1.22819248528224;1.23082771321
682;1.23337003909998;1.23574663495536;1.23793190013780;1.23992453257184;1.241
73663756457;1.24338829715860;1.24490468412703;1.24631441079291;1.247648511645
80;1.24893977140466;1.25022226534845];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 2: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
```

```
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 6: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 6: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 6: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 2: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 6: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 6: xcorr HF2 and Phasic');
```

```
%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 6:  xcorr HF3 and Phasic');
hold off;

%% subject 7

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 7';

%used to plot log(LF norm) at baseline and during stimuli for subject 7
LF_Norm_B = xlsread(filename, 'N3:N6'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O6'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C6'); %Time for baseline

LF_Norm_S1 = xlsread(filename, 'N7:N105');
LF_Norm_S2 = xlsread(filename, 'N106:N189');
LF_Norm_S3 = xlsread(filename, 'N190:N277');

HF_Norm_S1 = xlsread(filename, 'O7:O105'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O106:O189');
HF_Norm_S3 = xlsread(filename, 'O190:O277');
Time_S = xlsread(filename, 'C7:C277'); %Time for stimuli

x = [71;72;73;74;75;76;77;78;79;80;81;82;83;84;85;86;87;88;89;90;91];
phasic =
[1.71670000000000;1.69870000000000;1.68220000000000;1.65820000000000;1.646200
00000000;1.63720000000000;1.62670000000000;1.61620000000000;1.61470000000000;
1.60870000000000;1.59820000000000;1.59070000000000;1.58320000000000;1.5862000
0000000;1.57870000000000;1.59220000000000;1.63720000000000;1.63270000000000;1
.64170000000000;1.65670000000000;1.65220000000000];
tonic =
[1.60602689002453;1.60267311458349;1.59930524564179;1.59587192568608;1.592393
78718080;1.58893937170506;1.58560665294877;1.58251125099583;1.57977928254040;
1.57754309154104;1.57593871310876;1.57513314757090;1.57523638435697;1.5762403
0014588;1.57804999154816;1.58051579385613;1.58345493105779;1.58666487672095;1
.58993137631871;1.59303322144275;1.59574508262842];

phasic2=
[0.534537200000001;0.549578599999999;0.555959799999999;0.605641999999998;0.62
7520400000001;0.632990000000002;0.662161200000002;0.699536800000002;0.7072854
00000002;0.703638999999998;0.694523000000000;0.685862800000001;0.683128000000
001;0.685406999999999;0.685862800000001;0.684495399999998;0.684951200000002;0
.684039600000002;0.682672199999999;0.684495399999998;0.688141799999999;0.6963
46200000001;0.695434600000001;0.695890400000002;0.695890400000002;0.695434600
000001;0.695890400000002;0.690700000000001;0.696802000000001;0.69771360000000
2;0.699080999999998;0.698625199999999;0.698169400000001;0.696346200000001;0.6
94978799999999;0.695890400000002;0.707741199999998;0.710020199999999;0.705918
000000001;0.702271600000000;0.699536800000002;0.697257799999998;0.69680200000
```

```
0001;0.699080999999998;0.699080999999998;0.700904200000000;0.701815800000001;
0.700448399999999;0.700448399999999;0.699536800000002;0.699080999999998;0.698
625199999999;0.697713600000002;0.698625199999999;0.701359999999998;0.70090420
0000000;0.700904200000000;0.716401400000002;0.727796400000000;0.7309869999999
98;0.730075399999998];
tonic2=
[0.534537200000001;0.534537200000001;0.536769795209166;0.541627482168059;0.54
8805635918642;0.557780151002062;0.567997652121076;0.578943641857159;0.5901604
62928007;0.601245941633640;0.611845675827311;0.621644181913855;0.630477892202
482;0.638369519501118;0.645402253420579;0.651669312758273;0.657255575116750;0
.662232455241311;0.666657933069981;0.670578319534361;0.674030379154359;0.6770
43295801581;0.679659793642278;0.681939816383708;0.683939208722892;0.685703043
160749;0.687264771644829;0.688647457830670;0.689865551829550;0.69092661639195
8;0.691832811006843;0.692582100123653;0.693181869884049;0.693653758471054;0.6
94021495343240;0.694306515581417;0.694526776784843;0.694696813601697;0.694828
203647119;0.694930111626465;0.695009788771756;0.695072831471063;0.69512636441
7186;0.695179469916729;0.695240596985204;0.695316768000472;0.695413496928599;
0.695534958864040;0.695684222390053;0.695863472806126;0.696074203084746;0.696
317360252914;0.696649651966365;0.697185144899368;0.698027039551745;0.69924601
9857270;0.700877182774701;0.702923652244244;0.705361981069441;0.7081474512195
76;0.711218646880239];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 7: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
```

```
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 7: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 7: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 7: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 7: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 7: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 7: xcorr HF2 and Phasic');
```

```
%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 7:  xcorr HF3 and Phasic');
hold off;

%% subject 9
filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 9';

%used to plot log(LF norm) at baseline and during stimuli for subject 9
LF_Norm_B = xlsread(filename, 'N3:N4'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O4'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C4'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N4:N39'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N40:N76');
LF_Norm_S3 = xlsread(filename, 'N77:N136');

HF_Norm_S1 = xlsread(filename, 'O4:O39'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O5:O76');
HF_Norm_S3 = xlsread(filename, 'O77:O136');
Time_S = xlsread(filename, 'C5:C136'); %Time for stimuli

x = [73;74;75;76;77;78;79;80;81;82;83;84;85];
phasic =
[2.87470000000000;2.86570000000000;2.85670000000000;2.85220000000000;2.870200
00000000;2.86270000000000;2.84320000000001;2.83870000000000;2.93620000000000;
2.93920000000000;2.88670000000000;2.85220000000000;2.88820000000000];
tonic =
[2.80289935407414;2.80403924059561;2.80531675971098;2.80669259235542;2.808111
11701410;2.80950619190741;2.81080505887207;2.81193086321967;2.81280423875084;
2.81293342126613;2.81156235229288;2.80825477627537;2.80295927653394];

phasic2 =
[1.88620000000000;1.86970000000000;1.85470000000000;1.84120000000000;1.830700
00000000;1.82170000000000;1.82020000000000;1.81120000000000;1.80070000000000;
1.79320000000000;1.78720000000000;1.78120000000000;1.77370000000000;1.7662000
0000000;1.75870000000000;1.75270000000000;1.74820000000000;1.80970000000000;1
.85470000000000;1.84720000000000;1.82920000000000;1.81570000000000;1.80520000
000000;1.79770000000000;1.80520000000000;1.97240000000000;1.78270000000000;1.
81570000000000;1.91320000000000;1.90870000000000;1.88020000000000;1.856200000
00000;1.83970000000000;1.82620000000000;1.81420000000000;1.80370000000000;1.7
9470000000000;1.78720000000000;1.77970000000000;1.77220000000000;1.7677000000
0000;1.76020000000000;1.75270000000000;1.74670000000000;1.74070000000000;1.73
470000000000;1.73020000000000;1.72420000000000;1.71820000000000;1.71220000000
000;1.70620000000000;1.70020000000000;1.69270000000000;1.68820000000000;1.683
70000000000;1.67770000000000;1.67320000000000;1.66870000000000;1.661200000000
00;1.65220000000000;1.64620000000000];
tonic2 =
[1.78908030211344;1.78908030211344;1.78899053120640;1.78865069748899;1.787949
22814576;1.78683275153990;1.78529139977360;1.78334355883318;1.78102484791428;
1.77838106097061;1.77546389131598;1.77232841693831;1.76858571491610;1.7635735
```

```
1739605;1.75697925845824;1.74886256077586;1.73955378048213;1.72955714866767;1
.71948236067392;1.71000119050648;1.70182134291114;1.69567111622497;1.69218308
110395;1.69160796288368;1.69382941772440;1.69847132599168;1.70499267693003;1.
71275303788969;1.72105364564154;1.72916203923337;1.73632646549232;1.741784185
59616;1.74533150531800;1.74742526618707;1.74852402757222;1.74895863422769;1.7
4894320686619;1.74861049150358;1.74804192256876;1.74728810092171;1.7463815715
2799;1.74534445978811;1.74389696201405;1.74155231304145;1.73802327782297;1.73
324496313657;1.72731604489299;1.72044074301611;1.71288744591686;1.70496236161
465;1.69699360403169;1.68932184785165;1.68214071470056;1.67542460303278;1.669
08974719320;1.66304227913841;1.65719050872451;1.65144670786929;1.645726332888
28;1.63994696659076;1.63402750640982];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 9: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 9: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
```

```
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
legend('LF post 2 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 9: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
legend('LF post 3 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 9: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 9: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 9: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 9: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
```

```
title('Subject 9:  xcorr HF3 and Phasic');
hold off;

%% subject 10

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 10';

