THE RELATIONSHIP BETWEEN RESTING HEART RATE VARIABILITY AND HEART RATE RECOVERY FROM EXERCISE IN COLLEGE-AGED MEN

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ABSTRACT

THE RELATIONSHIP BETWEEN RESTING HEART RATE VARIABILITY AND HEART RATE RECOVERY FROM EXERCISE IN COLLEGE-AGED MEN

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The primary aim of this study was to examine the relationship between resting heart rate variability (HRV) and heart rate recovery (HRR) from exercise with a focus on a previously unstudied vagal index of HRR, T30. Participants were males aged 18 to 25 years ($N = 23$) of varying fitness levels. It was hypothesized that resting HRV would be significantly correlated with HRR. Resting HRV was measured for 5 minutes in the supine and seated positions and was assessed in the time (i.e., SDNN) and frequency (i.e., HF power, normalized HF power [HFnu], LF power, normalized LF power [LFnu], and LF:HF ratio) domains. Two indices of HRR, T30 (i.e., the negative reciprocal of the slope of the regression line of natural log of the HR data for 30 seconds after exercise) and delta 60 (i.e., HR at the end of exercise minus HR at 1 minute of recovery), were each assessed during a passive recovery following submaximal exercise tests on a cycle ergometer. A logarithmic transformation was applied to variables that violated normality. Pearson product correlations were used to assess the relationship between HRV and HRR measures. With the exception of a significant negative correlation between LogT30 and LogLF (supine) ($r = -.45$, $p = .032$) no other significant relationships were found between indices of HRV and HRR. Therefore, resting HRV may not be related to HRR from exercise. It is possible that HRV and HRR assess different aspects of autonomic control. It is also possible that there is a physiologic ceiling in HRV and/or HRR due to

fitness and/or training.

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CHAPTER ONE

Introduction

Heart rate variability (HRV), the variation in heart rate from beat to beat (Esco et al., 2010), is a measurement of autonomic nervous system function (Esco et al., 2010; Lopes & White, 2006). HRV has been associated with cardiovascular health (Bilchick et al., 2002; Dekker et al., 2000; Malpas, 2010; Villareal, Liu, & Massumi, 2002), training status (Levy et al., 1998; Lopes & White, 2006), training volume (Lee & Mendoza, 2012), and fitness levels (De Meersman, 1993; Levy et al., 1998; Lopes & White, 2006). A reduced HRV is associated with higher risk of CHD and thus is a good indicator of mortality risk (Acharya, Joseph, Kannathal, Lim, & Suri, 2006; Bilchick et al., 2002; Buchheit & Gindre, 2006; Dekker et al., 2000; Esco et al., 2010; Lopes & White, 2006; Malpas, 2010; Ravenswaaij-Arts, Kolée, Hopman, Stoelinga, & Geijn, 1993; Stauss, 2003; Villareal et al., 2002). Higher HRV recently has been used as an indicator of training volume (Lee & Mendoza, 2012), and is associated with higher fitness levels (Levy et al., 1998; Lopes & White, 2006). See Appendix A for definitions.

Measurement of HRV is complex and is not ideal for use by the general population. Another method of assessing autonomic function, risk of CHD, and training status is heart rate recovery (HRR), which is a measure of the decrease in heart rate immediately after cessation of exercise. An accelerated HRR from a bout of exercise is associated with lower risk of mortality and higher fitness level (Cay, 2009; Cole, Blackstone, Pashkow, Snader, & Lauer, 1999; Esco et al., 2010; Imai et al., 1994). Additionally, some researchers have shown that increased training volume and overtraining may negatively impact HRR (Borresen & Lambert, 2007; Lopes & White, 2006), while others have shown no significant change in HRR related to changes in training volume (Wilder, 2012). HRR is easily measured using a heart rate monitor. Because HRR is easy to assess and is a valid indicator of cardiac health (Shetler et al., 2001), it may be more practical than HRV as a tool for assessing everyday health, fitness and training status, yet the relationship between HRV and HRR is not well established (Esco et al., 2010; Evrengul et al., 2006; Jae, Heffernan, Lee, & Fernhall, 2011; Javorka, Zila, Balhárek, & Javorka, 2002; Lee & Mendoza, 2012).

Literature Review

Autonomic Nervous System Control of Heart Rate

Resting heart rate control. Heart rate is controlled through internal and external mechanisms. Heart rate is controlled internally through the actions of the SA node, which is a specialized bundle of cells that, under normal conditions, sets the rate of contraction for the heart. The inherent rate of the SA node is approximately 100 bpm (Lopes & White, 2006). However, due to parasympathetic nervous system activity at rest, the vagus nerve inhibits the SA node, keeping resting heart rate between 60 and 80 bpm (Lopes & White, 2006). Changes in heart rate are a result of chemical and neural factors (Aubert, Seps, & Beckers, 2003), with higher heart rate being a result of higher sympathetic dominance and inhibition of the vagus nerve. Lower heart rate is a result of higher parasympathetic dominance and activation of the vagus nerve (Acharya et al., 2006; Arai et al., 1989).

Autonomic modulation during exercise and recovery. During exercise, many cardiovascular variables must be adjusted to meet the increasing metabolic demands of the active skeletal muscle (Evrengul et al., 2006). These adjustments are made primarily due to the actions of the autonomic nervous system (Arai et al., 1989; Bilchick & Berger, 2006; Esco et al., 2010; Evrengul et al., 2006; Imai et al., 1994). Upon initiation of exercise, there is simultaneous activation of the motor cortex and the cardiovascular control centers of the medulla; at the same time muscles are stimulated to contract, an autonomic response is initiated in the medulla. This phenomenon is referred to as central command (Aubert et al., 2003; Smith & Fernhall, 2011). The autonomic response to exercise is an immediate withdrawal of parasympathetic stimulation and increase in sympathetic stimulation of the heart, resulting in an almost instantaneous rise in heart rate and thus cardiac output (Arai et al., 1989; Esco et al., 2010; Evrengul et al., 2006; Imai et al., 1994; Javorka et al., 2002; Smith & Fernhall, 2011).

During recovery from exercise, heart rate recovers rapidly (Arai et al., 1989; Esco et al., 2010), with the speed of recovery reflecting the degree of autonomic control. A faster recovery of heart rate indicates better ability of the autonomic nervous system to respond to changes (Evrengul et al., 2006). Because the autonomic nervous system is largely responsible for the control of heart rate, measures of autonomic function are critical to understanding acute changes in cardiovascular parameters in response to exercise.

Heart Rate Variability

One measure of autonomic function is heart rate variability (HRV), which is the variation in heart rate from beat to beat (Acharya et al., 2006; Bilchick & Berger, 2006;

Dekker et al., 2000; Esco et al., 2010). HRV is measured by determining the variation in distance between R waves on electrocardiogram (EKG) tracings (Esco et al., 2010). While HRV can be assessed during exercise and recovery from exercise, HRV is typically assessed during rest, as relatively few studies have reported the effects of acute exercise on HRV during recovery from exercise (Lopes & White, 2006).

It has been well established that a higher HRV is associated with a decreased risk of mortality, specifically cardiac-related death (Bilchick et al., 2002; Dekker et al., 2000; Futterman & Lemberg, 1994; Malik, 2003). This is due to lower sympathetic dominance being associated with lower risk of CHD (Malpas, 2010). Higher HRV is associated with higher aerobic fitness levels, as measured by VO_{2Max}, while lower HRV is associated with lower fitness levels related to sedentary lifestyles (Aubert et al., 2003; Borresen & Lambert, 2007; Buchheit & Gindre, 2006; De Meersman, 1993; Goldsmith, Bigger, Steinman, & Fleiss, 1992; Levy et al., 1998; Lopes & White, 2006), although at the highest levels of aerobic fitness there is no association between fitness and HRV (Iellamo et al., 2002; Lee & Mendoza, 2012; Manzi et al., 2009).

Resting HRV is also an indicator of training status (Levy et al., 1998; Lopes & White, 2006), which connotes whether an individual has been engaging in physical activity (PA) for enough time for training adaptations to occur within the body. Buchheit and Gindre (2006) found that resting HRV is better correlated to fitness as measured by VO_{2Max} than it is correlated to training volume. Some researchers have concluded that HRV is not associated with training volume, especially in well-trained athletes (Iellamo et al., 2002; Lee & Mendoza, 2012; Manzi et al., 2009). Therefore HRV measures may be an appropriate index of fitness level and training status, but perhaps not training volume, yet the consistency of the findings across studies is lacking (Aubert et al., 2003).

Causes of heart rate variability. A cause of HRV is normal respiration. This change in heart rate due to respiration is called respiratory sinus arrhythmia, and it results from the medullary responses to hemodynamic changes and thoracic stretch receptors (Ravenswaaij-Arts et al., 1993) and is primarily a function of vagal activity (Smith & Fernhall, 2011). When a person inhales, thoracic stretch receptors signal the medulla to increase the heart rate by inhibiting the vagus nerve; conversely, upon exhalation, the medulla signals the vagus nerve, which is stimulated, reducing heart rate.

Another common cause of HRV is baroreflex-related HRV, or the change in heart rate due to the response of baroreceptors located in the carotid artery and the aorta (Malpas, 2010; Ravenswaaij-Arts et al., 1993). While the main function of these receptors is to control blood pressure, they achieve this partially through changes in heart rate (Smith & Fernhall, 2011). As pressure in these vessels increases, the baroreceptors signal the medulla that pressure is high. The vagus nerve is then stimulated, causing the heart rate to decrease in order to reduce the stress on the heart (Ravenswaaij-Arts et al., 1993).

Methods of heart rate variability measurement. There are many methods of measuring HRV, the most common being time domain and frequency domain measures (Acharya et al., 2006; Malik, 2003; Ravenswaaij-Arts et al., 1993), with new methods such as Poincaré plots thought to be more qualitative measures of HRV (Kamen, Krum, & Tonkin, 1996). A table illustrating the variety of methods for assessing HRV is shown in Appendix B.

Time domain measures. Time domain measures involve statistical operations on R-R intervals, where frequency domain measures require spectral analysis of an array of R-R intervals (Acharya et al., 2006; Ravenswaaij-Arts et al., 1993). Both time and frequency domain measures have been validated for use at rest, but they have limited prognostic significance during exercise and recovery from exercise (Ng, Sundaram, Kadish, & Goldberger, 2009).

Time domain measures of HRV include SDNN and pNN50 among others. SDNN, or the standard deviation of normal R-R interval length, is a measure of total variability (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), with high values representing higher vagal influence and better cardiac health (Dekker et al., 2000). SDNN should be calculated from short-term, 5-minute recordings, as this measure is dependent on length of recording (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). SDNN is a preferred method of time domain HRV analysis, as it has better statistical properties than other time domain measures (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

The pNN50 is calculated by dividing the number of interval distances of successive R-R intervals greater than 50 ms by the total number of R-R intervals. This measure estimates high frequency power, which is indicative of vagal influence. However, SDNN is preferred to pNN50, as pNN50 does not have statistical properties of the same quality as SDNN measures (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Frequency domain measures. While time domain measures are useful in investigating short-term HRV, frequency domain measures typically provide results that are easier to interpret in terms of physiologic regulation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Frequency domain methods of HRV assessment require spectral density analysis on R-R intervals, with low frequency (LF) power and high frequency (HF) power being the most common components analyzed and reported (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Very low frequency (VLF) power is not often reported, as the physiologic explanation is not well refined (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). HF power (0.15-0.40 Hz) is governed almost exclusively by parasympathetic effects, with high values representing higher vagal influence and better cardiovascular health (Bilchick & Berger, 2006; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). LF power (0.04-0.15 Hz), however, is related to both sympathetic and parasympathetic modulation, with lower values being indicative of better cardiovascular health (Bilchick & Berger, 2006; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The ratio of LF to HF power can also be calculated, representing sympathetic-parasympathetic balance, with low values being desirable (Bilchick & Berger, 2006;

Lombardi et al., 1987; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

LF and HF measures can also be normalized. Normalized LF, or LFnu, is calculated by dividing LF by the sum of HF and LF. Similarly, HFnu is calculated by dividing HF by the sum of HF and LF. Representing LF and HF in normalized units "emphasizes the controlled and balanced behavior of the two branches of the autonomic nervous system" (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), and HFnu in particular may give insight into vagal activity (Buchheit & Gindre, 2006).