%used to plot log(LF norm) at baseline and during stimuli for subject 10
LF_Norm_B = xlsread(filename, 'N3:N6'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O6'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C6'); %Time for baseline

LF_Norm_S1 = xlsread(filename, 'N7:N93'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N94:N214');
LF_Norm_S3 = xlsread(filename, 'N215:N336');

HF_Norm_S = xlsread(filename, 'O7:O336'); %HF norm for stimuli
Time_S = xlsread(filename, 'C7:C336'); %Time for stimuli

tonic =
[3.04385410622828;3.05277955435878;3.06073686021546;3.06789876654638;3.074417
43880217;3.08043276032387;3.08600677885985;3.09112676268474;3.09579527157362;
3.10004990157970;3.10395985365375;3.10761752958045;3.11113085744992;3.1146176
3134252;3.11820171413053;3.12201062106603;3.12630072421502;3.13136225104204;3
.13731206923192;3.14408197901434;3.15145978831183];
phasic =
[3.32470000000000;3.55270000000000;3.63220000000000;3.68470000000001;3.597700
00000000;3.62019999999999;3.51670000000000;3.31120000000000;3.16270000000000;
3.17770000000000;3.35320000000000;3.32920000000000;3.26170000000000;3.3997000
0000000;3.52120000000000;3.58270000000000;3.56320000000000;3.51670000000000;3
.48220000000000;3.38920000000000;3.30070000000001];
x =
[346;347;348;349;350;351;352;353;354;355;356;357;358;359;360;361;362;363;364;
365;366];

phasic2 =
[1.10291980000000;1.11704960000000;1.18359640000000;1.13437000000000;1.204563
20000000;1.26017080000000;1.29481160000000;1.29617900000000;1.27430060000000;
1.25105480000000;1.23464600000000;1.22233940000000;1.22370680000000;1.2227952
0000000;1.24467360000000;1.25105480000000;1.24376200000000;1.24102720000000;1
.24376200000000;1.30720000000000;1.31532260000000;1.30028120000000;1.28751880
000000;1.30483920000000;1.32124800000000;1.31486680000000;1.30711820000000;1.
30119280000000;1.30256020000000;1.29845800000000;1.29207680000000;1.285695600
00000;1.28113760000000;1.27657960000000;1.27156580000000;1.26609620000000;1.2
6153820000000;1.25698020000000;1.25287800000000;1.24832000000000;1.2446736000
0000;1.24102720000000;1.23783660000000;1.23464600000000;1.23236700000000;1.22
917640000000;1.22735320000000;1.22644160000000;1.22370680000000;1.22006040000
000;1.21823720000000;1.21823720000000;1.21504660000000;1.21094440000000;1.210
48860000000;1.21140020000000;1.21094440000000;1.27111000000000;1.343126400000
00;1.34950760000000;1.33173140000000];
tonic2 =
[1.10291980000000;1.10291980000000;1.10421698161340;1.10687911446771;1.110662
51032221;1.11530591370786;1.12060436940330;1.12641284103118;1.13263231597643;
1.13919518689762;1.14605406096679;1.15317413524282;1.16078698073933;1.1692814
8414622;1.17882885838009;1.18934749856777;1.20055690688239;1.21203941783989;1
```

```
.22328857332979;1.23374242922022;1.24280509664895;1.24986019609479;1.25478984
220176;1.25808076026590;1.26024277364984;1.26166559665914;1.26261445773706;1.
26325972386691;1.26370726433987;1.26402151426099;1.26424113263791;1.264389053
29958;1.26433656845090;1.26383843190102;1.26272698127206;1.26093897796257;1.2
5849625746444;1.25548020307235;1.25201104566496;1.24823340162719;1.2443068472
8846;1.24040000560606;1.23651705279193;1.23250597388301;1.22827323398624;1.22
382018094116;1.21922831353085;1.21463605834993;1.21021925958873;1.20617735058
997;1.20272427427572;1.20008276257601;1.19853533699956;1.19831877459962;1.199
50444198746;1.20201069890955;1.20564349795105;1.21013366660762;1.215164224197
69;1.22038861562883;1.22544230689452];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 10: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 10: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
```

```
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 10: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 10: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 10: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 10: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 10: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 10:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;
```

```
%% subject 11

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 11';

%used to plot log(LF norm) at baseline and during stimuli for subject 11
LF_Norm_B = xlsread(filename, 'N3:N51'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O51'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C51'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N52:N200'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N201:N319');
LF_Norm_S3 = xlsread(filename, 'N320:N408');

HF_Norm_S1 = xlsread(filename, 'O52:O200'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O201:O319');
HF_Norm_S3 = xlsread(filename, 'O320:O408');
Time_S = xlsread(filename, 'C52:C408'); %Time for stimuli

tonic =
[0.257839774204436;0.257839774204436;0.257831869944936;0.257815738603436;0.25
77793451089252;0.257767508619221;0.257740144645354;0.257713116502116;0.2576876
80733117;0.257664632247490;0.257644361138155;0.257626910033300;0.257618306955
125;0.257630495762532;0.257673660473258;0.257753822173454;0.257872428655157;0
.258026650048117;0.258209882817987;0.258412275802534;0.258621213818914;0.2588
21741276584;0.259003288136702;0.259163371788131;0.259302640775757;0.259422919
035172;0.259526439837314;0.259615550565614;0.259692603074586;0.25975991655995
7;0.259819768220307;0.259874394107155;0.259931670509513;0.260005784428512;0.2
60110834547723;0.260258697282312;0.260458522772026;0.260716824279670;0.261037
757789561;0.261423438809110;0.261874241629614;0.262389064379543;0.26301269581
4410;0.263833701967875;0.264925622327955;0.266328705838319;0.268046948414209;
0.270050533707850;0.272279851712061;0.274649665108013;0.277052930591048;0.279
364142870707;0.281491355252735;0.283406934438368;0.285110872618763;0.28661588
9153984;0.287941237752089;0.289110014496528;0.290147892798334;0.2910824558436
88;0.291942793023905];
phasic =
[0.261513000000000;0.261057200000000;0.260601400000000;0.260145600000000;0.26
1057200000000;0.262424600000000;0.261057200000000;0.261057200000000;0.2606014
00000000;0.260145600000000;0.259689800000000;0.259689800000000;0.259234000000
000;0.258778200000000;0.258322400000000;0.258322400000000;0.257866600000000;0
.258322400000000;0.259234000000000;0.259689800000000;0.260601400000000;0.2601
45600000000;0.260145600000000;0.259689800000000;0.259234000000000;0.259689800
000000;0.260145600000000;0.260601400000000;0.261513000000000;0.26105720000000
0;0.261968800000000;0.261513000000000;0.261513000000000;0.261057200000000;0.2
61057200000000;0.261057200000000;0.261057200000000;0.261057200000000;0.261513
000000000;0.262880400000000;0.266982600000000;0.266982600000000;0.26743840000
0000;0.268350000000000;0.271084800000000;0.275642800000000;0.277921800000000;
0.280656600000000;0.282479800000000;0.287949400000000;0.292963200000000;0.292
963200000000;0.292963200000000;0.294330600000000;0.295242200000000;0.29660960
0000000;0.297521200000000;0.297521200000000;0.295698000000000;0.2975212000000
00;0.297521200000000];
x =
[0;1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28
;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43;44;45;46;47;48;49;50;51;52;53;5
4;55;56;57;58;59;60];
```

```
tonic2 =
[0.194054600000000;0.194054600000000;0.194015394400446;0.193984000986781;0.19
3959551738351;0.193941178634501;0.193928013654577;0.193919188777924;0.1939138
35983889;0.193911087251817;0.193910074561054;0.193909929890945;0.193926757496
479;0.193972901332845;0.194041852929685;0.194127103816645;0.194222145523366;0
.194320469579494;0.194415567514672;0.194500930858544;0.194570051140754;0.1946
16419890945;0.194645695647637;0.194668944004543;0.194687767074091;0.194703766
968712;0.194718545800837;0.194733705682896;0.194750848727319;0.19477157704653
6;0.194797492752978;0.194830197959074;0.194883251527866;0.194965904371626;0.1
95073296676638;0.195200568629183;0.195342860415544;0.195495312222003;0.195653
064234841;0.195811256640342;0.195965029624787;0.196109523374459;0.19624314292
6640;0.196370122191390;0.196494344664154;0.196619693840379;0.196750053215511;
0.196889306284996;0.197041336544279;0.197210027488808;0.197399262614028;0.197
612925415385;0.197893787547661;0.198268721729869;0.198717763053799;0.19922094
6611243;0.199758307493992;0.200309880793837;0.200855701602569;0.2013758050119
79;0.201850226113859];
phasic2 =
[0.194054600000000;0.194054600000000;0.194054600000000;0.194054600000000;0.19
4054600000000;0.194054600000000;0.194054600000000;0.194054600000000;0.1940546
00000000;0.194054600000000;0.194054600000000;0.194054600000000;0.194510400000
000;0.194510400000000;0.194054600000000;0.194510400000000;0.194510400000000;0
.194510400000000;0.194966200000000;0.194966200000000;0.194966200000000;0.1949
66200000000;0.194966200000000;0.194966200000000;0.194966200000000;0.194966200
000000;0.194966200000000;0.194966200000000;0.194966200000000;0.19496620000000
0;0.194966200000000;0.194966200000000;0.194966200000000;0.194966200000000;0.1
95422000000000;0.195877800000000;0.195877800000000;0.195877800000000;0.196333
600000000;0.195877800000000;0.196333600000000;0.196333600000000;0.19678940000
0000;0.196789400000000;0.196789400000000;0.196789400000000;0.197245200000000;
0.197245200000000;0.197245200000000;0.197245200000000;0.197701000000000;0.197
701000000000;0.198612600000000;0.199068400000000;0.199980000000000;0.20043580
0000000;0.200891600000000;0.201347400000000;0.201347400000000;0.2018032000000
00;0.202259000000000];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
```

```
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 11: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 11: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 11: xcorr LF2 and Tonic');

subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 11: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 11: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
```

```
title('Subject 11: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 11: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 11:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;

%% subject 12
%investigate this one
filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 12';

%used to plot log(LF norm) at baseline and during stimuli for subject 12
LF_Norm_B = xlsread(filename, 'N3:N15'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O15'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C15'); %Time for baseline

LF_Norm_S1 = xlsread(filename, 'N16:N79'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N80:N161');
LF_Norm_S3 = xlsread(filename, 'N162:N321');

HF_Norm_S1 = xlsread(filename, 'O16:O79'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O80:O161');
HF_Norm_S3 = xlsread(filename, 'O162:O321');
Time_S = xlsread(filename, 'C16:C321'); %Time for stimuli

tonic =
[1.94544268387236;1.97270708632782;1.99812592069735;2.02139715423894;2.042192
90320190;2.06060502657934;2.07711963545345;2.09209738234355;2.10576361872889;
2.11824324174611;2.12959004614724;2.13980788679615;2.14886558761466;2.1567074
0494869;2.16326036626358;2.16858429131244;2.17288761267227;2.17636385461126;2
.17918205935277;2.18149244908397;2.18343185348801;2.18512768746723;2.18670076
083088;2.18826725105000;2.18994008699128;2.19195411927438;2.19456224952026;2.
19785686164152;2.20179738304629;2.20624760124872;2.21100395085761;2.215815599
96207;2.22039856566133;2.22444561646074;2.22763321703278;2.22957966697675;2.2
2998696107040;2.22874216627944;2.22587701279290;2.22152643141584;2.2158979316
4757;2.20924994525601;2.20187661764470;2.19409713981911;2.18624826680913;2.17
854264360971;2.17100173300485;2.16359304959863;2.15625570692155;2.14891001168
685;2.14146321246190;2.13381341578107;2.12585231886326;2.11746712441447;2.108
```

```
54188325296;2.09865795453206;2.08729872235238;2.07426763307858;2.059638351535
09;2.04367942883332;2.02679672018315];
phasic =
[2.43070000000000;2.49970000000000;2.39920000000000;2.62870000000000;2.868700
00000000;3.11770000000000;3.07120000000000;2.83270000000000;2.65420000000000;
2.52370000000000;2.48470000000000;2.60920000000000;2.55220000000000;2.4697000
0000000;3.02620000000000;2.99620000000000;2.99620000000000;2.58370000000000;2
.96170000000000;2.96170000000000;2.70670000000000;2.97970000000000;2.84470000
000000;2.72770000000000;2.83420000000000;2.69920000000000;2.74570000000000;2.
65270000000000;2.78920000000000;2.63920000000000;2.50870000000000;2.420200000
00000;2.37070000000000;2.31070000000000;2.31370000000000;2.40070000000000;2.3
9470000000000;2.34520000000000;2.29120000000000;2.33770000000000;2.3077000000
0000;2.35270000000000;2.40820000000000;2.37820000000000;2.50120000000000;2.54
770000000000;2.50570000000000;2.38570000000000;2.32570000000000;2.61220000000
000;2.59270000000000;2.54470000000000;2.43070000000000;2.41870000000000;2.346
70000000000;2.26720000000000;2.21020000000000;2.16970000000000;2.129200000000
00;2.09320000000000;2.06020000000000];
x =
[297;298;299;300;301;302;303;304;305;306;307;308;309;310;311;312;313;314;315;
316;317;318;319;320;321;322;323;324;325;326;327;328;329;330;331;332;333;334;3
35;336;337;338;339;340;341;342;343;344;345;346;347;348;349;350;351;352;353;35
4;355;356;357];

tonic2 =
[0.955776439918227;0.955776439918227;0.955776439918227;0.955776439918227;0.95
5776439918227;0.955776439918227;0.955776439918227;0.955776439918227;0.9557764
39918227;0.955776439918227;0.955776439918227;0.955776439918227;0.955758618965
718;0.955684015373363;0.955511792432013;0.955207028391586;0.954743384298565;0
.954103544034231;0.953278737431963;0.952267933533548;0.951076961057744;0.9497
17663477462;0.948176864548265;0.946408500010877;0.944364458712174;0.942006984
078687;0.939312853495060;0.936273989049161;0.932896606293220;0.92919984362211
3;0.925214284292804;0.920980542542602;0.916521945554376;0.911834337461057;0.9
06909749773975;0.901746081373539;0.896350520712588;0.890740234525004;0.884941
920731813;0.878990942369830;0.872930357610496;0.866809978555239;0.86067374341
2800;0.854549935479390;0.848457599744689;0.842409759582726;0.836415129729338;
0.830479108084569;0.824604409344158;0.818791510557501;0.813038989778776;0.807
343797781750;0.801714111293235;0.796169371172992;0.790724727364174;0.78538516
8576789;0.780143923867790;0.774982676961300;0.769872485316662;0.7647749128190
90;0.759643165531834];
phasic2 =
[1.16126220000000;1.14895560000000;1.13664900000000;1.12525400000000;1.125254
00000000;1.10291980000000;1.09608280000000;1.08742260000000;1.07876240000000;
1.07101380000000;1.06235360000000;1.05187020000000;1.04047520000000;1.0295360
0000000;1.02042000000000;1.01996420000000;1.04685640000000;1.05141440000000;1
.04457740000000;1.03865200000000;1.03318240000000;1.02680120000000;1.01996420
000000;1.01449460000000;1.00446700000000;0.992160400000000;0.982132800000000;
0.973016800000000;0.964812400000000;0.956608000000000;0.947036200000000;0.938
376000000000;0.932450600000000;0.924702000000000;0.916497600000000;0.91102800
0000000;0.905558400000000;0.898265600000000;0.890061200000000;0.8836800000000
00;0.874564000000000;0.870461800000000;0.870917600000000;0.865448000000000;0.
859978400000000;0.851318200000000;0.843569600000000;0.833542000000000;0.82761
6600000000;0.822602800000000;0.813486800000000;0.828072400000000;0.8463044000
00000;0.845392800000000;0.836276800000000;0.825793400000000;0.817589000000000
;0.809384600000000;0.804370800000000;0.796622200000000;0.790241000000000];

%mean zero
```

```
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 12: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 12: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 12: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
```

```
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 12: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 12: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 12: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 12: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 12:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;

%% subject 13

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 13';

%used to plot log(LF norm) at baseline and during stimuli for subject 13
LF_Norm_B = xlsread(filename, 'N3:N6'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O6'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C6'); %Time for baseline
```

```
LF_Norm_S1 = xlsread(filename, 'N7:N44'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N45:N83');
LF_Norm_S3 = xlsread(filename, 'N84:N135');