Poincaré plots. Poincaré plots are created by plotting each R-R interval as a function of the previous R-R interval, producing an ellipse (Esco, 2009; Kamen et al., 1996). A larger ellipse is desirable, as it represents greater parasympathetic control (Esco, 2009; Kamen et al., 1996). Poincaré plots were validated in a blocking study by Kamen et al. (1996) as a measure of parasympathetic control. Poincaré plots may be preferable to other methods of HRV measurement, as they are sensitive, practical tools of that may simplify HRV analysis (Kamen et al., 1996). However, they are mainly visual tools, as norms have not been established regarding the quantitative characterization of these plots (Brennan, Palaniswami, & Kamen, 2001).

Heart rate variability measurement equipment. HRV measures typically require the placement of at least three EKG electrodes on the chest of a patient (Acharya et al., 2006; Gold et al., 2000; Ravenswaaij-Arts et al., 1993). HRV can also be measured using certain Polar (USA) heart rate monitors that record R-R intervals. While the validity for the Polar S810 heart rate monitor for HRV measurement was found to be "near perfect" (Gamelin, Berthoin, & Bosquet, 2006; Nunan et al., 2009), the reliability of this equipment for HRV measurement has not been established. While considered a "gold standard" measure of autonomic modulation at rest (Acharya et al., 2006; Ravenswaaij-Arts et al., 1993), HRV measures are complex in analysis and not accessible to the general population, as they require extensive equipment, software, knowledge, and analysis skills that typical athletes and exercisers do not possess.

Heart Rate Recovery

While HRV is a valuable tool, it is not the only method used to assess autonomic function. Heart rate recovery (HRR) measurement is another method of assessing autonomic control of the cardiovascular system (Arai et al., 1989; Cay, 2009; Cole et al., 1999; Cole, Foody, Blackstone, & Lauer, 2000; Esco et al., 2010; Javorka et al., 2002; Shetler et al., 2001) and may be an independent predictor of mortality (Esco et al., 2010). While heart rate increases rapidly with exercise due to increased sympathetic dominance, it decreases rapidly in healthy subjects following the cessation of a bout of exercise (Arai et al., 1989; Esco, 2009; Imai et al., 1994; Otsuki et al., 2007). This cardiodeceleration following the cessation of exercise is termed heart rate recovery, and is due primarily to increased parasympathetic activation (Arai et al., 1989; Esco et al., 2010; Imai et al., 1994; Otsuki et al., 2007) and secondarily to sympathetic withdrawal after the first minute of recovery (Pierpont & Voth, 2004; Sugawara, Murakami, Maeda, Kuno, & Matsuda, 2001).

Methods of heart rate recovery measurement. HRR can be measured using a heart rate monitor and can be computed in several ways. One-minute HRR (delta 60), two-minute HRR, and time constants of beat-by-beat heart rate decay for the first 30 seconds following the cessation of exercise (T30) are typical measures of HRR (Imai et al., 1994; Shetler et al., 2001).

Delta 60. One-minute HRR, also called delta 60, is calculated by subtracting the heart rate at one minute of recovery from the heart rate at the cessation of exercise, with higher values being desirable (Imai et al., 1994; Otsuki et al., 2007; Shetler et al., 2001; Sugawara et al., 2001). delta 60 HRR measures primarily reflect parasympathetic reactivation (Sugawara et al., 2001), and can be taken after submaximal or maximal exercise (Cole et al., 1999; Perini et al., 1989). Delta 60 HRR measures were validated for prognostic use in patients with history of chest pain (Cole et al., 1999; Shetler et al., 2001). Shetler et al. (2001) conducted symptom-limited exercise testing and HRR evaluation in said patients, and the patients "were determined to be dead or alive after a mean seven years of follow-up." It was found that HRR "was ranked similarly to traditional variables including age and metabolic equivalents for predicting death but failed to have diagnostic power for discriminating those who had angiographic disease" (Shetler et al., 2001). Cole et al. (1999), Shetler et al. (2001), and Vivekananthan, Blackstone, Pothier, and Lauer (2003) determined delta 60 to be a valid prognostic measurement for cardiovascular disease. Delta 60 has also been used by many researchers as a training tool to detect changes in fitness level and training volume, including overtraining (Borresen & Lambert, 2007; Buchheit & Gindre, 2006; Lee & Mendoza, 2012; Wilder, 2012). While some researchers found that high training volume results in slower HRR (Borresen & Lambert, 2007; Buchheit & Gindre, 2006), others did not find a significant relationship between training volume and HRR (Lee & Mendoza, 2012; Wilder, 2012).

Two-minute heart rate recovery. Two-minute HRR is calculated by subtracting the heart rate at two minutes of recovery from the heart rate at cessation of exercise, with higher values being desirable (Cole et al., 2000; Shetler et al., 2001). Two-minute HRR represents parasympathetic activation and sympathetic withdrawal. Two-minute HRR was validated by Shetler et al. (2001) as a prognostic tool, with higher values indicating faster recovery and better cardiac health.

T30. T30 is calculated by performing linear regression on the natural logarithm of heart rate data in beats per minute (bpm) for the first 30 seconds following the cessation of exercise (Imai et al., 1994; Otsuki et al., 2007; Sugawara et al., 2001), with lower values being desirable. The negative reciprocal of the slope of the regression line is defined as T30 (Otsuki et al., 2007). T30 was introduced by Imai et al. (1994) in a study where this vagally-mediated HRR measure was derived through pharmacologic autonomic blockade in normal volunteers. T30 was obtained at six levels of exercise, some involving administration of autonomic blockade drugs, in order to "extract a vagally mediated component from the post-exercise heart rate decay" (Imai et al., 1994).

Imai et al. (1994) found that T30 was nearly independent of exercise intensity, indicating that T30 is mediated by vagal reactivation rather than sympathetic withdrawal. T30 should be collected after exercise completed below the ventilatory threshold to avoid sympathetic interference (Buchheit, Papelier, Laursen, & Ahmaidi, 2007; Imai et al., 1994). T30 has been shown to be valid as an indicator of autonomic function and reliable as a measure of HRR from submaximal exercise (Arduini, Gomez-Cabrera, & Romagnoli, 2011; Pierpont, Stolpman, & Gornick, 2000). While time constants of heart rate decay can be computed for varying lengths of recovery, according to Imai et al. (1994) T30 seems to be better than T120 and other time constant methods as a predictor of mortality, as T120 is influenced by sympathetic nerve activity and work load.

HRR as a training tool. An accelerated HRR (or less time taken for heart rate to recover), measured as T30, is associated with higher aerobic fitness (Imai et al., 1994; Sugawara, Hamada, Nabekura, Nishijima, & Matsuda, 1999), and has been shown by some to be associated with higher anaerobic fitness levels (Otsuki et al., 2007), while others found no association between HRR and anaerobic fitness (Wilder, 2012). HRR, measured as T30, may therefore be used as a training tool, measured using a heart rate monitor and the included software, potentially giving athletes and exercisers the ability to determine current fitness status. HRR has also been shown by some (Buchheit & Gindre, 2006; Iellamo et al., 2002; Lee & Mendoza, 2012; Manzi et al., 2009; Sugawara et al., 2001), but not all (Wilder, 2012) researchers, to be a good indicator of training volume, indicating whether an athlete is overtrained, as well as being able to detect changes in training volume.

Relationship of Heart Rate Variability to Heart Rate Recovery

Because HRR is an indicator of autonomic function, it begs the question of whether HRR may be related to HRV. See Appendix C for a summary of the studies regarding the relationship between resting HRV and HRR from exercise. Evrengul et al.

(2006) demonstrated a strong, positive correlation between HRR (measured as 3-minute heart rate recovery) and resting HRV (measured as HF power), but subjects used were those with CHD. Zdrenghea, Sitar-Tăut, and Pop (2007) found no relationship between HRR measured as delta 60 and HRV in the time domain; however, all subjects had myocardial ischemia, and ambulatory HRV rather than resting HRV was measured over a period of 24 hours. Additionally, Zdrenghea et al. (2007) did not specify whether a passive or active recovery was used. The focus of the present research will be on non-cardiac populations.

While Jae et al. (2011) found a positive correlation between resting HRV and HRR from exercise in persons with paraplegia, their results are not generalizable to the population and exercise situations, as upper body exercise places greater demand on the cardiovascular system than does lower body exercise (Pendergast, 1989). Dewland, Androne, Lee, Lampert, and Katz (2007) found no relationship between resting HRV and HRR from maximal exercise.

Several researchers have demonstrated no relationship between resting HRV and HRR from a bout of exercise (Bosquet, Gamelin, & Berthoin, 2007; Dewland et al., 2007; Esco et al., 2010; Javorka et al., 2002; Lee & Mendoza, 2012). Perhaps, as Dewland et al. (2007) posit, resting HRV and HRR from exercise capture different aspects of cardiac parasympathetic regulation. As Lee and Mendoza (2012) suggest, reactivity of the ANS as measured by HRR may be a more sensitive measure of cardiac autonomic control than HRV is, especially in well-trained athletes.

Discrepancies exist among methods of assessing the variables in this relationship.

These discrepancies are in the subjects, exercise protocol, type of recovery from exercise, methods of HRV analysis, and HRR methods.

Subjects. In the few studies in which researchers examined the relationship of resting HRV and HRR from exercise, the subjects that researchers chose to use varied considerably. It is difficult to reconcile the literature regarding the relationship between HRV and HRR from exercise, as there are many inconsistencies in the ways in which subjects are classified, specifically concerning PA and fitness levels. Additionally, some researchers have classified subjects as trained or untrained, often based on PA levels or VO_{2Max}. Typically, trained subjects are those who engage in regular physical activity and who often have a higher VO_{2Max} than untrained subjects, who do not engage in regular physical activity, hence activity levels (e.g., volume of PA) and training status (i.e., determined by VO_{2Max}) are often confounded (Buchheit & Gindre, 2006).

Esco et al. (2010) and Javorka et al. (2002) used apparently healthy, untrained, college-aged men, while Lee and Mendoza (2012) chose to use highly fit males and females with a VO_{2Max} at or above the 99^{th} percentile and Bosquet et al. (2007) used trained male and female runners. Esco et al. (2010) studied subjects that varied in fitness as assessed by VO_{2Max}, and Javorka et al. (2002) did not report on fitness. Additionally, Esco et al. (2010) and Javorka et al. (2002) did not report on training volume or level of physical activity (PA) of the subjects. Lee and Mendoza (2012) were the only researchers to report on the PA levels of their highly fit subjects. Because resting HRV and HRR from exercise are both influenced by training volume and fitness, controlling for or reporting on training volume, fitness, and PA levels may be appropriate.

Interestingly, Buchheit and Gindre (2006) reported that vagal-related indices of HRV are more related to cardiorespiratory fitness, while HRR is better related to training volume. Finally, with regard to fitness and training volume, because Lee and Mendoza (2012) used a homogenous subject group with such high aerobic fitness levels, restriction of range may have been a factor leading to poor correlations between resting HRV and HRR from exercise.

None of the researchers examining the relationship between resting HRV and HRR from exercise mentioned whether they controlled for body composition of the subjects. Central obesity is linked with increased sympathetic nervous system activity and thus HRV measures (Alvarez, Beske, Ballard, & Davy, 2002; Beske, Alvarez, Ballard, & Davy, 2002; Christou, Jones, Pimentel, & Seals, 2004; Esco & Williford, 2013; Esco, Williford, & Olson, 2011; Millis et al., 2010). Therefore, it may be prudent to control for, or at least report on, abdominal obesity when studying the relationship between resting HRV and HRR from exercise in order to attempt to isolate vagal activity.

Sex of subjects may have influenced results as well. Lee and Mendoza (2012) and Bosquet et al. (2007) used both male and female subjects, and did not state whether they controlled for the menstrual cycle of female subjects. Because HRV measures are altered by the phases of the menstrual cycle (Yildirir, Kabakci, Akgul, Tokgozoglu, & Oto, 2001), not controlling for the menstrual cycle may have contributed to the absence of a relationship between resting HRV and HRR from exercise.

Exercise protocol. In research regarding the relationship of resting HRV and HRR from exercise, different exercise protocols are used. In research settings, HRR is assessed after a bout of exercise, which can be of maximal or submaximal intensity. The increase in heart rate during submaximal exercise is due primarily to parasympathetic withdrawal, while exercise at higher intensities is due to increased sympathetic activation as well (Robinson, Epstein, Beiser, & Braunwald, 1966). Due to the difference in autonomic control based on exercise intensity, and because not all HRR methods capture the same information regarding autonomic control, HRR may be affected and methods must be selected wisely.