HF_Norm_S1 = xlsread(filename, 'O7:O44'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O45:O83');
HF_Norm_S3 = xlsread(filename, 'O84:O135');
Time_S = xlsread(filename, 'C7:C135'); %Time for stimuli

tonic =
[2.53843857055631;2.53843857055631;2.53843857055631;2.53843857055631;2.538438
57055631;2.53843857055631;2.53843857055631;2.53843857055631;2.53843857055631;
2.53843857055631;2.53843857055631;2.53843857055631;2.54006657151793;2.5459886
3834490;2.55765568715248;2.57524546884186;2.59803330151239;2.62473202732799;2
.65372430749788;2.68320511693427;2.71126470141445;2.73593551331971;2.75666738
196463;2.77452117064014;2.79044416648265;2.80498094638975;2.81833989976267;2.
83050645930025;2.84133114593420;2.85058650457127;2.85800114498187;2.863279249
91694;2.86598509521181;2.86578544663253;2.86270175963625;2.85705112861167;2.8
4934660983494;2.84021980750361;2.83037083485486;2.82053840321243;2.8114826479
9407;2.80397545392893;2.79822412016226;2.79378209876083;2.79022397914877;2.78
726563852619;2.78474440895353;2.78257895733742;2.78073738892010;2.77921645207
770;2.77802905632085;2.77719709239193;2.77669359427821;2.77643982077445;2.776
37066325746;2.77644281642691;2.77662977434553;2.77691585749161;2.777291848496
01;2.77775223742662;2.77829359435472];
phasic =
[3.33670000000000;3.18820000000000;3.07570000000000;2.95570000000000;2.838700
00000000;3.34570000000000;3.73270000000000;3.38920000000000;3.21970000000000;
3.99520000000000;3.67120000000000;3.35020000000000;3.99220000000000;3.6487000
0000000;3.34120000000000;3.18670000000000;3.10570000000000;2.97670000000000;3
.15820000000000;3.50020000000000;3.65620000000000;3.47320000000000;3.22420000
000000;3.92770000000000;3.87070000000000;4.02520000000000;4.04620000000000;3.
64870000000000;3.67270000000000;3.90220000000000;3.59020000000000;4.028200000
00000;3.85270000000000;3.54070000000000;3.48070000000000;3.75370000000000;3.5
6770000000000;4.14070000000000;4.18720000000000;3.75820000000000;3.5032000000
0000;3.36220000000000;3.88570000000000;4.07170000000000;3.71320000000000;3.54
070000000000;3.46720000000000;3.46720000000000;3.18370000000000;3.08770000000
000;3.00070000000000;3.00970000000000;3.31720000000000;3.36370000000000;3.231
70000000000;3.79870000000000;3.57670000000000;3.34570000000000;3.222700000000
00;3.12670000000000;3.04570000000000];
x =
[0;1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28
;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43;44;45;46;47;48;49;50;51;52;53;5
4;55;56;57;58;59;60];

phasic2 =
[1.09243640000000;1.09243640000000;1.29162100000000;1.26974260000000;1.240115
60000000;1.22689740000000;1.21185600000000;1.31760160000000;1.56145460000000;
1.55620000000000;1.58020000000000;1.55170000000000;1.50520000000000;1.4677000
0000000;1.43770000000000;1.41820000000000;1.44978360000000;1.45889960000000;1
.48214540000000;1.47986640000000;1.44249080000000;1.41286380000000;1.38961800
000000;1.42836100000000;1.48715920000000;1.47075040000000;1.43793280000000;1.
41696600000000;1.40329200000000;1.54276680000000;1.55770000000000;1.524700000
00000;1.48870000000000;1.48570000000000;1.46920000000000;1.44670000000000;1.4
2870000000000;1.41370000000000;1.41240800000000;1.40055720000000;1.3946318000
0000;1.39007380000000;1.38551580000000;1.37412080000000;1.36181420000000;1.36
135840000000;1.35041920000000;1.33811260000000;1.33902420000000;1.33446620000
```

```
000;1.32124800000000;1.31122040000000;1.30575080000000;1.29709060000000;1.286
15140000000;1.28341660000000;1.28706300000000;1.27840280000000;1.267007800000
00;1.25834760000000;1.27475640000000];
tonic2 =
[0.977684015328329;0.977684015328329;0.977684015328329;0.977684015328329;0.97
7684015328329;0.977684015328329;0.977684015328329;0.977684015328329;0.9776840
15328329;0.977684015328329;0.977684015328329;0.977684015328329;0.978455318973
407;0.981495322300834;0.988056262314026;0.998860275545606;1.01406775892127;1.
03333088139621;1.05586844598480;1.08053913748412;1.10590594434568;1.130290433
40973;1.15254926212562;1.17247079209486;1.19016911410475;1.20585198840234;1.2
1973549997086;1.23201563364617;1.24286140063216;1.25241568396772;1.2607984736
1262;1.26811050413957;1.27446685127582;1.28000293830326;1.28484232835222;1.28
908769846496;1.29282030166898;1.29610222317697;1.29897928044646;1.30148380170
417;1.30363705026089;1.30545125986208;1.30688731660743;1.30785928580853;1.308
29134162084;1.30813495199940;1.30737131720575;1.30600878345960;1.304078931877
15;1.30163268435478;1.29873685648896;1.29547124532861;1.29184017822079;1.2877
6082993314;1.28315950508701;1.27800160567653;1.27229684705793;1.2660959125037
2;1.25948473034882;1.25257863456688;1.24551708088633];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 13: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
```

```
ylabel('Correlation');
title('Subject 13: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 13: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 13: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 13: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 13: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 13: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
```

```
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 13:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;
%% subject 14

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 14';

%used to plot log(LF norm) at baseline and during stimuli for subject 14
LF_Norm_B = xlsread(filename, 'N3:N12'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O12'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C12'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N13:N45'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N46:N127');
LF_Norm_S3 = xlsread(filename, 'N128:N195');

HF_Norm_S1 = xlsread(filename, 'O13:O45'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O46:O127');
HF_Norm_S3 = xlsread(filename, 'O128:O195');
Time_S = xlsread(filename, 'C13:C195'); %Time for stimuli

tonic =
[1.61384283833110;1.61908986659375;1.62326352802135;1.62658678349036;1.629233
72429705;1.63133702817126;1.63299622502964;1.63428510844622;1.63495129552021;
1.63444885906296;1.63234211067399;1.62842948496240;1.62275397483511;1.6155730
5933213;1.60731881858295;1.59856016578164;1.58997100595315;1.58230481522396;1
.57612315920987;1.57160600538944;1.56872939526518;1.56735470580282;1.56727517
514161;1.56824130570475;1.56997547675495;1.57218086143395;1.57454716089610;1.
57675442381922;1.57841486780844;1.57914527624985;1.57869367319144;1.576964882
53917;1.57400774531119;1.56999089190477;1.56517788222546;1.55990558229869;1.5
5456665155430;1.54959582043432;1.54526831799559;1.54160207086211;1.5385253276
0966;1.53594673241220;1.53378215660874;1.53196294439080;1.53043664150609;1.52
916500148867;1.52812132401029;1.52728795886704;1.52710017035184;1.52840475555
234;1.53187722285257;1.53784465243337;1.54627265558252;1.55681064354027;1.568
85096153237;1.58158464225410;1.59404830441384;1.60516156637278;1.613790372758
04;1.61904701434643;1.62046061609776];
phasic =
[2.05720000000000;2.12620000000000;2.14570000000000;2.15620000000000;2.190700
00000000;2.11270000000000;2.01220000000000;2.14570000000000;2.23420000000000;
2.15320000000000;2.05420000000000;2.13670000000000;2.13220000000000;2.0812000
0000000;2.00320000000000;1.92970000000000;2.06620000000000;2.06620000000000;2
.04520000000000;2.07670000000000;2.13070000000000;2.06170000000000;1.97170000
000000;1.90720000000000;1.93270000000000;1.95070000000000;1.89370000000000;1.
83070000000000;1.78270000000000;1.84420000000000;1.85020000000000;1.947700000
00000;1.94470000000000;1.89820000000000;1.95220000000000;1.90120000000000;1.8
3070000000000;1.78120000000000;1.74070000000000;1.70770000000000;1.7632000000
0000;1.83220000000000;1.78420000000000;1.72570000000000;1.78420000000000;1.84
120000000000;1.81120000000000;1.80370000000000;1.78270000000000;1.74220000000
000;1.71370000000000;1.67770000000000;1.65070000000000;1.78120000000000;1.832
20000000000;1.83370000000000;1.81420000000000;1.93270000000000;2.016700000000
00;2.01520000000000;1.93570000000000];
```

```
x =
[74;75;76;77;78;79;80;81;82;83;84;85;86;87;88;89;90;91;92;93;94;95;96;97;98;9
9;100;101;102;103;104;105;106;107;108;109;110;111;112;113;114;115;116;117;118
;119;120;121;122;123;124;125;126;127;128;129;130;131;132;133;134];

phasic2 =
[0.511747200000000;0.507189200000000;0.504454400000000;0.514026200000000;0.52
7244400000000;0.554136600000000;0.581028800000000;0.604730400000000;0.6133906
00000000;0.614758000000000;0.630255200000000;0.623874000000000;0.612934800000
000;0.627976200000000;0.639827000000000;0.689965000000000;0.716857200000000;0
.727340600000000;0.710931800000000;0.709108600000000;0.752409600000000;0.7665
39400000000;0.775199600000000;0.775199600000000;0.861801600000000;0.865903800
000000;0.859522600000000;0.838555800000000;0.815765800000000;0.79343160000000
0;0.784771400000000;0.780213400000000;0.789329400000000;0.790241000000000;0.8
02091800000000;0.799812800000000;0.783859800000000;0.766539400000000;0.760614
000000000;0.766995200000000;0.813942600000000;0.820323800000000;0.80345920000
0000;0.787962000000000;0.774288000000000;0.773376400000000;0.783404000000000;
0.775655400000000;0.763804600000000;0.754232800000000;0.797533800000000;0.821
691200000000;0.809384600000000;0.800268600000000;0.837188400000000;0.83399780
0000000;0.844025400000000;0.847216000000000;0.831718800000000;0.8166774000000
00;0.805282400000000];
tonic2
=[0.502792829674191;0.502792829674191;0.504385862953176;0.507796472255316;0.5
12813672757437;0.519135918155870;0.526486489776239;0.534642580616696;0.543434
401649047;0.552735773208300;0.562453877781994;0.572520538813912;0.58300715440
5793;0.594082793081476;0.605837984242093;0.618247315544654;0.631178626510078;
0.644414090432331;0.657671095776710;0.670619465754178;0.682894647087383;0.694
107456924627;0.704097379697896;0.713005012177665;0.721014148260435;0.72826973
8205969;0.734860867446285;0.740825475783258;0.746160549140348;0.7508321349472
28;0.754783578005365;0.757941820345237;0.760274555341529;0.761823131611009;0.
762658806547007;0.762864780997524;0.762528976762752;0.761741133175786;0.76059
1653792715;0.759171158235572;0.757570315301487;0.755879786213208;0.7541319292
38663;0.752296665015088;0.750350676324229;0.748296259461568;0.746162352025146
;0.744000232219640;0.741878419476079;0.739878224185145;0.738090253199354;0.73
6611794832209;0.735628236944619;0.735373881484422;0.736005090359710;0.7375770
65382520;0.740054587192253;0.743330726241954;0.747244629939716;0.751595972813
561;0.756155947770991];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));
```

```
hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 13: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 14: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 14: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 14: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 14: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
```

```
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 14: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 14: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 14:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;

%% subject 15

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 15';

%used to plot log(LF norm) at baseline and during stimuli for subject 15
LF_Norm_B = xlsread(filename, 'N3:N5'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O5'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C5'); %Time for baseline

LF_Norm_S1 = xlsread(filename, 'N6:N41'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N42:N87');
LF_Norm_S3 = xlsread(filename, 'N88:N246');
HF_Norm_S1 = xlsread(filename, 'O6:O41'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O42:O87');
HF_Norm_S3 = xlsread(filename, 'O88:O246');

Time_S = xlsread(filename, 'C6:C246'); %Time for stimuli

tonic =
[4.37299160174895;4.38441545264759;4.39739544708821;4.41166966146392;4.426814
47481491;4.44227369566496;4.45738244218942;4.47138672080517;4.48345947803358;
4.49296140825742;4.49965528473993;4.50351088184159;4.50466677839682;4.5033999
4391830;4.50010080998267;4.49525283210243;4.48941573315534;4.48321176520528;4
.47731444600641;4.47204118227561;4.46730928292938;4.46305277899480;4.45922196
716567;4.45578049878301;4.45270297437854;4.44997297137818;4.44758142707771;4.
44552531289612;4.44380654743799;4.44261556935995;4.44223345148111;4.442797989
48830;4.44432789806746;4.44674424922695;4.44988806076189;4.45353471656439;4.4
```

```
5740578937778;4.46117873389656;4.46449483383080;4.46492053283520;4.4589437043
4993;4.44453657807171;4.42090591780505;4.38827077273697;4.34768013359630;4.30
086343378292;4.25010797999297;4.19815846148835;4.14813456094403;4.10141670679
966;4.05745683631741;4.01592507208769;3.97668375707194;3.93975292846023;3.905
28191265617;3.87352603618134;3.84482753168149;3.81959988336848;3.798314992346
19;3.78125120693084;3.76832660505287];
phasic =
[4.92080000000000;4.80740000000000;4.94780000000000;5.06660000000000;4.969400
00000000;4.95860000000000;4.95860000000000;5.10440000000000;5.06660000000000;
5.13140000000000;5.08820000000000;4.97480000000000;4.88840000000000;4.8344000
0000000;4.86680000000000;4.82360000000000;4.75880000000000;4.70480000000000;4
.65620000000000;4.62920000000000;4.64000000000000;4.61840000000000;4.52120000
000000;4.55020000000000;4.96400000000000;4.87760000000000;4.79120000000000;4.
75340000000000;4.72100000000000;4.80200000000000;4.96400000000000;4.883000000
00000;4.80740000000000;4.76960000000000;4.72100000000000;4.68320000000000;4.6
4540000000000;4.61840000000000;4.58600000000000;4.62380000000000;4.7264000000
0000;4.68320000000000;4.62920000000000;4.58600000000000;4.55360000000000;4.53
740000000000;4.59680000000000;4.56440000000000;4.52120000000000;4.22320000000
000;4.19920000000000;4.18120000000000;4.16020000000000;4.13770000000000;4.116
70000000000;4.09420000000000;4.07020000000000;4.05070000000000;4.028200000000
00;4.02820000000000;3.98770000000000];
x =
[153;154;155;156;157;158;159;160;161;162;163;164;165;166;167;168;169;170;171;
172;173;174;175;176;177;178;179;180;181;182;183;184;185;186;187;188;189;190;1
91;192;193;194;195;196;197;198;199;200;201;202;203;204;205;206;207;208;209;21
0;211;212;213];

tonic2 =
[1.41413219410881;1.41413219410881;1.41413219410881;1.41413219410881;1.414132
19410881;1.41413219410881;1.41413219410881;1.41413219410881;1.41413219410881;
1.41413219410881;1.41413219410881;1.41413219410881;1.41421825751569;1.4145390
1075983;1.41520028533765;1.41625891224107;1.41772597617143;1.41957067274238;1
.42172391988484;1.42408166575334;1.42650791154556;1.42883747310370;1.43096620
944948;1.43288009618809;1.43457596325456;1.43605347380036;1.43731417737929;1.
43836127732237;1.43919948088626;1.43983486856538;1.44027477531655;1.440527682
11205;1.44055067097338;1.44025927056099;1.43958932938335;1.43850103488067;1.4
3697738183586;1.43502225754513;1.43265864141429;1.42992695512462;1.4268835549
1459;1.42359935414443;1.42010821362939;1.41640159974678;1.41247997613211;1.40
835675561638;1.40405764955832;1.39961965116357;1.39509006484390;1.39052561533
535;1.38599163341645;1.38156131197522;1.37729113800152;1.37320651300212;1.369
32003221383;1.36563413678198;1.36214214464042;1.35882905432943;1.355672265657
95;1.35264223671453;1.34970308394953];
phasic2 =
[1.54420000000000;1.52920000000000;1.58470000000000;1.68070000000000;1.715200
00000000;1.69870000000000;1.68970000000000;1.73620000000000;1.70620000000000;
1.68370000000000;1.69420000000000;1.69420000000000;1.78720000000000;1.7452000
0000000;1.71520000000000;1.69870000000000;1.68820000000000;1.69270000000000;1
.71670000000000;1.69720000000000;1.67770000000000;1.67470000000000;1.67620000
000000;1.66120000000000;1.65670000000000;1.69720000000000;1.69420000000000;1.
71370000000000;1.69720000000000;1.67020000000000;1.65070000000000;1.634200000
00000;1.62070000000000;1.60720000000000;1.60720000000000;1.65070000000000;1.6
9270000000000;1.66870000000000;1.68070000000000;1.68820000000000;1.6612000000
0000;1.63870000000000;1.62370000000000;1.61020000000000;1.59670000000000;1.58
320000000000;1.56970000000000;1.55470000000000;1.53670000000000;1.52020000000
000;1.50520000000000;1.48720000000000;1.47670000000000;1.46770000000000;1.458
70000000000;1.44670000000000;1.43470000000000;1.42270000000000;1.417877600000
00;1.40739420000000;1.45935540000000];
```

```
%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 15: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 15: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 15: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
```

```
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 15: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 15: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 15: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 15: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 15:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;

%% subject 16

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 16';

%used to plot log(LF norm) at baseline and during stimuli for subject 16
LF_Norm_B = xlsread(filename, 'N3:N12'); %LF norm for baseline
```

```
HF_Norm_B = xlsread(filename, 'O3:O12'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C12'); %Time for baseline

LF_Norm_S1 = xlsread(filename, 'N13:N43'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N44:N129');
LF_Norm_S3 = xlsread(filename, 'N130:N174');