Of the existing non-clinical studies in which researchers examined the relationship between resting HRV and HRR from exercise, only one used a submaximal exercise protocol, at an intensity of 70% maximal power output (Javorka et al., 2002), which may have been above the ventilatory threshold for untrained subjects, while the others used maximal exercise protocols (Bosquet et al., 2007; Esco et al., 2010; Lee & Mendoza, 2012). Also, it should be noted that HRR is often determined from a maximal HR value, and maximal HR attained during exercise itself has been found to be weakly, inversely related to HRV measures (Esco et al., 2010). Little research exists regarding HRR from submaximal exercise and its relationship to resting HRV (Javorka et al., 2002).

Type of recovery from exercise. The most significant discrepancy among current research is the method of recovery from exercise. All current research designs, except that of Bosquet et al. (2007) and Javorka et al. (2002), employed an active recovery from exercise (Esco et al., 2010; Lee & Mendoza, 2012), which may influence HRR measures. During an active recovery, the subject continues exercise at a lower intensity in order to prevent blood pooling and other negative effects of immediate exercise cessation (ACSM, 2014). Mechanoreceptors within the muscles sense changes in muscle length and tension. This information is relayed to the medulla, resulting in continued sympathetic outflow to the heart (Smith & Fernhall, 2011) and thus elevated heart rate (Esco et al., 2010).

An active recovery can be done at an intensity that is either absolute or relative. An active recovery at an absolute intensity is one in which the subject exercises at a given intensity that is the same for other subjects, (e.g., the same intensity as the first stage of a standardized exercise test protocol) (ACSM, 2014). For a less fit subject, this work rate is more difficult because it is at an intensity that is a greater percentage of VO_{2Max}. Due to the linear relationship between work rate and heart rate, working at this intensity will require a greater heart rate to achieve a cardiac output equal to that of the trained person (Blomqvist & Saltin, 1983). Consequently, greater sympathetic activation is required in a less fit subject, confounding HRR measures.

An active recovery at a relative intensity is one in which the subject recovers at an exercise intensity that is a percentage of VO_{2max}, heart rate reserve, max heart rate, or another variable (ACSM, 2014). An active recovery at a relative intensity may be preferred to an active recovery at an absolute intensity in assessment of HRR. An active recovery at a relative intensity increases the likelihood that all subjects will have similar levels of autonomic activity; this is important, as several researchers have demonstrated that autonomic responses to exercise and recovery are dependent on exercise intensity (Leuenberger et al., 1993; Saito, Tsukanaka, Yanagihara, & Mano, 1993; Seiler, Haugen,

& Kuffel, 2007). However, all researchers investigating the relationship between HRV and HRR that required an active recovery have employed an active recovery at an absolute intensity (Esco et al., 2010; Lee & Mendoza, 2012). That said, in homogenous samples with regards to fitness, such as Lee and Mendoza (2012), the issues with a recovery stimulus at a given absolute workload are less problematic.

When recovering from submaximal exercise, a passive recovery may be used in which the subject does not engage in exercise. A passive recovery may be preferable to an active recovery when assessing HRR, as skeletal muscle action does not require increased SNS activity, and therefore does not require elevated heart rate. When using a passive recovery, absolute versus relative recovery intensities do not need to be considered, and thus parasympathetic reactivation can be more consistently monitored.

Methods of analysis of heart rate variability. While most researchers investigating the relationship between resting HRV and HRR from exercise used the delta 60 HRR measurement, discrepancies exist among HRV analysis methods. Most researchers used both time and frequency domain measures, but the sampling frequency differed. Esco et al. (2010) and Javorka et al. (2002) used a sampling frequency of 1000 Hz, while Lee and Mendoza (2012) used a sampling frequency of 500 Hz. This difference in methodology could lead to differences in results, as a sampling frequency below 1000 Hz will produce data with extraneous noise and error (Abboud & Barnea, 1995; González, 2004; Merri, Farden, Mottley, & Titlebaum, 1990). A sampling frequency of 1000 Hz will produce results with a standard error of +1ms between R-R intervals (Lopes & White, 2006).

Some researchers (Bosquet et al., 2007; Dewland et al., 2007; Esco et al., 2010; Evrengul et al., 2006) controlled for diurnal variations in HRV by testing all subjects in early to mid-morning and testing each subject at the same time of day for repeated sessions. Armstrong, Kenny, Green, and Seely (2011) found that younger individuals have less sympathetic and more parasympathetic activity in the mornings and afternoons. HRV measurements should be conducted at the same time of day, preferably in the morning. This is particularly important for parasympathetic measures of HRV.

Some (Bosquet et al., 2007; Jae et al., 2011) but not all (Esco et al., 2010; Evrengul et al., 2006; Zdrenghea et al., 2007) researchers controlled breathing rate during HRV measurements, while others neglected to report whether breathing rate was controlled. Because respiratory causes of HRV are more dominant when breathing rate "approaches the frequency of the intrinsic baroreflex-related heart rate fluctuations," which is 6 breaths per minute (Ravenswaaij-Arts et al., 1993), and controlled breathing results in enhanced vagal tone (Pagani et al., 1986), control of breathing rate may be prudent.

HRR methods. Four HRR methods are used in current research regarding the relationship between resting HRV and HRR from exercise, all being measured for one minute or more: delta 60 (Bosquet et al., 2007; Esco et al., 2010; Lee & Mendoza, 2012), two-minute HRR (Esco et al., 2010), 30-minute HRR (Javorka et al., 2002), and %D1 or the percent decrease in first minute of recovery (Javorka et al., 2002). The 30-minute HRR and the %D1 measures have not been validated as measurements of HRR. No researchers have investigated the relationship between resting HRV and T30 measures of

HRR.

During the first minute of recovery, heart rate decreases primarily due to parasympathetic reactivation (Arai et al., 1989; Esco et al., 2010; Imai et al., 1994; Otsuki et al., 2007), indicating that T30 is primarily due to vagal reactivation. Because T30 is vagally-mediated and captures vagal activity more exclusively than delta 60 does, it may be differently related to measures of HRV. Hence, a stronger linear relationship between T30 and the more exclusively vagal indices of HRV may emerge than has been found in most of the previous research. If not, then perhaps, as some (Bosquet et al., 2007; Buchheit et al., 2007; Dewland et al., 2007; Esco et al., 2010; Jae et al., 2011; Javorka et al., 2002) have asserted, resting HRV and HRR from exercise may be capturing different aspects of autonomic control. Alternately, restriction of range or simply the idea that these relationships may not be linear, and ceiling effects in either parameter, such as has been discussed by Dewland et al. (2007) and shown by Goldberger, Kim, Ahmed, and Kadish (1996), could lessen the magnitude of the correlation. Such explanations might be elucidated by selecting subjects across a wide spectrum of fitness levels, and/or in some way addressing the proposed ceiling in autonomic function when highly fit, active, or overtrained subjects are used (Dewland et al., 2007; Goldberger et al., 1996).

Finally, with regard to understanding the relationship between resting HRV and HRR from exercise, it is interesting to note the results of a study by Buchheit and Gindre (2006) in which 61 middle-aged, nonsmoking, nonobese males of varying fitness levels (based on VO_{2Max}) and certain training loads were studied. Subjects who reported high training volumes (Baecke Sport score of greater than 14) were excluded from participation in order to account for low HRV in especially high-trained individuals (Buchheit et al., 2006; Buchheit, Simon, Piquard, Ehrhart, & Brandenberger, 2004). Subjects were then separated into four groups for analysis: low fit/low training, low fit/moderate training, high fit/low training, high fit/moderate training. HRR was determined during a seated, passive recovery from maximal exercise (Buchheit & Gindre, 2006).

Buchheit and Gindre (2006) found that vagal-related indices of HRV were better related to cardiorespiratory fitness, while HRR measures were more strongly correlated with training load. While the relationship between HRV and HRR was not the primary focus of their study, Buchheit and Gindre (2006) found "small to moderate correlations" (Pearson r values ranging from .2 to .6) between resting HRV measures (unspecified from among SDNN, RMSSD, pNN50, LF, HF, and HFnu) and HRR measured as delta 60 (M. Buchheit, personal communication, October 22, 2013). These results support the idea that across a spectrum of activity and/or training levels a relationship exists between resting HRV and HRR from exercise.

Statement of Purpose

While a majority of researchers have failed to find a relationship between resting HRV and HRR from exercise (Bosquet et al., 2007; Dewland et al., 2007; Esco et al., 2010; Javorka et al., 2002; Lee & Mendoza, 2012; Zdrenghea et al., 2007), there is some evidence that such a relationship exists (Buchheit & Gindre, 2006; Evrengul et al., 2006; Jae et al., 2011). Differences among the methods, such as the subjects used, the exercise mode and intensity, the type of recovery from exercise, the HRV methods and measures, and the HRR methods and measures may explain the discrepant findings. Furthermore, because fitness level and training volume can influence both resting HRV and HRR from exercise, it may be prudent to control or at least report on these variables when assessing the relationship between HRV and HRR.

Most researchers investigating the relationship between HRR and resting HRV used the same HRR method: delta 60 (Bosquet et al., 2007; Esco et al., 2010; Javorka et al., 2002; Lee & Mendoza, 2012). No current research, however, exists regarding the relationship between resting HRV and T30. T30, the 30-second time constant of the beat-to-beat heart rate decay following an exercise bout done below the ventilatory threshold, reflects vagal nerve reactivation (Imai et al., 1994). As such, T30 may be better related to select resting HRV indices than delta 60. Therefore, the primary purpose of this study was to determine if there is a relationship between T30 HRR measures and resting HRV across subjects who vary with respect to fitness levels. It was hypothesized that there would be a significant negative correlation between predominately vagal-related resting HRV indices (SDNN, HF, and HFnu) and T30 HRR.

Exploratory analyses were done in order to provide information helpful in synthesizing previous research. Questions asked included, but were not limited to, the following: A) What are the separate relationships between fitness and activity to various HRV and HRR indices? B) Is there a non-linear relationship and/or ceiling in HRV or HRR at the highest levels of fitness and/or training? C) What are the relationships between the other HRV and HRR indices studied in this group of subjects that is heterogeneous with respect to fitness?

CHAPTER TWO

Materials and Methods

The following methods, with the exception of HRV measures, were adapted with permission from those described by Wilder (2012).

Experimental Approach to the Problem

A cross-sectional approach was used to investigate the relationship between resting HRV and HRR from exercise. Subjects from a spectrum of fitness levels were recruited following Institutional Review Board approval. For a schematic of the study design and overall procedures, please see Appendix D.

Oral and written informed consent were provided to each subject (Appendix E). Subjects were screened with a personal medical history (Appendix F) and demographic questionnaire prior to participation in this study (Appendix G). Additionally, all subjects were asked to complete the long form of the International Physical Activity Questionnaire (IPAQ) (IPAQ, Solna, Sweden), which has been validated for use in many populations, including those in the present study (Craig et al., 2003; Hagströmer, Oja, & Sjöström, 2007). Additionally, questions regarding the nature of resistance training were asked. Resistance training was reported on but not controlled for. Refer to Appendix H for the IPAQ, resistance training, and other activity questions. Three visits were required for each subject. Subjects were asked to be in a euhydrated state, refrain from alcohol and caffeine for 3 hours prior to testing, refrain from exercise for 24 hours prior to testing, and refrain from ingesting over the counter medications (i.e. pseudoephedrine) for 24 hours prior to testing. Subjects were also instructed to refrain from any marijuana exposure for 48 hours prior to testing. Complete pretest instructions for subjects are given in Appendix I. In order to assess reliability of HRV measurements, all subjects had resting HRV measurements taken at the beginning of the second and third visits. Each visit was a minimum of 48 hours but no more than 1 week apart. The temperature of the testing facility ranged from 18 to 23 degrees Celsius. Humidity ranged from 34 to 60 percent, and barometric pressure ranged from 738 to 766 mmHg.

Subjects

Prior to conducting the study, a power analysis was completed to estimate the number of subjects needed. This estimate was made using r^2 values from pilot testing on a small sample (n = 12), with an alpha level set at $p < .05$ and a power of .80 (Faul, Erdfelder, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007). The power analysis estimated that the number of subjects needed was 29. Males between the ages of 18 and 25 years were recruited from local health clubs, the college campus, and the surrounding community for this study via personal contact and recruitment flyers. For the subject recruitment flyer, see Appendix J. An attempt was made to recruit subjects from across a spectrum of fitness levels using the University of Houston Nonexercise VO_{2Max} prediction questionnaire as a preliminary screening tool (Appendix K). Each potential subject completed the questionnaire to determine whether he qualified for participation. An attempt was made to recruit approximately 42 subjects in light of heterogeneous values for reliability of HRV (Sandercock, Bromley, & Brodie, 2005), with an attempt to recruit seven subjects from each of six fitness categories as per ACSM (2014). If the predicted fitness of the subject fell into a category that had fewer than seven subjects, the subject was permitted to participate further.