HF_Norm_S1 = xlsread(filename, 'O13:O43'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O44:O129');
HF_Norm_S3 = xlsread(filename, 'O130:O174');
Time_S = xlsread(filename, 'C13:C174'); %Time for stimuli

tonic
=[2.54201999644531;2.54962455417211;2.55810251868485;2.56716918116637;2.57647
942212908;2.58564164745718;2.59441457833450;2.60278631992629;2.61080115262878
;2.61849085038180;2.62585198005793;2.63284244861302;2.63938531886591;2.645374
70654370;2.65068163868330;2.65515913464765;2.65850522646926;2.66031915633223;
2.66031755089349;2.65839570175994;2.65462598697198;2.64923423022835;2.6425713
2584060;2.63508689216919;2.62730706915170;2.61981667199801;2.61300495779549;2
.60693824874995;2.60156576506280;2.59680780506367;2.59259075300895;2.58885868
746433;2.58557518732242;2.58272141608646;2.58029316108910;2.57829789246370;2.
57689642705708;2.57638730185742;2.57701613980000;2.57891501383982;2.582095766
66726;2.58646331509970;2.59183430000538;2.59795518460909;2.60451781741777;2.6
1117207833824;2.61769004870577;2.62403560854969;2.63022354998943;2.6362630317
7478;2.64213828212998;2.64780501213687;2.65319286211030;2.65820967729048;2.66
274585158261;2.66667812978954;2.66995773177025;2.67264613174337;2.67483550519
560;2.67661654531280;2.67806725504995];
phasic =
[2.59720000000000;2.58670000000000;2.58970000000000;2.71420000000000;2.778700
00000000;2.77570000000000;2.78170000000000;2.77870000000000;2.85220000000000;
2.91970000000000;2.91220000000000;2.88820000000000;2.86870000000000;2.8492000
0000000;2.84170000000000;2.81770000000000;2.79520000000000;2.77570000000000;2
.75770000000000;2.74120000000000;2.72470000000000;2.71120000000000;2.69470000
000000;2.68270000000000;2.65870000000000;2.64520000000000;2.63170000000000;2.
61970000000000;2.60470000000000;2.59870000000000;2.58970000000000;2.636200000
00000;2.82670000000000;2.90920000000000;2.90920000000000;2.86270000000000;2.8
2070000000000;2.78770000000000;2.76220000000000;2.74420000000000;2.7262000000
0000;2.72620000000000;2.73970000000000;2.73970000000000;2.73520000000000;2.72
620000000000;2.71270000000000;2.69770000000000;2.68420000000000;2.67220000000
000;2.66020000000000;2.65120000000000;2.65420000000000;2.76520000000000;2.841
70000000000;2.86120000000000;2.86420000000000;2.84020000000000;2.822200000000
00;2.80120000000000;2.78320000000000];
x =
[216;217;218;219;220;221;222;223;224;225;226;227;228;229;230;231;232;233;234;
235;236;237;238;239;240;241;242;243;244;245;246;247;248;249;250;251;252;253;2
54;255;256;257;258;259;260;261;262;263;264;265;266;267;268;269;270;271;272;27
3;274;275;276];

tonic2 =
[1.77070000000000;1.77070000000000;1.77132217060567;1.77265346677787;1.774617
69060343;1.77709954444924;1.77998423462471;1.78316862234548;1.78656304036121;
1.79009025895318;1.79368376395684;1.79728603795972;1.80087617827737;1.8044655
3280740;1.80805963376678;1.81164809228043;1.81520356794445;1.81868342526411;1
.82203196018917;1.82518253212712;1.82805942419219;1.83057941275704;1.83263338
710570;1.83410706392140;1.83491860254460;1.83502552275203;1.83442213934806;1.
83313460758259;1.83121586175351;1.82874110523591;1.82580397486774;1.822513336
```

```
98704;1.81893605407171;1.81507671788499;1.81092919827093;1.80649246498655;1.8
0177447961137;1.79679226371513;1.79157087697215;1.78614220419770;1.7805438276
9862;1.77481805336017;1.76901198829458;1.76316551568492;1.75730207771341;1.75
142795629647;1.74553404158057;1.73959810130330;1.73358693111634;1.72745822410
120;1.72116214596348;1.71464264590419;1.70778868404479;1.70045752877615;1.692
55019307499;1.68402787261897;1.67490959863734;1.66526494414724;1.655206151338
09;1.64488099985085;1.63446670433099];
phasic2 =
[1.77070000000000;1.97020000000000;2.11720000000000;2.15770000000000;2.123200
00000000;2.19970000000000;2.35120000000000;2.39320000000000;2.34520000000000;
2.26270000000000;2.20270000000000;2.15920000000000;2.13220000000000;2.1082000
0000000;2.08570000000000;2.06320000000000;2.04070000000000;2.05870000000000;2
.07670000000000;2.06620000000000;2.04370000000000;2.02120000000000;1.99720000
000000;1.97620000000000;1.95670000000000;1.95670000000000;1.91770000000000;1.
89970000000000;1.88470000000000;1.87120000000000;1.87270000000000;1.883200000
00000;1.94620000000000;1.95820000000000;1.94170000000000;1.91920000000000;1.8
9820000000000;1.88020000000000;1.86220000000000;1.84720000000000;1.8397000000
0000;1.83820000000000;1.83220000000000;1.82170000000000;1.80670000000000;1.79
320000000000;1.78420000000000;1.77220000000000;1.76170000000000;1.75270000000
000;1.74370000000000;1.73620000000000;1.73320000000000;1.72570000000000;1.716
70000000000;1.70620000000000;1.69570000000000;1.68370000000000;1.674700000000
00;1.66420000000000;1.65520000000000];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 15: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
```

```
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 16: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 16: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 16: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 16: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 16: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
```

```
title('Subject 16: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 16:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;

%% subject 17

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 17';

%used to plot log(LF norm) at baseline and during stimuli for subject 17
LF_Norm_B = xlsread(filename, 'N3:N57'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O57'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C57'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N58:N102'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N103:N158');
LF_Norm_S3 = xlsread(filename, 'N159:N233');

HF_Norm_S1 = xlsread(filename, 'O58:O102'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O103:O158');
HF_Norm_S3 = xlsread(filename, 'O159:O233');

Time_S = xlsread(filename, 'C58:C233'); %Time for stimuli

tonic =
[3.80860528796123;3.80860528796123;3.80849412810071;3.80808052179202;3.807232
43933231;3.80586877021709;3.80394394643340;3.80143659662878;3.79834176582228;
3.79466563152266;3.79042192005109;3.78562947644381;3.77724699301324;3.7607834
9858385;3.73434527042711;3.69813819060071;3.65382384002733;3.60405390638387;3
.55215173602051;3.50189614140263;3.45737478053638;3.42288473400762;3.40000635
011091;3.38705329181522;3.38227108034469;3.38406199295833;3.39095378730969;3.
40156112080242;3.41455774739656;3.42865751311865;3.44260145101590;3.455149025
59788;3.46590241700312;3.47532095553898;3.48374559980866;3.49137090679165;3.4
9828590908652;3.50450749414388;3.51000357327409;3.51470894180196;3.5185359096
3188;3.52138142578952;3.52307096947791;3.52344223817820;3.52244123091346;3.52
009683905563;3.51649505555965;3.51176067738727;3.50604482175386;3.49951654636
461;3.49235711143919;3.48475597769973;3.47647553166885;3.46700307957881;3.456
10111249337;3.44376236725826;3.43013983234123;3.41549554989518;3.400165546197
33;3.38453599139716;3.36902705088497];
phasic =
[4.50248863966698;4.44997305111353;4.39745746256009;4.34494187400665;4.292426
28545320;4.23991069689976;4.18739510834632;4.13487951979288;4.08236393123943;
4.02984834268599;3.97733275413255;3.92481716557910;3.87230157702566;3.8197859
8847222;3.76727039991877;3.71475481136533;3.66223922281189;3.60970000000000;3
.55720000000000;3.52870000000000;3.49720000000000;3.69970000000000;3.93670000
000000;3.90070000000000;4.11070000000000;4.08670000000000;4.16320000000000;3.
94870000000000;3.71920000000000;3.67570000000000;3.90820000000000;3.779200000
00000;4.00420000000000;4.08670000000000;3.86470000000000;3.78220000000000;3.7
```

```
8220000000000;3.95170000000000;3.84520000000000;3.75070000000000;3.6967000000
0000;3.67120000000000;3.65320000000000;3.64270000000000;3.61420000000000;3.61
570000000000;3.63820000000000;3.61870000000000;3.57970000000000;3.58870000000
000;3.54970000000000;3.51820000000000;3.51070000000000;3.49870000000000;3.477
70000000000;3.45970000000000;3.47170000000000;3.44620000000000;3.413200000000
00;3.38920000000000;3.39970000000000];
x =
[0;1;2;3;4;5;6;7;8;9;10;11;12;13;14;15;16;17;18;19;20;21;22;23;24;25;26;27;28
;29;30;31;32;33;34;35;36;37;38;39;40;41;42;43;44;45;46;47;48;49;50;51;52;53;5
4;55;56;57;58;59;60];

tonic2 =
[1.56620302607552;1.56620302607552;1.56620081405692;1.56619191014530;1.566172
15099680;1.56613815817383;1.56608730465859;1.56601758586021;1.56592749239703;
1.56581590393442;1.56568200453092;1.56552521608409;1.56508848097335;1.5639100
8741353;1.56165492595150;1.55816052675200;1.55341823183012;1.54754438231548;1
.54075418499917;1.53334036978393;1.52565628332713;1.51810262574980;1.51093213
062737;1.50417252929254;1.49780170021887;1.49179101320768;1.48611510747905;1.
48075332669638;1.47568924221874;1.47090986934791;1.46640494933570;1.462166361
43766;1.45818791726014;1.45446125312333;1.45097322127965;1.44770614350338;1.4
4463859921600;1.44174619291012;1.43900219254840;1.43637803813971;1.4338437414
5429;1.43136819880634;1.42892927299963;1.42651840086614;1.42413149312553;1.42
176637576326;1.41942196375582;1.41709791767728;1.41479445331275;1.41251221302
677;1.41025217048294;1.40801555757455;1.40580679255026;1.40363163578173;1.401
49264311148;1.39938875667387;1.39731581488911;1.39526716003110;1.393234166571
30;1.39120666762389;1.38917329150986];
phasic2 =
[1.68820000000000;1.67770000000000;1.67020000000000;1.66120000000000;1.652200
00000000;1.65220000000000;1.63570000000000;1.62820000000000;1.62070000000000;
1.61170000000000;1.60420000000000;1.59670000000000;1.58920000000000;1.5802000
0000000;1.57420000000000;1.56520000000000;1.55620000000000;1.54870000000000;1
.54120000000000;1.53370000000000;1.52620000000000;1.51870000000000;1.51270000
000000;1.50670000000000;1.50070000000000;1.49620000000000;1.49020000000000;1.
48570000000000;1.48420000000000;1.47970000000000;1.47820000000000;1.473700000
00000;1.47070000000000;1.46620000000000;1.46320000000000;1.45870000000000;1.4
5420000000000;1.45270000000000;1.44970000000000;1.44520000000000;1.4437000000
0000;1.43920000000000;1.43470000000000;1.43170000000000;1.42870000000000;1.42
570000000000;1.43064000000000;1.42790520000000;1.42517040000000;1.42243560000
000;1.41970080000000;1.41696600000000;1.41468700000000;1.41195220000000;1.409
21740000000;1.40602680000000;1.40329200000000;1.40010140000000;1.397366000000
00;1.39463180000000;1.39189700000000];



%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
```

```
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 17: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 17: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 17: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 17: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
```

```
% title('Subject 17: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 17: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 17: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 17:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;
%% subject 18

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 18';

%used to plot log(LF norm) at baseline and during stimuli for subject 18
LF_Norm_B = xlsread(filename, 'N3:N13'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O13'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C13'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N14:N93'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N94:N147');
LF_Norm_S3 = xlsread(filename, 'N148:N254');

HF_Norm_S1 = xlsread(filename, 'O14:O93'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O94:O147');
HF_Norm_S3 = xlsread(filename, 'O148:O254');

Time_S = xlsread(filename, 'C14:C254'); %Time for stimuli

tonic =
[0.755210233841223;0.759093429122616;0.763015602791118;0.766913574008353;0.77
0702262569542;0.774282448529821;0.777546040636439;0.780379481287799;0.7827435
40970013;0.784699271041664;0.786324950546431;0.787691357398453;0.788857390444
026;0.789871782299152;0.790775925295072;0.791606307308957;0.792396275543823;0
```

```
.793177216747349;0.793983148726687;0.794839666971676;0.795753556021454;0.7967
14646456607;0.797700282999386;0.798679381917878;0.799615430126863;0.800468513
021427;0.801196621969472;0.801756473935711;0.802125901242139;0.80231406902701
6;0.802339549003188;0.802222643758141;0.801983071029458;0.801639524598643;0.8
01209806742797;0.800711071632587;0.800160038880503;0.799573149253416;0.798920
584700465;0.798137853855425;0.797188997044083;0.796075578088191;0.79483006424
0677;0.793506884034728;0.792175018326172;0.790912721721481;0.789804020098089;
0.788936476812222;0.788391952431406;0.788216189011566;0.788412885375764;0.788
952147362507;0.789780520833148;0.790829049174225;0.792018937522835;0.79326528
4453972;0.794479451949276;0.795570537112798;0.796499020483944;0.7972911154422
54;0.797980641324885];
phasic =
[0.770641600000000;0.769730000000000;0.769274200000000;0.767451000000000;0.77
1097400000000;0.778846000000000;0.812119400000000;0.811207800000000;0.8071056
00000000;0.802091800000000;0.815765800000000;0.813486800000000;0.813486800000
000;0.811207800000000;0.807561400000000;0.804370800000000;0.801636000000000;0
.797989600000000;0.796166400000000;0.796166400000000;0.795710600000000;0.8125
75200000000;0.807561400000000;0.806649800000000;0.810752000000000;0.814398400
000000;0.816677400000000;0.813942600000000;0.813942600000000;0.808928800000000
0;0.813031000000000;0.817133200000000;0.811207800000000;0.806649800000000;0.8
10752000000000;0.810752000000000;0.810752000000000;0.808928800000000;0.805282
400000000;0.802547600000000;0.798901200000000;0.796166400000000;0.80163600000
0000;0.799357000000000;0.797533800000000;0.799812800000000;0.800268600000000;
0.807105600000000;0.805282400000000;0.804370800000000;0.802547600000000;0.800
724400000000;0.799357000000000;0.795710600000000;0.797078000000000;0.79616640
0000000;0.804826600000000;0.827160800000000;0.823970200000000;0.8185006000000
00;0.820323800000000];
x =
[234;235;236;237;238;239;240;241;242;243;244;245;246;247;248;249;250;251;252;
253;254;255;256;257;258;259;260;261;262;263;264;265;266;267;268;269;270;271;2
72;273;274;275;276;277;278;279;280;281;282;283;284;285;286;287;288;289;290;29
1;292;293;294];

tonic2 =
[0.254054476281654;0.254054476281654;0.254668922502837;0.255386694410978;0.25
6200068525598;0.257101321366219;0.258082729452363;0.259136569303551;0.2602551
17439306;0.261430650379148;0.262655444642601;0.263921776749186;0.265284427877
132;0.266793283742956;0.268433277673611;0.270189342996050;0.272046413037227;0
.273989421124094;0.276003300583605;0.278072984742713;0.280183406928371;0.2823
19500467532;0.284580535285669;0.287042640187881;0.289656036820566;0.292370946
830121;0.295137591862945;0.297906193565435;0.300626973583988;0.30325015356500
1;0.305725955154873;0.308004600000000;0.310115466159205;0.312131400887132;0.3
14067829623909;0.315940177809666;0.317763870884531;0.319554334288633;0.321326
993462103;0.323097273845067;0.324880600877657;0.326692400000000;0.32854097141
4818;0.330414995523068;0.332300468062236;0.334183384769809;0.336049741383273;
0.337885533640112;0.339676757277813;0.341409408033861;0.343069481645744;0.344
642973850945;0.346143333680988;0.347595683352217;0.349003528379352;0.35037037
4277113;0.351699726560221;0.352995090743394;0.354259972341354;0.3554978768688
19;0.356712309840510];
phasic2 =
[0.254220200000000;0.254676000000000;0.254676000000000;0.258322400000000;0.25
9689800000000;0.261513000000000;0.262880400000000;0.264703600000000;0.2656152
00000000;0.266982600000000;0.267894200000000;0.269261600000000;0.270173200000
000;0.271996400000000;0.274275400000000;0.275642800000000;0.276554400000000;0
.277466000000000;0.278377600000000;0.278377600000000;0.286126200000000;0.2888
61000000000;0.290684200000000;0.292051600000000;0.293419000000000;0.296609600
000000;0.299344400000000;0.302079200000000;0.304358200000000;0.30618140000000
```

```
0;0.308004600000000;0.310739400000000;0.312562600000000;0.314841600000000;0.3
16209000000000;0.317576400000000;0.318943800000000;0.320311200000000;0.322134
400000000;0.324413400000000;0.326692400000000;0.328971400000000;0.33079460000
0000;0.333529400000000;0.335352600000000;0.337175800000000;0.338543200000000;
0.340366400000000;0.342189600000000;0.344012800000000;0.344924400000000;0.346
291800000000;0.347659200000000;0.348570800000000;0.349026600000000;0.35039400
0000000;0.352217200000000;0.354952000000000;0.356319400000000;0.3572310000000
00;0.358598400000000];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 18: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 18: xcorr LF1 and Tonic');

%post 2
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
```

```
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 18: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 18: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 18: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 18: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 18: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
title('Subject 18:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off;
```

```
%% subject 19

filename = 'C:\Users\cruzmolinag12\Documents\HRV\subject 19';

%used to plot log(LF norm) at baseline and during stimuli for subject 19
LF_Norm_B = xlsread(filename, 'N3:N4'); %LF norm for baseline
HF_Norm_B = xlsread(filename, 'O3:O4'); %HF norm for baseline
Time_B = xlsread(filename, 'C3:C4'); %Time for baseline
LF_Norm_S1 = xlsread(filename, 'N5:N30'); %LF norm for stimuli
LF_Norm_S2 = xlsread(filename, 'N31:N66');
LF_Norm_S3 = xlsread(filename, 'N67:N125');