Subjects were screened prior to participation for health status. Subjects were stratified for cardiovascular risk according to ACSM (2014), and were only allowed to participate if classified as low risk. Any subject who was hypertensive or currently taking antihypertensive medication was not allowed to participate in this study. Subjects with a history of abnormal EKG tracings were excluded. Subjects with musculoskeletal disorders were excluded from participation. Additionally, subjects who currently smoke tobacco cigarettes or have environmental exposure to tobacco smoke, or those who have quit smoking within the past six months, were excluded from participation in this study. Subjects with a BMI of 30 or above, or a waist circumference of 102 cm or above, were classified as obese and were excluded from participation in this study. Subjects were limited to those who spoke English. A total of 23 men met study inclusion criteria and participated in all phases of the research.

Procedures

Resting blood pressure. Resting blood pressure was taken using a mercury sphygmomanometer, using procedures from ACSM (2014). After the subject sat for 5 minutes, two blood pressure measurements were taken; subjects sat in a chair that supported the back, with feet uncrossed and flat on the ground. The measurements were made at least 2 minutes apart. The average of the two measurements was recorded as the resting blood pressure.

Anthropometrics and body composition. Weight was measured with a balance-beam scale (Health-o-Meter, Illinois), with subjects in minimal clothing and barefoot.

Height was obtained with subjects standing barefoot and with the back, heels, and buttocks against the wall. The Frankfort horizontal plane was held parallel to the floor, and measurements were taken following inhalation. The measuring device was laid over the tallest point of the participant's head.

Waist and hip circumference measurements were taken according to standardized procedures (ACSM, 2014) with a spring-loaded Gulick tape measure. During all circumference measures, subjects stood with arms at the sides, feet together, and abdomen relaxed. Waist circumference was measured at the narrowest part of the torso, between the umbilicus and the xiphoid process (ACSM, 2014). Hip circumference was measured at the maximal circumference of the buttocks (ACSM, 2014). Body composition, calculated using the Siri equation, was determined using underwater weighing (UWW) (EXERTECH, Bradford Products LLC, Willmington, NC). The lowest value after three trials was considered the body fat of the subject. Residual volume was estimated according to default settings of proprietary software, based on height, age, and sex of the subject.

Heart rate variability measurement. The following HRV measures were analyzed: SDNN, LF power, HF power, LF:HF power ratio, LFnu, and HFnu. All HRV measures were collected using a Biopac MP36 data acquisition unit and Biopac Student Lab Pro software (Goleta, CA), and were measured using EKG recordings. All HRV measurements were made in the early morning (i.e., 0600-1000 hours) in order to control for diurnal variations in HRV (Armstrong et al., 2011; Bosquet et al., 2007; Dewland et al., 2007; Esco et al., 2010; Evrengul et al., 2006). Reliability of HRV measures was assessed during pilot testing, with HRV being assessed on two different days.

In order to determine if body position during resting HRV measurements affected the relationship between HRV and HRR, pilot subjects completed HRV measurements in both the supine and seated positions, with the order of positional measurements being counterbalanced. It was determined during pilot testing that there were not significant differences in HRV due to body position. To remain consistent with the seated position of HRR measurements, and to enable comparison of results to prior research, it was determined that all HRV measurements would be collected in both the seated and supine positions.

To obtain the HRV measures, subjects were in a seated position with feet flat, back supported, and legs uncrossed, or supine with the legs uncrossed, while three EKG electrodes were placed on the chest in a modified lead II configuration (Esco, 2009; Lee & Mendoza, 2012). All external stimuli such as external noise were eliminated from the testing environment, and the lights were dimmed (Esco et al., 2010; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Subjects remained supine for 10 minutes, during which time subjects were instructed to remain still and breathe normally while a resting EKG was recorded. Subjects then sat in a chair for 10 minutes, during which time a resting EKG was recorded. Breathing rate was recorded using a respiration force transducer, placed at the level of the diaphragm and tightened upon exhalation. No attempt was made to control tidal volume (Bosquet et al., 2007; Esco et al., 2010; Evrengul et al., 2006; Jae et al., 2011; Zdrenghea et al., 2007). HRV data was recorded at a sampling frequency of

1000 Hz. Data from the last 5 minutes of each recording was analyzed. EKG segments were visually inspected, and any recordings that included ectopic beats (i.e., premature atrial contractions and premature ventricular contractions) were excluded from analysis.

The EKG data were converted to a tachogram, with interval length plotted as a function of interval number. From this tachogram, SDNN was calculated as the standard deviation of all normal R-R intervals. Spectral analysis was performed to determine frequency domain measures, with LF power between 0.04 Hz and 0.15 Hz, and HF power between 0.15 Hz and 0.40 Hz (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). All HRV data was analyzed using Biopac Acq*Knowledge*® 4.3 software (BIOPAC Systems Inc., Goleta, CA, USA).

VO_{2Max} test and maximal heart rate protocol. Maximal oxygen uptake and HR values were determined in an incremental cycle ergometer test to volitional exhaustion (2-min initial workload at 50 W, with a 30-W increase every 2 minutes) (Otsuki et al., 2007) on an Excalibur Sport (Lode B.V., Groningen, Netherland) cycle ergometer. Subjects were instructed to maintain a pedaling cadence of 50-70 revolutions per minute. In some instances, early stages in the protocol were adjusted by an experienced technician to insure completion of maximal protocol in the recommended 8 to 12 minute period for all subjects (Buchfuhrer et al., 1983). Maximal HR was established as the highest HR achieved during the test. Gas exchange data was analyzed by a metabolic measurement system (TrueOne 2400, ParvoMedics, Sandy, UT), and VO_{2Max} was determined as highest oxygen uptake.

T30 test protocol. The time constant of the HR decay for the first 30 seconds after exercise (T30), which is an index of vagally-mediated HRR immediately after exercise, was calculated as described by previous researchers (Iellamo et al., 2002; Imai et al., 1994; Otsuki et al., 2007; Sugawara et al., 2001). The subjects began with a brief warm-up pedaling at a cadence around 50 rpm with minimal resistance. Subjects then performed 8 minutes of steady-state exercise at an intensity equal to 40% of their VO_{2max} ascertained from the maximal test, to insure that participants were working below ventilatory threshold (Imai et al., 1994; Kannankeril, Le, Kadish, & Goldberger, 2004). At the end of the 8 minutes, the subjects were instructed to remain still, with arms resting at their sides, and not to talk through the first 30 seconds after exercise.

T30 measures were taken in a room with no music or other extraneous noise in order to avoid psychogenic factors that may influence heart rate at rates less than 110 bpm. Beat-by-beat HR data was collected using a Polar RS800CX® HR monitor (Polar Electro Inc., Lake Success, NY, USA). The Polar RS800CX® HR monitor was programmed to collect HR in R-R interval mode. A linear regression analysis was performed on the natural logarithm of the beat-to-beat HR data for the first 30 seconds after exercise. The negative reciprocal of the slope of the regression line was then defined as T30 (Iellamo et al., 2002; Imai et al., 1994; Otsuki et al., 2007; Sugawara et al., 2001). Because T30 is related to parasympathetic activity, and parasympathetic activity is highest in the morning, measurements of HRV and HRR were done at the same time of the day, in mornings for each trial.

Delta 60 protocol. After the collection of T30 HRR, the subjects rested until HR returned to baseline measures (i.e., within 20 bpm of resting), with no less than 5 minutes of rest being taken. Subjects then began cycling again for the delta 60 HRR test. Subjects completed a submaximal bout of exercise that was terminated at 85% of the participants' maximal HR (Evrengul et al., 2006) in order to ensure safety of the subject during a passive recovery. The incremental testing protocol for the measurement of the delta 60 was the same protocol used for the VO_{2max} test for each subject. Once the subject reached 85% of the maximal HR (determined from the initial maximal test), the test was terminated, and the subject was asked to sit passively, quietly, and with the arms resting at the sides for one minute during the collection of HRR. To determine delta 60, the average of the test termination HR and the two heart rates before and two heart rates after the termination was computed. Then the average of the HR after 60 seconds of recovery and the two heart rates before and two heart rates after was computed. Delta 60 HRR measures were calculated by taking the difference between these two averages.

Statistical Analysis

All analyses were performed using SPSS version 21 (SPSS, Chicago, IL, USA). Test-retest reliability of resting HRV indices was determined during pilot testing and reported as intraclass correlation coefficients (ICC), using a two factor mixed effects model and type consistency (McGraw & Wong, 1996; Shrout & Fleiss, 1979). Reliability of outcome measures was also determined using the coefficient of variation (CV) (see Figure 1 for the formula used to calculate the CV) (Shechtman, 2013).

$$SD_i = \sqrt{(x_1 - x_2)^2/2}$$

$$\bar{x}_i = (x_1 + x_2)/2$$

$$CV_i = \frac{SD_i}{\bar{x}_i}$$

$$CV(\%) = 100 \times \frac{\sum CV_i}{n}$$

Figure 1. Formula used to calculate the CV

The HRV data for both HRV visits was averaged for each subject before further analysis. Normality of the distribution of the data was verified using the Kolmogorov-Smirnov test. When normality was violated, a logarithmic transformation was applied before analysis. Means and standard deviations were computed for the descriptive statistics of all subject characteristics. Means and standard errors of the transformed data were computed for each index of HRV and HRR. Zero-order Pearson product correlations were calculated to answer the primary research question as to whether HRV measures are related to HRR measures. Similarly, the Pearson *r* was used to determine the relationship between fitness and both HRV and HRR measures. Further exploratory correlations were made. Multiple regression procedures were used to determine the relationship between HRV and HRR measures accounting for other variables such as fitness, volume of PA, and body composition that may influence said relationships. A simpler, nonparametric statistic (Spearman's rho) was applied upon the recommendations of a committee member to examine the relationship between HRV and HRR variables. The criterion for significance was set at $p < .05$.

Limitations

The following limitations may have affected the outcomes of this study:

1. Pretest instructions were given, and subjects reported on adherence to said conditions on testing days, but subject honesty in reporting on adherence was unknown, potentially affecting resting HRV and HRR from exercise.
2. Validity and reliability of the Polar RS800CX HR Monitor and ProTrainer Software for HRR measurement has not yet been established.
3. Psychological stress was not measured or controlled for (Bernardi et al., 2000).
4. Race and ethnicity was recorded but not controlled for (Choi et al., 2006).
5. It is impossible to isolate PNS or SNS activity with any measure.
6. Local muscle fatigue during the maximal test on the cycle ergometer may lead to attainment of VO_{2Peak} rather than VO_{2Max}.
7. Volume of resistance training was reported on but not controlled for.
8. Respiration rate was recorded, but not controlled.

Delimitations

The following delimitations are noted as they may have affected the outcomes of this study:

1. Subjects were limited to males aged 18-25 years.
2. Only 23 subjects were included in the final analysis of results.
3. HRV was only analyzed using SDNN and frequency domain measures.
4. HRR was only measured using T30 and delta 60.
5. Exercise testing was only conducted on a cycle ergometer.

CHAPTER THREE

Results

Descriptive statistics for the 23 subjects who completed the study are presented in Table 1. Subjects ranged in age from 18 to 24 years, with body fat of the subjects ranging from 7.0 to 27.4% body fat. VO_{2Max} of the subjects ranged from 31.5 to 57.2 ml/kg/min, while physical activity ranged from 200 to 24054 METmin/week.

Table 1

Subject Descriptive Characteristics (*N* = 23)

Variable	Mean $\pm$ *SD*
Age (years)	21.74 $\pm$ 1.66
Mass (kg)	81.19 $\pm$ 15.28
Height (cm)	163.40 $\pm$ 7.22
BMI (kg/m^2)	25.25 $\pm$ 3.61
Waist Circumference (cm)	82.19 $\pm$ 1.81
Body Fat (% fat)	14.72 $\pm$ 6.40
Resting Systolic Blood Pressure (mmHg)	111.22 $\pm$ 9.82
Resting Diastolic Blood Pressure (mmHg)	66.48 $\pm$ 10.48
Resting Heart Rate (bpm)	63.04 $\pm$ 9.33
Maximal Heart Rate (bpm)	185.78 $\pm$ 7.81
VO_{2Max} (ml/kg/min)	42.85 $\pm$ 7.14
Physical Activity (METmin/week)	5320.45 $\pm$ 6150.50

Means and standard errors for raw outcome variables are presented in Appendix L. The range of values for HRV and HRR variables were consistent with the values reported by previous researchers (Dewland et al., 2007; Esco et al., 2010; Lee & Mendoza, 2012; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). A logarithm transformation was applied to all outcome variables that violated normality (i.e., T30 and all HRV variables except for HFnu and LFnu for both positions). ICCs and CVs were then computed using transformed data to assess reliability of HRV measurements taken on two separate days. A moderate to high degree of reliability (ICCs ranging from .69 to .95, and CVs ranging from -264.35% to 56.59%) was found between HRV measurements. The transformed data from both visits was averaged for each HRV variable for all subsequent analyses. Means and standard errors for HRV and HRR measurements are presented in Table 2.