HF_Norm_S1 = xlsread(filename, 'O5:O30'); %HF norm for stimuli
HF_Norm_S2 = xlsread(filename, 'O31:O66');
HF_Norm_S3 = xlsread(filename, 'O67:O125');
Time_S = xlsread(filename, 'C5:C125'); %Time for stimuli

tonic =
[2.11521663397079;2.11420576856985;2.11252169024795;2.11034322098773;2.107741
41114878;2.10476057931764;2.10145257575557;2.09788920021289;2.09416481212771;
2.09039485999263;2.08671299549565;2.08326795767976;2.08022071057867;2.0781426
6958793;2.07797207794502;2.08047992534187;2.08608188062508;2.09480462046753;2
.10631554018005;2.11997372791645;2.13488354804006;2.14994334517303;2.16388691
022901;2.17510297403698;2.18193625906720;2.18318976939969;2.17826858384146;2.
16716931268709;2.15041104401190];
phasic =
[2.60920000000000;2.67670000000000;2.79820000000000;2.73970000000000;2.820700
00000000;2.87020000000000;2.76070000000000;2.68720000000000;2.69920000000000;
2.74120000000000;2.69320000000000;2.64370000000000;2.60470000000000;2.5747000
0000000;2.55220000000000;2.52670000000000;2.50120000000000;2.49070000000000;2
.46970000000000;2.43820000000000;2.41420000000000;2.38720000000000;2.35870000
000000;2.32720000000000;2.30170000000000;2.27470000000000;2.24920000000000;2.
22220000000000;2.19670000000000];
x =
[139;140;141;142;143;144;145;146;147;148;149;150;151;152;153;154;155;156;157;
158;159;160;161;162;163;164;165;166;167];

tonic2 =
[0.819116895888976;0.819116895888976;0.819038922071978;0.818860617284095;0.81
8580915547511;0.818206191398236;0.817744828266315;0.817205212652953;0.8165950
94372003;0.815921469643815;0.815190646820481;0.814408361341085;0.813573734113
173;0.812679479471189;0.811719618412519;0.810691758553153;0.809597330687197;0
.808441141702556;0.807230770690770;0.805975997605544;0.804688320376927;0.8033
80566212434;0.802045054716780;0.800655515032935;0.799194806277095;0.797662505
462777;0.796075041374414;0.794463434230903;0.792870581118839;0.79134876762359
4;0.789957591626085;0.788762302213229;0.787796864346650;0.787048689066589;0.7
86491875948045;0.786099628027895;0.785848331479447;0.785718420957812;0.785694
102145085;0.785762747955503;0.785914273238726;0.786140593280429;0.78665531151
6794;0.787868768580523;0.790100711766748;0.793501091620026;0.798048021399549;
0.803570610413315;0.809776605220476;0.816277785780648;0.822611175307046;0.828
256017589441;0.832868694112167;0.836404767765710;0.838931074002102;0.84055061
9704021;0.841373702061715;0.841507706650619;0.841054253565261;0.8401090756998
24;0.838762784511462];
phasic2 =
[0.855876200000000;0.857243600000000;0.851774000000000;0.847216000000000;0.84
2202200000000;0.838100000000000;0.847216000000000;0.849950800000000;0.8485834
```

```
00000000;0.844481200000000;0.841746400000000;0.835821000000000;0.830807200000
000;0.827616600000000;0.823970200000000;0.819868000000000;0.816677400000000;0
.812119400000000;0.808473000000000;0.806649800000000;0.821235400000000;0.8399
23200000000;0.839011600000000;0.833086200000000;0.829895600000000;0.826705000
000000;0.824426000000000;0.821235400000000;0.820323800000000;0.81758900000000
0;0.813031000000000;0.808928800000000;0.805738200000000;0.803003400000000;0.7
99357000000000;0.796166400000000;0.794343200000000;0.791152600000000;0.787506
200000000;0.785683000000000;0.798445400000000;0.805282400000000;0.80710560000
0000;0.830351400000000;0.854508800000000;0.854508800000000;0.851318200000000;
0.850406600000000;0.850862400000000;0.853597200000000;0.854508800000000;0.859
978400000000;0.857699400000000;0.853141400000000;0.850862400000000;0.85769940
0000000;0.867271200000000;0.864992200000000;0.858611000000000;0.8535972000000
00;0.853597200000000];

%mean zero
LF_Norm_S1=LF_Norm_S1(:)-mean(LF_Norm_S1(:));
LF_Norm_S2=LF_Norm_S2(:)-mean(LF_Norm_S2(:));
LF_Norm_S3=LF_Norm_S3(:)-mean(LF_Norm_S3(:));
LF_Norm_B=LF_Norm_B(:)-mean(LF_Norm_B(:));

HF_Norm_S1=HF_Norm_S1(:)-mean(HF_Norm_S1(:));
HF_Norm_S2=HF_Norm_S3(:)-mean(HF_Norm_S2(:));
HF_Norm_S3=HF_Norm_S3(:)-mean(HF_Norm_S3(:));
HF_Norm_B=HF_Norm_B(:)-mean(HF_Norm_B(:));

%post
tonic = tonic(:)-mean(tonic(:));
phasic = phasic(:)-mean(phasic(:));

%pre
tonic2 = tonic2(:)-mean(tonic2(:));
phasic2 = phasic2(:)-mean(phasic2(:));

hold on;
%pre
% subplot(2,2,1);
[C1,L1] = xcorr(LF_Norm_B/std(LF_Norm_B),tonic2/std(tonic2)); %xcorr of tonic
and LF pre
% plot(L1/fs,C1,'b');
% ylim([-65 65]);
% title('Subject 19: Cross-Correlation of LF(pre) and Tonic');

figure(1);
%post 1
subplot(1,3,1);
[C2,L2] = xcorr(LF_Norm_S1/std(LF_Norm_S1),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L2/fs,C2,'r',L1/fs,C1,'-.k');
legend('LF post 1 and Tonic', 'LF pre and Tonic');
ylim([-80 100]);
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 19: xcorr LF1 and Tonic');

%post 2
```

```
subplot(1,3,2);
[C3,L3] = xcorr(LF_Norm_S2/std(LF_Norm_S2),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L3/fs,C3,'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 2 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 19: xcorr LF2 and Tonic');

%post 3
subplot(1,3,3);
[C4,L4] = xcorr(LF_Norm_S3/std(LF_Norm_S3),tonic/std(tonic)); %xcorr of tonic
and LF post
plot(L4/fs,C4, 'r',L1/fs,C1,'-.k');
ylim([-80 100]);
legend('LF post 3 and Tonic', 'LF pre and Tonic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 19: xcorr LF3 and Tonic');

%HF and Phasic
%pre
figure(2);
% subplot(2,2,1);
[C5,L5] = xcorr(HF_Norm_B/std(HF_Norm_B),phasic2/std(phasic2));
% plot(L5/fs,C5,'b');
% ylim([-80 80]);
% title('Subject 19: Cross-Correlation of HF (pre) and Phasic');

%post 1
subplot(1,3,1);
[C6,L6] = xcorr(HF_Norm_S1/std(HF_Norm_S1),phasic/std(phasic));
plot(L6/fs,C6,'r', L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 1 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 19: xcorr HF1 and Phasic');

%post 2
subplot(1,3,2);
[C7,L7] = xcorr(HF_Norm_S2/std(HF_Norm_S2),phasic/std(phasic));
plot(L7/fs,C7,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 2 and Phasic', 'HF pre and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
title('Subject 19: xcorr HF2 and Phasic');

%post 3
subplot(1,3,3);
[C8,L8] = xcorr(HF_Norm_S3/std(HF_Norm_S3),phasic/std(phasic));
plot(L8/fs,C8,'r',L5/fs,C5,'-.k');
ylim([-80 100]);
legend('HF post 3 and Phasic', 'HF pre and Phasic');
```

```
title('Subject 19:  xcorr HF3 and Phasic');
xlabel('Time delay (s)');
ylabel('Correlation');
hold off
```

Appendix C – IRB Approval

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office 252-744-2914 · Fax 252-744-2284 · www.ecu.edu/ORIC/irb

Notification of Initial Approval: Expedited

From: Social/Behavioral IRB
To: Genesis Cruz-Molina
CC: Brian Sylcott
Date: 8/11/2017
Re: UMCIRB 17-001152
Identifying the cross correlation between heart rate variability and skin conductance on healthy college students

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 8/10/2017 to 8/9/2018. The research study is eligible for review under expedited category #4,6,7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Name	Description
Cruz-Molina_Genesis_Thesis_Proposal_Draft_Rev6 (1).docx	Study Protocol or Grant Application
Email Script	Recruitment Documents/Scripts
Pain Survey.docx	Surveys and Questionnaires
Study Flyer	Recruitment Documents/Scripts
Thesis_Survey.docx	Surveys and Questionnaires
Updated Informed Consent Thesis Research.doc	Consent Forms

The Chairperson (or designee) does not have a potential for conflict of interest on this study.