Table 2

Heart Rate Variability and Heart Rate Recovery Data (*N* = 23)

Variable[a]	Mean ± *SE*
LogHF Supine (ms^2/Hz)	-.42 ± .13
LogHF Seated (ms^2/Hz)	-.64 ± .12
LogLF Supine (ms^2/Hz)	-.42 ± .11
LogLF Seated (ms^2/Hz)	-.37 ± .076
LogLF:HF Ratio Supine	.0017 ± .070
LogLF:HF Ratio Seated	.27 ± .071
HFnu Supine (ms^2/Hz)	.50 ± .035
HFnu Seated (ms^2/Hz)	.37 ± .034
LFnu Supine (ms^2/Hz)	.50 ± .035
LFnu Seated (ms^2/Hz)	.63 ± .034
LogSDNN Supine (ms)	2.06 ± .058
LogSDNN Seated (ms)	2.05 ± .050
LogT30 HRR	2.05 ± .036
delta 60 HRR	46.62 ± 2.72

Note: [a]transformed using logarithm

Pearson product correlations were computed to examine the relationship between resting HRV variables and HRR. A correlation matrix depicting correlations between all HRV and HRR variables is presented in Appendix M. Correlations between select HRV variables (mean transformed data for each body position) and HRR variables are presented in Table 3. Contrary to the hypothesis that vagal indices of HRV would be significantly correlated with T30, no significant correlations were found between LogSDNN, LogHF, or HFnu and LogT30. That said, there was a significant, negative correlation between LogT30 and LogLF in the supine position ($r = -.45$, $p = .032$) (Figure 2). Finally, as expected, there was a significant, negative correlation between LogT30 and delta 60 ($r = -.68$, $p < .001$).

Table 3

Pearson Product Correlation Values of HRR and Resting HRV Data ($N = 23$)

	LogT30	delta 60
LogHF Supine (ms^2/Hz)	-.40	.24
LogHF Seated (ms^2/Hz)	-.30	.13
LogLF Supine (ms^2/Hz)	-.45*	.32
LogLF Seated (ms^2/Hz)	-.32	.37
LogLF:HF Ratio Supine	.024	.075
LogLF:HF Ratio Seated	.12	.19
HFnu Supine (ms^2/Hz)	-.030	-.064
HFnu Seated (ms^2/Hz)	-.11	-.18
LFnu Supine (ms^2/Hz)	.030	.064
LFnu Seated (ms^2/Hz)	.11	.18
LogSDNN Supine (ms)	-.40	.21
LogSDNN Seated (ms)	-.32	.27

Note: *p < .05, two-tailed

Pearson product correlations were used to examine the relationships between fitness and HRV indices, as well as between fitness and T30 HRR (Figure 3); no significant correlations were found. Scatterplots depicting the relationships are shown in Appendix N. It is clear that there was no discernible relationship between the primary research variable, T30 HRR, and any of the variables other than delta 60 HRR.

Pearson product correlations were also used to examine the relationship between HRV or HRR and subject descriptive variables. A significant, negative correlation was found between resting HR and LogSDNN in the supine position (r = -.45, p = .030). A significant, negative correlation was found between resting HR and LogSDNN in the seated position (r = -.47, p = .023). A significant, negative correlation was found between resting HR and LogHF in the seated position (r = -.49, p = .019). No significant correlations were found between HRV or HRR and physical activity as measured by the IPAQ. Additionally, no significant correlations were found between HRV or HRR and BMI, waist circumference, or body fat percentage.

Multiple linear regression was used to determine whether percent body fat, VO_{2Max}, and PA level predicted either LogT30 or HFnu supine. None of the aforementioned variables significantly predicted LogT30 or HFnu supine. Interestingly, no collinearity issues were found between VO_{2Max} and PA. A simpler, nonparametric statistic (Spearman's rho) was used upon the recommendation of a committee member to account for the non-normal distribution of the data. The results of this analysis will be further explored upon the submission of the paper.

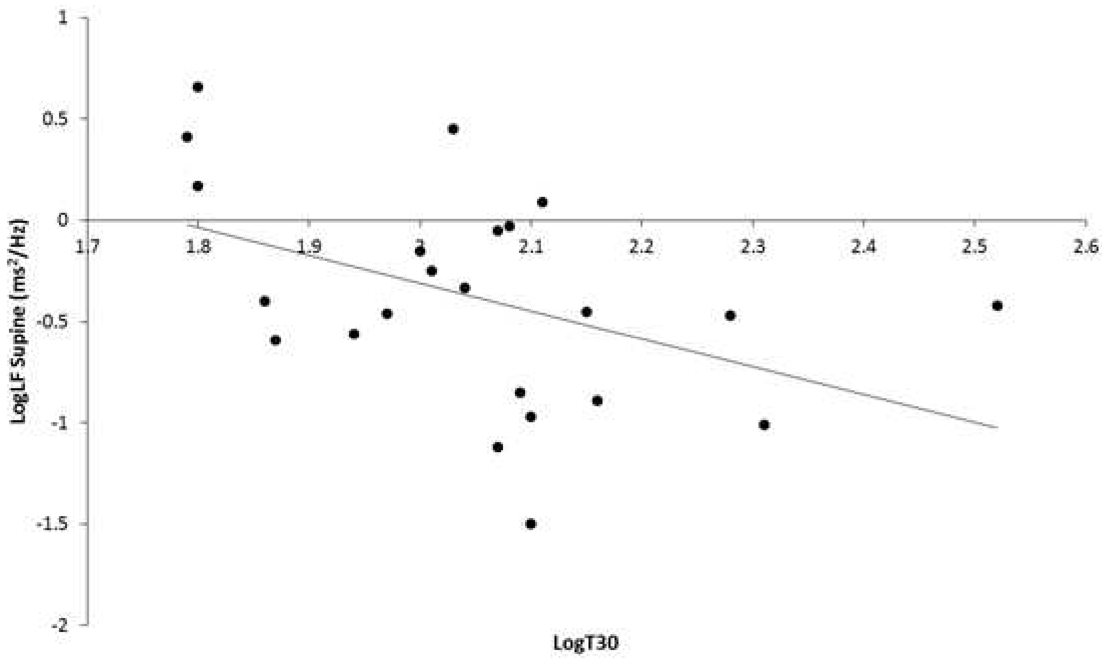

Figure 2. Relationship between LogT30 HRR and LogLF Supine HRV.

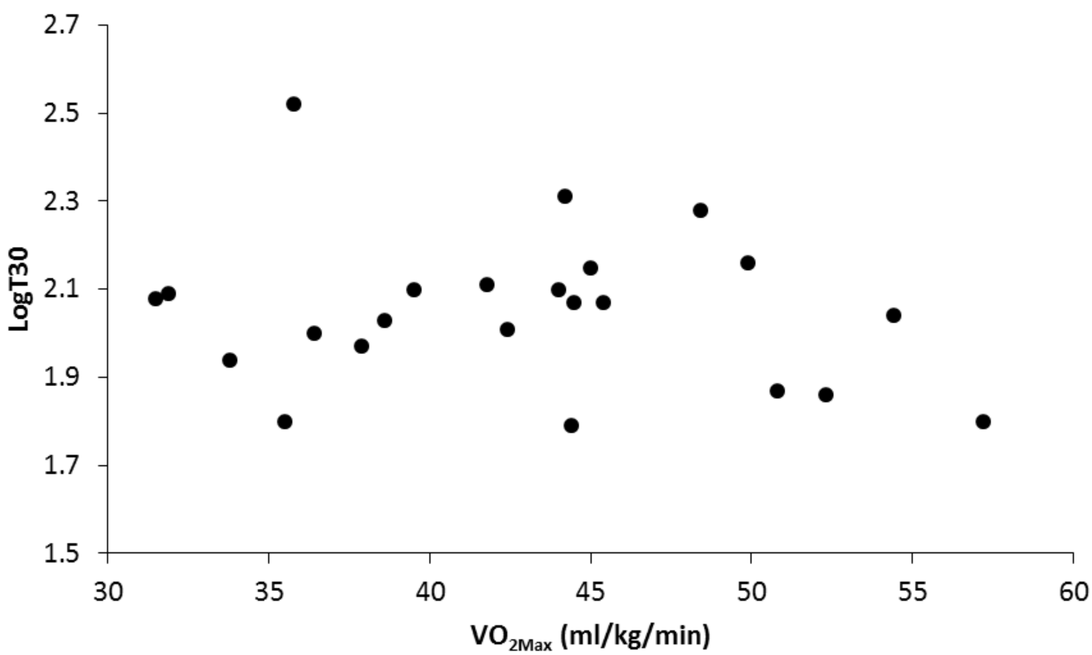

Figure 3. Relationship between fitness and LogT30 HRR.

CHAPTER FOUR

Discussion

The main finding of this study was that there were no significant relationships between the vagal indices of resting HRV and T30 HRR, which is consistent with the findings of several other researchers (Bosquet et al., 2007; Buchheit & Gindre, 2006; Dewland et al., 2007; Esco et al., 2010; Javorka et al., 2002; Lee & Mendoza, 2012; Zdrenghea et al., 2007). The only significant relationship between any of the HRV variables and T30 was a significant, negative correlation between LogT30 HRR and LogLF supine HRV.

The findings of no relationship between resting HRV and HRR from exercise in the current study is similar to the findings of most previous researchers, many of whom used different methodologies (Bosquet et al., 2007; Dewland et al., 2007; Esco et al., 2010; Javorka et al., 2002; Lee & Mendoza, 2012; Zdrenghea et al., 2007). The researchers who have examined the relationship between resting HRV and HRR from exercise have used different methods. A primary difference in the methods of past research and the current study lies in the measures of HRR used. To the knowledge of the researcher, the current study is the first to examine the relationship between resting HRV and the predominantly vagal T30 HRR variable. Because T30 primarily represents vagal reactivation following the cessation of exercise, it was hypothesized that it would be related to vagal indices of resting HRV. However, the results of the present study suggest that resting HRV and HRR from exercise may not capture the same aspects of autonomic control (Bosquet et al., 2007; Buchheit & Gindre, 2006; Buchheit et al., 2007;

Dewland et al., 2007; Esco et al., 2010; Jae et al., 2011; Javorka et al., 2002). Dewland et al. (2007) examined the effects of pyridostigmine, an acetylcholinesterase inhibitor that selectively augments the parasympathetic efferent signal, on resting and postexercise autonomic function in sedentary and trained men and women. It was found that pyridostigmine did not alter parasympathetic indices of resting HRV in either sedentary or trained subjects, while the drug did alter HRR (Dewland et al., 2007). This suggests that, as stated by Malik and Camm (1993), while resting HRV is an index of phasic changes in vagal efferent activity, HRR is a measure of mean cholinergic signaling in the sinoatrial nodal junction. Resting HRV may be an index of the rapid changes in activity of the vagal nerve, while HRR may be an index of the mean amount of acetylcholine at the SA node junction (which is a function of mean acetylcholine release at the junction and breakdown of acetylcholine through the actions of acetylcholinesterase). The difference between the aspects of autonomic control that HRV and HRR capture seems to be subtle, and more in depth research is required to distinguish between the physiologic determinants of HRV and HRR.

The lack of significant relationships in this study may be partially attributed to methodological issues. In this study, no attempt was made to control respiration rate, while some other researchers controlled respiration rate. Subjects were instructed to maintain comfortable, normal breathing patterns. However, when respiration rate approaches 6 breaths per minute, increases in respiration-related HRV result (Ravenswaaij-Arts et al., 1993); this increase in respiratory sinus arrhythmia occurs when respiratory frequency approaches the frequency of baroreflex-related heart rate fluctuations. The lack of significant relationships in this study may have been because the primary HRR variable, T30, is primarily vagal, and vagal activity during collection of the HRV data was not maximized.

In the current study, the resting HRV data and HRR from exercise were measured under very well controlled conditions. Subjects were asked to adhere to a specific set of pretest instructions, including avoidance of exercise, alcohol, caffeine, and marijuana exposure for specific amounts of time before testing. However, subject honesty in reporting on adherence to pretest instructions is unknown. Failure to adhere to the pretest instructions may have altered the resting HRV variables by altering the PNS and SNS balance (e.g., exposure to SNS stimulants, such as caffeine and drugs containing pseudoephedrine may have increased SNS activity during HRV and HRR measurement). Subjects reported to the testing facility in the early morning, when parasympathetic activity is highest (Armstrong et al., 2011). The environmental conditions in the testing room were controlled as well, with SNS stimulating factors such as light and extraneous noise being limited.

The quality of the VO_{2Max} tests may be another contributor to the lack of findings in this study. To be considered a true VO_{2max} rather than a VO_{2Peak}, at least two of three criteria for VO_{2max} of: 1) a respiratory exchange ratio (RER) >1.1, or 2) no change in HR with a change in workload, or 3) a plateau in O_2 (< 150 mL) uptake with an increase in workload, must be met. Most subjects met the criteria for RER, while the criteria for HR and oxygen consumption plateaus were not met for most subjects. Exercise testing was conducted on a cycle ergometer, thus leg fatigue may have led to the attainment of a

VO_{2Peak} rather than a true VO_{2Max}. This is not likely to affect T30 values, as T30 is nearly independent of exercise intensity (Imai et al., 1994), but because subjects may not have been working at 40% of their VO_{2Max}, the intensity of the exercise for the T30 test may not have been consistent among subjects. Because subjects may not have reached true maximal aerobic capacity, HR_{Max} may not have been correct. The intensity for the delta 60 test was determined as 85% of the HR_{Max}, but the HR_{Max} of the subjects tended to be more than 10-12 bpm lower than the age-predicted HR_{Max}. Because the intensity of exercise after which delta 60 was measured may have been inappropriate, and because the intensity of exercise affects autonomic regulation during recovery (Robinson et al., 1966; Seiler et al., 2007), results may have been confounded.

Multiple linear regression was conducted to examine predictors of HRV and HRR. None of the variables included in the models (body fat percent, VO_{2Max}, and PA) significantly predicted either LogT30 or HFnu Supine. Additionally, no issues of multicollinearity were discovered during analysis. This is interesting to note, as one may presume to find issues of collinearity when using VO_{2Max} and PA as two of the predictor variables in the model because increased PA typically results in increased fitness as measured by VO_{2Max}. The lack of evidence of collinearity issues between VO_{2Max} and PA indicates potential methodological issues within the VO_{2Max} tests, as well as potential issues of reporting accuracy on the PA questionnaire. Many subjects became confused when answering the questions on the IPAQ, providing answers to questions that were impossible (e.g., indicating that the subject engaged in PA 8 days per week). Such confusion may have led to inaccurate estimations of the PA of subjects. Methods of PA assessment that are more accurate (e.g., heart rate monitors or accelerometers) should be used if attempting to understand how PA predicts HRV or HRR within a multiple regression model.

There are multiple other possible limitations to this study. Restriction of range may be an issue. Restriction of the range of subjects reduces the correlation that exists in an unrestricted population (Guilford & Fruchter, 1978). While an effort was made to recruit subjects from across a spectrum of fitness levels, most subjects were in the moderate to low fitness categories, with few being in the higher fitness categories. Due to the restriction of range, the correlations found in this study may be lower than those that exist for the population. Additionally, as some (Dewland et al., 2007; Goldberger et al., 1996) have suggested, perhaps there is a ceiling in the relationship between resting HRV and HRR from exercise (i.e., the relationship is not linear at higher fitness and/or activity levels), the physiologic cause of which is unknown. When assessing a nonlinear relationship with a linear function such as a correlation, results may be inaccurate. Reliability of measures may also result in a lack of findings. While reliability of short-term recordings of HRV has been established in previous studies (Melanson, 2000; Sandercock et al., 2005) and demonstrated in the current study, reliability of T30 has not yet been established. Additionally, the sample size in the current study was small, so reliability is difficult to assess.

Further studies should be conducted to examine whether there may be a ceiling in either HRV or HRR due to fitness, as well as the potential physiologic determinants of the proposed ceiling. Further researchers should also investigate the relationship between

HRV and T30 HRR in other subject groups such as women and children. Further research needs to be conducted to determine the reliability of T30, as unstable measurements of HRR may lead to inaccurate results.

In conclusion, no significant relationships between vagal indices of HRV and T30 HRR were found, indicating that the two variables may measure of separate aspects of autonomic control. There was, however, a significant, negative relationship between LogLF supine HRV and LogT30 HRR.

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APPENDIX A: DEFINITIONS

Definitions

1. T30: calculated after a submaximal bout of exercise as the negative reciprocal of the slope of the natural logarithm of heart rate recovery taken for the first 30 seconds of recovery as per methodology described by Imai et al. (1994).
2. delta 60: calculated as the heart rate at cessation of exercise minus the heart rate at one minute of recovery
3. R-R interval: distance in milliseconds between R waves on an electrocardiogram recording
4. SDNN: measurement of heart rate variability, computed by calculating the standard deviation of R-R intervals
5. Hypertension: a blood pressure at or above 140 mm Hg systolic and/or 90 mm Hg diastolic, or currently taking antihypertensive medication (ACSM, 2014)
6. Physical activity: any bodily movement that is produced by skeletal muscles, resulting in energy expenditure (Caspersen, Powell, & Christenson, 1985); a behavior
    a. Training volume: also known as training load; amount of training one engages in at a specific moment in time, based on frequency, intensity, and duration of physical activity (ACSM, 2014); when training volume is excessive and adequate recovery is not provided, overtraining may result (Kuipers & Keizer, 1988); changes in training volume may be

measured; behavior

7. Trained: subject has participated in moderate physical activity for 30 or more minutes on 3 or more days of the week for at least 3 months
8. Untrained: sedentary, meaning that the subject has not participated in moderate physical activity for 30 or more minutes on 3 or more days of the week for at least 3 months (ACSM, 2014)
9. Fitness: set of attributes that individuals possess or achieve at a specific moment in time, which are related to the ability to perform physical activity (Caspersen et al., 1985; U.S. Department of Health and Human Services, 1996); can be present in varying degrees (i.e., low fitness, moderate fitness, high fitness) (Caspersen et al., 1985)

APPENDIX B: HRV AND HRR MEASURES

Measure	Procedure	What Results Mean	Physiology	Validation	Application	References
Delta 60 (1-Minute HRR)	• Submax/max exercise • Passive/active recovery • (HR@end of ex)-(HR@ 1 minute recovery)	• High Delta 60=good	• Parasympathetic reactivation	• Validated in blocking studies for prognostic use • Validated for fitness assessment • Validated by Vivekananthan et al., 2003 as an independent predictor of mortality	• Training Volume • Training Status • Fitness • CV Health	• Esco et al., 2010 • Evrengul et al., 2006 • Jae et al., 2011 • Lee & Mendoza, 2012 • Shetler et al., 2001 • Cole et al., 1999 • Vivekananthan et al., 2003
2-Minute HRR	• Submax/max exercise • Passive/active recovery • (HR@end of ex)-(HR@ 2 minutes recovery)	• High 2-minute HRR=good	• Sympathetic withdrawal and parasympathetic reactivation	• Validated by Cole et al., 2000 as an independent predictor of mortality (even after submax exercise) in healthy adults…subjects followed for 12 years and mortality was determined	• CV Health/Mortality	• Cole et al., 2000 • Esco et al., 2010 • Evrengul et al., 2006 • Jae et al., 2011 • Shetler et al., 2001
T30	• Submax exercise (below VT) • linear regression on the natural logarithm of heart rate data for the first 30 seconds following the cessation of exercise	• Smaller/faster T30=good	• Vagal (parasympathetic) reactivation • NEARLY independent of exercise intensity	• Validated in blocking studies for prognostic use • Validated for fitness assessment	• Training Volume • Training Status • Fitness • CV Health/Mortality	• Imai et al., 1994 • Otsuki et al., 2007 • Pierpont et al., 2000
T_{120}	• Submax exercise (below VT) • linear regression on the natural logarithm of heart rate data for the first 120 seconds following the cessation of exercise	• Smaller/faster T120=good	• Vagal (parasympathetic) reactivation • Affected by work load/sympathetic activity	• Validated in blocking studies	• CV Health • Fitness	• Imai et al., 1994 • Pierpont et al., 2000
HRV_{rest}-LF	• Supine for 10-20 minutes • Three-lead EKG	• Low LF=good	• Parasympathetic and sympathetic modulation	• Validated by La Rovere et al., 2003 as a predictor of sudden	• CV Health/Mortality	• Esco et al., 2010 • Jae et al., 2011 • Lee & Mendoza,

	• Low-frequency component • 0.04-0.15 Hz		• Low values represent less sympathetic dominance, increased vagal influence	death in patients with CHF • Validated by Lombardi et al., 1987 as an index of sympathovagal interaction after acute MI		2012 • Armstrong et al., 2011 • Bernardi et al., 2000 • La Rovere et al., 2003 • Lombardi et al., 1987 • Galinier et al., 2000
HRV_{rest}-HF	• Supine for 10-20 minutes • Three-lead EKG • High frequency component • 0.15-0.4 Hz	• High HF=good	• Parasympathetic/vagal modulation is more "sensitive" • High values represent less sympathetic dominance, increased vagal influence	• Validated by Lombardi et al., 1987 as an index of sympathovagal interaction after acute MI	• CV Health/Mortality	• Esco et al., 2010 • Jae et al., 2011 • Lee & Mendoza, 2012 • Armstrong et al., 2011 • Bernardi et al., 2000 • Lombardi et al., 1987 • Galinier et al., 2000
HRV_{rest}-LF:HF	• Supine for 10-20 minutes • Three-lead EKG • Ratio of low to high frequency	• Low LF:HF=good (indicates high HRV)	• Sympathetic-parasympathetic balance • Low values represent less sympathetic dominance, increased vagal influence	• Validated by Lombardi et al., 1987 as an index of sympathovagal interaction after acute MI	• CV Health/Mortality	• Esco et al., 2010 • Jae et al., 2011 • Armstrong et al., 2011 • Galinier et al., 2000
HRV_{rest}-LFnu	• Supine for 10-20 minutes • Three-lead EKG • LF/(HF+LF)	• Low LFnu=good	• Sympathetic-parasympathetic balance • Low values represent less sympathetic dominance, increased vagal influence	• Validated by Lombardi et al., 1987 as an index of sympathovagal interaction after acute MI	• CV Health/mortality	• Buchceit & Gindre, 2006 • Esco et al., 2010 • Jae et al., 2011 • Lee & Mendoza, 2012 • Pagani et al., 1986

HRV_{rest}-HFnu	• Supine for 10-20 minutes • Three-lead EKG • HF/(HF+LF)	• High HFnu=good	• Sympathetic-parasympathetic balance • High values represent less sympathetic dominance, increased vagal influence	• Validated by Lombardi et al., 1987 as an index of sympathovagal interaction after acute MI	• CV Health/mortality	• Buchceit & Gindre, 2006 • Esco et al., 2010 • Jae et al., 2011 • Lee & Mendoza, 2012 • Pagani et al., 1986
HRV_{rest}-SDNN	• Supine for 10-20 minutes • Three-lead EKG • Standard deviation of R-R interval length	• High SDNN=good	• High values represent increased vagal influence	• Dekker et al., 2000 demonstrated that low SDNN is correlated with increased cardiac risk/poor general health • Galinier et al., 2000 demonstrated that low SDNN is correlated with increased risk of sudden death	• CV Health/mortality	• Esco et al., 2010 • Evrengul et al., 2006 • Armstrong et al., 2011 • Dekker et al., 2000 • Galinier et al., 2000 • Nolan et al., 1998
HRV_{rest}-pNN50	• Supine for 10-20 minutes • Three-lead EKG • (Number of interval differences of successive R-R intervals greater than 50ms)/(total number R-R intervals)	• High pNN50=good	• High values represent increased vagal influence	• Shown by Nolan et al., 1998 to be lower in patients with CHF	• CV Health/mortality	• Kleiger et al., 2005 • Esco, 2009 • Galinier et al., 2000 • Nolan et al., 1998 • Task Force, 1996
HRV_{rest}-Poincaré Plots	• Supine for 10-20 minutes • Three-lead EKG • Scattergram where each R-R interval is plotted as a function of the previous R-R interval	• Larger elipse=good (high HRV)	• Width is reflective of parasympathetic activity (wide=more parasympathetic control)	• Validated by Kamen et al., 1996 in a study where drug were administered to healthy subjects • Validated as a measure of PNS activity • Correlated to time domain measures by Carrasco et al., 2001	• Training volume/load • CV Health • Fitness • Training Status	• Tulppo et al., 1996 • Mourot et al., 2004 • Esco, 2009 • Kamen et al., 1996 • Carrasco et al., 2001

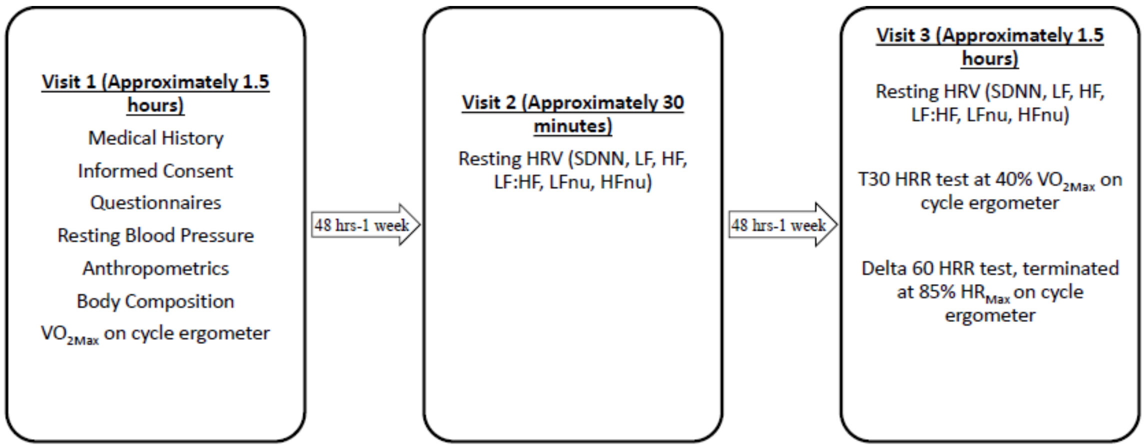
APPENDIX C: STUDY GRID

Title	Info	Subjects	HRV Method	HRV Software	Protocol/ Mode	Recovery	HRR Measure	Results
Is aerobic endurance a determinant of cardiac autonomic regulation?	Bosquet et al., 2007. European Journal of Applied Physiology	• 26 males and females, high (HEG) and low (LEG) endurance groups after exercise test • HEG: • Age 30.4±9.0 years • VO_{2Max}=58.2±7.2ml/kg/min • BMI=21.14 kg/m² • LEG: • Age 32.6±10.4 years • VO_{2Max}=59.8±7.6ml/kg/min • BMI=23.51 kg/m² • Recruited from running clubs	• Resting • Within 2 hours of waking (6:00-10:00am) • Supine position • Breathing rate controlled at 12 breaths per min • Breathing depth not controlled • 20 minute recording, with 256 second section (taken within last 300 sec) for analysis • Time and frequency domain measures • Fast Fourier transformation • Mean NN interval, SDNN, RMSSD, pNN50, LF, HF, LF:HF, total power	• Polar S810 Heart Rate Monitor • HRV Analysis Software v1.1 (Biosignal Laboratory)	• MAX, initial velocity 10km/h, 0.5km/h increase every minute, 0% grade throughout • Treadmill	• Passive • Standing 5 minutes, seated 4 minutes	• HRR1: HR_{Max}-HR1min	• Resting HRV not significantly correlated with HRR, correlations not reported
Effect of acetylcholinesterase inhibition with pyridostigmine on cardiac parasympathetic function in sedentary adults and trained athletes	Dewland et al., 2007. American Journal of Physiology-Heart and Circulatory Physiology	• 10 sedentary adults, age 35±7 years, BMI=24.46kg/m² • 10 trained athletes, age 27±8 years, BMI=22.92kg/m²	• Resting • Morning or afternoon, but same time of day on both study days for each subject • Breathing patterns not reported • Supine position • 30 minute recording time, with middle 20 minute section analyzed • Time and frequency domain measures • Fast Fourier transformation • LF, HF, LF:HF, total power, SDNN, pNN50, rMSSD	• Holter recording system • GE-Marquette system for analysis • Sampling frequency not reported	• Bruce MAX • Treadmill • Peak VO_2 used as plateau in oxygen uptake not evident in all subjects	• Passive • Seated	• HRR30sec: HR_{Max}-HR30sec • HRR1: HR_{Max}-HR1min	• Resting HRV not significantly correlated with HRR, correlations not reported

The relationship between resting heart rate variability and heart rate recovery	Esco et al., 2010. Clinical Autonomic Research	• 66 apparently healthy college-aged men, age 22.74±3.64 years • VO_{2Max} = 46.39±8.23 ml/kg/min • Body fat = 9.64±4.73 % • BMI=24.97 ± 3.20 kg/m²	• Resting • Either 7:00-9:00am or 9:00-11:00am • Breathing depth and rate not controlled • Supine position • Modified II lead, 3 electrode EKG for 5 minutes in supine position • Time and frequency domain measures • SDNN, HF, LF, HFnu, LFnu, VLF, VLFnu, LF:HF	• Biopac MP100 Data Acquisition system • 1000 Hz sampling frequency	• Bruce MAX • Treadmill	• Active • Absolute intensity (2.5mph, 1.5%grade)	• HRR1: MHR-HR1min (aka delta 60) • HRR2: MHR-HR2min	• Resting HRV <u>not significantly correlated</u> with HRR, $p > .05$ for all correlations below: ○ HRR1 & SDNN: $r = -.05$ ○ HRR1 & HFnu: $r = -.17$ ○ HRR1 & LFnu:HFnu: $r = -.17$ ○ HRR2 & SDNN: $r = -.10$ ○ HRR2 & HFnu: $r = -.02$ ○ HRR2 & LFnu:HFnu: $r = -.09$
The relationship between heart rate recovery and heart rate variability in coronary artery disease	Evrengul et al., 2006. Annals of Noninvasive Electrophysiology	• 28 male CAD patients with stable angina pectoris, age 52.4±9.6 years • 21 healthy males with atypical angina pectoris, age 48.3±7.8 years	• Resting • 9:30am-12:30pm • Breathing depth and rate not controlled • Recumbent position • 1 hour recording time, with 1 hour and 5 minute sections analyzed • Time and frequency domain measures • SDNN, SDANN, RMSSD, pNN50, LF, HF, LF:HF	• Holter recording system • Biomedical Systems Century 2000/3000 for analysis • Sampling frequency not reported	• Bruce SUBMAX, terminated at 85% age-predicted max HR • Treadmill	• Passive • Supine	• 12-lead EKG • HRR1: PeakHR-HR1min • HRR2: PeakHR-HR2min • HRR3: PeakHR-HR3min	• Resting HRV <u>strongly correlated</u> with HRR ○ HRR3 & SDNN: $r = .41$, $p = .0001$ ○ HRR3 & SDANN: $r = .15$, $p > .05$ ○ HRR3 & RMSSD: $r = .31$, $p = .008$ ○ HRR3 & pNN50: $r = .44$, $p = .0001$ ○ HRR3 & LF: $r = -.67$, $p = .0001$ ○ HRR3 & HF: $r = .69$, $p = .0001$ ○ HRR3 & LF:HF: $r = -.62$, $p = .0001$
Relation of heart rate recovery to heart rate variability in persons with paraplegia	Jae et al., 2011. Clinical Autnonomic Research	• 9 male and 8 female wheelchair athletes, age 23.4±3.3 years • VO_{2Peak} = 28.5±6 ml/kg/min • BMI = 22.9±4.4 kg/m²	• Resting • Time of day not reported • Breathing rate controlled at 12 breaths per min • Breathing depth not controlled • Seated position • Modified CM5 EKG • Breathing frequency controlled @ 12 breaths/min • Frequency Domains • TP, HF, LF, LF:HF, LFnu, HFnu	• Biopac • Sampling frequency 1000 Hz	• Discontinuous MAX • Arm ergometer	• Active • Absolute intensity (2 min light arm pedaling at 50 rpm, 0 W)	• Polar HRM • HRR1: MHR-HR1min • HRR2: MHR-HR2min	• Resting HRV <u>significantly associated</u> with HRR after max ex, $p < .05$ for all correlations below: ○ HRR1 & HF: $r = .46$ ○ HRR1 & LF: $r = -.43$ ○ HRR1 & LF:HF: $r = -.49$ ○ HRR2 & HF: $r = .47$ ○ HRR2 & LF: $r = -.44$ ○ HRR2 & LF:HF: $r = -.50$
Heart rate recovery after exercise: Relations to heart rate variability and complexity	Javorka et al., 2002. Brazilian Journal of Medical and Biological Research	• 17 healthy untrained males, age 20.3±0.2 years • BMI=23.9±.5 kg/m²	• Resting • Time of day not reported • Breathing patterns not reported • Supine position • Time and frequency domains • Spectral analysis/fast	• Telemetric ECG System • Sampling frequency 1000 Hz	• SUBMAX (70% max) • Step protocol	• Passive	• HRR in 30 minutes post-exercise • %D1: percent decrease in first minute of recovery	• Resting HRV <u>not related</u> to HRR, $p > .05$ for all correlations below: ○ %D1 & SDRR: $r = -.08$ ○ %D1 & RMSSD: $r = -.08$ ○ %D1 & pNN50: $r = .10$ ○ %D1 & logHF: $r = -.14$ ○ %D1 & logLF: $r = -.04$

			Fourier transformation • RR, SDRR, RMSSD, pNN50, LF, HF					
Dissociation of heart rate variability and heart rate recovery in well-trained athletes	Lee & Mendoza, 2012. European Journal of Applied Physiology	• 8 males, 11 females • Healthy • Age 21-40…highly fit (VO2max 99 percentile) • Males: • VO_{2Max}=71.9±8.0 ml/kg/min • PA=6984.9 ±3516.5 kcal/week • Body fat=9.7±6.3 % • BMI=23.7± 4.4 kg/m^2 • Waist=79.4 ±6.4 cm • Females: • VO_{2Max}=63.7±10.2 ml/kg/min • PA=6247.7 ±2430.2 kcal/week • Body fat=11.3±3.8 % • BMI=20.8± 1.8 kg/m^2 • Waist=67.7 ±4.2 cm	• Resting • Time of day not reported • Breathing patterns not reported • Supine position • Standard 3 electrode EKG • Autoregressive spectral analysis • Frequency domain • TP, LF, HF, LFnu, HFnu, lnTP, lnLF, lnHF, lnLF:lnHF	• Biopac MP100 for acquisition • Kubios analysis software • Sampling frequency 500 Hz	• MAX (self selected speed, starting at 0% grade, increase 2% grade every 2 minutes) • Treadmill	• Active • Absolute intensity (5 min, 2.41 km/h, 2.5% grade)	• 1 minute HRR (HRR1)	• Poor correlation between HRV and HRR • p > .05 for all correlations below: ○ HRR1 & lnTP: r = .03 ○ HRR1 & lnHF: r = .08 ○ HRR1 & lnLF: r = .14 ○ HRR1 & LFnu: r = .05 ○ HRR1 & HFnu: r = -.05 ○ HRR1 & lnLF:lnHF: r = .07
Comparison between heart rate variability and recovery in ischemic patients	Zdrenghea et al., 2007. Romanian Journal of Internal Medicine	• 35 males and 28 females with ischemic heart disease, age 54.03±8.894 years	• Ambulatory over 24 hours • Time domain • SDANN, SDNN, RMSSD	• Holter monitor • Sampling frequency not reported	• MAX (25W increase every 3 minutes) • Cycle ergometer	• Recovery type not reported	• 1 minute HRR (HRR1)	• No significant correlation between HRV and HRR • p > .05 for all correlations below: ○ HRR1 & SDNN: r = .06 ○ HRR1 & SDANN: r = .075 ○ HRR1 & RMSSD: r = -.084

APPENDIX D: STUDY DESIGN SCHEMATIC



APPENDIX E: INFORMED CONSENT

The Relationship between Resting Heart Rate Variability and Heart Rate Recovery from Exercise in College-Aged Men

INFORMED CONSENT FOR PARTICIPATION

Please read the following as it offers information about this study. Please know that you are being asked to volunteer in this study. It is your choice to participate. By signing this form, you show that you have been informed of the nature of the study including the risks and benefits and want to participate.

Principal Investigator:

Cassandra L. Winczura, B.S., HFS, USA-W
Humboldt State University
(907)529-2120
cassandra.winczura@humboldt.edu

Faculty Supervisor:

Dr. Tina Manos, CSCS, CES
Humboldt State University
(707)826-5962
tmm52@humboldt.edu

Project Description:

The purpose of this study is to look at how variations in your heartbeats relate to your heart rate recovery from exercise.

Consent:

1. You must be at least 18 years old to take part in this study.
2. Your participation in this study is voluntary.

You may choose not to participate. You may refuse to participate in certain measures. You may refuse to answer certain questions. You may end your participation at any time with no penalty or loss of benefits.

Procedures:

If you agree to participate in this study, you will:

1. Fill out a medical history form. This will determine if you qualify to be part of this study.
2. Answer some questions about who you are and your level of activity.
3. Be asked to take part in a number of tests. Testing will take place in the Human Performance Lab at Humboldt State University. Testing will take place over the course of 2 to 3 weeks.
4. Have electrodes put on your chest to measure heart rate.
5. Have resting measures taken for blood pressure and heart rate.
6. Have your height, weight, body size, and body fatness measured.
7. Have your maximal oxygen consumption (VO_{2Max}) and maximal heart rate measured during an exercise test. This test will take about 12 minutes to complete during a lab visit of about 2 hours.
8. Have your heart rate recovery measured after two low-level exercise tests.

These tests will be done on a bike. Each test will last about 15 minutes, in a lab visit expected to be 1 hour or less.

Possible Risks and Discomforts:

This study includes a maximal graded exercise test. All-out effort will be required in these tests.

1. ( ) You may feel discomfort related to these types of maximal and near maximal exercise.
2. ( ) There is a chance of injury during any of these activities.
3. ( ) As is true for any exercise, you might have abnormal heart rate, blood pressure and, in rare cases, death.
4. ( ) You may feel faint after the exercise.
5. ( ) You will be fully submerged in a tank of warm water in order to find body fatness values. You may feel discomfort while under water. You may breathe in or swallow water while in the tank. You may slip while getting in and out of the tank.

Risk Management Procedures:

You will be screened with a medical history form. Based on the replies to the medical history form, you will be excluded if you: have a pacemaker; have any coronary, pulmonary or metabolic diseases; have signs/symptoms of these diseases; have high blood pressure; are taking blood pressure medications; have abnormal EKG tracings; are a current tobacco smoker; are exposed to secondhand smoke; have quit smoking in the past 6 months; or have any contraindications to exercise. Anyone with a medical condition that is not controlled will be excluded.

Proper supervision and instruction during exercise tests will be given to lessen risk of injury. Standardized procedures for testing will be followed. Emergency equipment and trained persons will be present to respond to events that arise during the tests.

Benefits:

The only direct benefits to you for taking part in this study include receipt of your scores for VO_{2Max} tests and body fatness. These results will let you know how fit you are compared to others of your age and sex. The value of these tests is about $160.

Responsibilities You Have as a Participant in this Research:

Information you have about your health status, and current or prior cases of unusual feelings with physical effort may affect the value and safety of the exercise you will do as part of this study. You agree to report this information to the primary investigator.

You also agree to report to the primary investigator any abnormal feelings you have during the tests. These feelings include extreme fatigue, shortness of breath, chest discomfort, faintness, or similar events. Finally, you agree to tell the primary investigator of any changes in medical status or medication use.

You understand that the primary investigator may stop the exercise if he or she deems that any abnormal responses are occurring.

Confidentiality/Anonymity:

- You understand that taking part in this study is voluntary.
- We will maintain your confidentiality to the fullest extent of the law.
    - We will store hardcopy information in a locked cabinet in the Human Performance Lab.
    - We will store all electronic information in password-protected computers. Only the student researcher and the faculty advisor will have the passwords for these computers
    - We will only present information as group data.
    - We will maintain all information for 5 years. After 5 years, all information will either be shredded or deleted from computer.

Inquiries:

Any questions about the procedures used in this study are encouraged. If you have concerns or questions, please ask us for further details.

Freedom of Consent:

Your participation in this study is voluntary. You are free to stop any test at any point.

Contacts:

For questions about this study, please contact the Principal Investigator using the contact information above. If you have any other questions concerning your rights as a volunteer or you are not satisfied at any time with any aspect of this study you may contact Dr. Tina Manos (707) 826-5962 or The Office of Research, Graduate Studies, and International Programs; Humboldt State University; (707) 826-3949, if you wish.

I understand that the Investigator will answer any questions I have about this study. I also understand that my participation in this study is voluntary and that I may stop at any time.

If you have any concerns with this study, contact the IRB Chair, Dr. Ethan Gahtan, at eg51@humboldt.edu or (707) 826-4545.

If you have questions about your rights as a participant, report them to the Humboldt State University Dean of Research, Dr. Rhea Williamson, at Rhea.Williamson@humboldt.edu or (707) 826-5169.

Signature:

Your signature below shows your voluntary agreement to participate in this study.

I,____have read and agree to

participate in the study as described above. ***(Please PRINT Your Name Here)***

____ _______/_______/_______

(Please SIGN Your Name Here) (Date)

APPENDIX F: MEDICAL HISTORY

Humboldt State University Health and Wellness Institute Medical Information and History and Release of Liability

Name ______________________________

Address ______________________________

Home Phone ____________ Work Phone ____________

Age ________ Date of Birth ____________ Gender ____________

The following questions are designed to help us tailor the health and fitness assessment and follow-up counseling to your personal situation. It is extremely important for us to know if you have any medical conditions which may affect your testing process or your progress in our program. Please take the time to answer these questions accurately.

Medical History

YES	NO	In the past five years have you had:
( )	( )	1. Pain or discomfort in chest, neck, jaw, or arms
( )	( )	2. Shortness of breath or difficulty breathing at rest or with mild exertion (e.g., walking)
( )	( )	3. Dizziness or fainting
( )	( )	4. Ankle edema (swelling)
( )	( )	5. Heart palpitations (forceful or rapid beating of heart)
( )	( )	6. Pain, burning, or cramping in leg with walking
( )	( )	7. Heart murmur
( )	( )	8. Unusual fatigue with mild exertion
		Have you ever had:
( )	( )	9. Heart disease, heart attack, and/or heart surgery
( )	( )	10. Abnormal EKG
( )	( )	11. Stroke
( )	( )	12. Uncontrolled metabolic disease (e.g., diabetes, thyrotoxicosis, or myxedema)
( )	( )	13. Asthma or any other pulmonary (lung) condition
( )	( )	14. Heart or blood vessel abnormality (e.g., suspected or known aneurysm)
( )	( )	15. Liver or kidney disease
( )	( )	16. Are you currently under the care of a physician?
( )	( )	17. Do you currently have an acute systemic infection, accompanied by a fever, body aches, or swollen lymph glands?
( )	( )	18. Do you have a chronic infectious disease (e.g. mononucleosis, hepatitis, AIDS)?
( )	( )	19. Do you have a neuromuscular, musculoskeletal, or rheumatoid disorder that is made worse by exercise?
( )	( )	20. Do you have an implantable electronic device (e.g. pacemaker)?
( )	( )	21. Do you know of any reason why you should not do physical activity?

If you answered yes to any of these questions, please explain.

____

Risk Factors

YES	NO	DON'T KNOW	
( )	( )	( )	1. Are you a male 45 years of age or older?
( )	( )	( )	2. Are you a female 55 years of age or older
( )	( )	( )	3. Do you have a father or brother who had a heart attack or heart surgery before age 55?
( )	( )	( )	4. Do you have a mother or sister who had a heart attack or heart surgery before age 65?
( )	( )	( )	5. Do you smoke or have you quit in the past 6 months?
( )	( )	( )	6. Do you have frequent secondhand smoke exposure?
( )	( )	( )	7. Do you know your blood pressure?_______/_______mmHg-Date:
( )	( )	( )	8. What is your total cholesterol?__________mg/dL-Date:
( )	( )	( )	9. Are you taking cholesterol lowering medication?
( )	( )	( )	10. Do you know your HDL cholesterol?__________mg/dL-Date:
( )	( )	( )	11. Is your HDL cholesterol > 60mg/dL?
( )	( )	( )	12. What is your fasting blood glucose?__________mg/dL – Date:
( )	( )	( )	13. Do you exercise regularly? If so, explain.

If you answered yes to any of these questions, please explain.

____

____

____

____

Office Use

BMI____ SBP____ DBP____ TC____ LDL____ HDL____ FBG____

Family History____ Smoking____ Sedentary____

Health-Related Questions

YES	NO	
( )	( )	1. Are you pregnant?
( )	( )	2. Are you allergic to isopropyl alcohol (rubbing alcohol) or latex?
( )	( )	3. Do you have any allergies to medications, bees, foods, etc.? If so please list ________________
( )	( )	4. Do you have any skin problems?
( )	( )	5. Do you have any other medical condition(s)/surgeries?
( )	( )	6. Have you had any caffeine, food, or alcohol in the past 3 hours?
( )	( )	7. Have you exercised today?
( )	( )	8. Are you feeling well and healthy today?
( )	( )	9. Do you have any other medical concerns that we should be aware of?

If you answered yes to any of these questions, please explain.

____

____

Medications

Please Select Any Medications You Are Currently Using:

☐ Diuretics	☐ Other Cardiovascular
☐ Beta Blockers	☐ NSAIDS/Anti-inflammatories (Motrin, Advil)
☐ Vasodilators	☐ Cholesterol
☐ Alpha Blockers	☐ Diabetes/Insulin
☐ Calcium Channel Blockers	☐ Other Drugs (record below).

Please list the specific medications that you currently take:

____

____

____

____

What are your health and fitness goals?

____

____

____

____

I certify that the information I have provided is complete and accurate to the best of my knowledge.

Date ________________ Signature of Subject ______________________________

Date ________________ Signature of Witness ______________________________

Office Use Only		
____Low Risk	____Moderate Risk	____High Risk

HUMBOLDT STATE UNIVERSITYRELEASE OF LIABILITY, PROMISE NOT TO SUE, ASSUMPTION OF RISK AND AGREEMENT TO PAY CLAIMS

I have read this form, and I understand the test procedures that I will perform and the attendant risks and discomforts. Knowing these risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this test.

In consideration for being allowed to participate in this Activity, on behalf of myself and my next of kin, heirs and representatives, I **release from all liability and promise not to sue** the State of California, the Trustees of The California State University, California State University, Humboldt State University and their employees, officers, directors, volunteers and agents (collectively "University") from any and all claims, **including claims of the University's negligence,** resulting in any physical or psychological injury (including paralysis and death), illness, damages, or economic or emotional loss I may suffer because of my participation in this Activity, including travel to, from and during the Activity.

I am voluntarily participating in this Activity. I am aware of the risks associated with traveling to/from and participating in this Activity, which include but are not limited to physical or psychological injury, pain, suffering, illness, disfigurement, temporary or permanent disability (including paralysis), economic or emotional loss, and/or death. I understand that these injuries or outcomes may arise from my own or other's actions, inaction, or negligence; conditions related to travel; or the condition of the Activity location(s). **Nonetheless, I assume all related risks, both known or unknown to me, of my participation in this Activity, including travel to, from and during the Activity.**

I agree to **hold** the University **harmless** from any and all claims, including attorney's fees or damage to my personal property that may occur as a result of my participation in this activity, including travel to, from and during the Activity. If the University incurs any of these types of expenses, I agree to reimburse the University. If I need medical treatment, I agree to be financially responsible for any costs incurred as a result of such treatment. I am aware and understand that I should carry my own health insurance.

Date:_______ Signature of Subject:_______________________________________

Date:_______ Signature of Witness:_______________________________________

APPENDIX G: DEMOGRAPHIC QUESTIONNAIRE

1. Name: ____

2. Date: ____

3. Current Age: ___________

4. Please circle/mark yes or no for the following:

   ( ) Yes or ( ) No: Are you currently injured?

   ( ) Yes or ( ) No: Do you have chronic back pain?

   ( ) Yes or ( ) No: Do you have any medical condition made worse by exercise?

5. Which ONE of the following ethnicities BEST represents you:

   a. African American
   b. Asian
   c. Caucasian
   d. Latino
   e. Middle Eastern
   f. Native American
   g. Pacific Islander
   h. Other____

6. ( ) Yes or ( ) No: Did you participate in collegiate athletics?

7. If yes: What sport(s) did you play? ____________________________________

   What was your position? _______________________________________

8. ( ) Yes or ( ) No: Are you currently participating in a collegiate athletic sport?

9. If yes: What sport are you participating in? ______________________________

10. ( ) Yes or ( ) No: Have you been cleared for athletic participation within the last 2 years?

I certify that the information I have provided is complete and accurate to the best of my knowledge.

Date_________________Signature of Subject_____________________________________

Date_________________Signature of Witness____________________________________

APPENDIX H: PHYSICAL ACTIVITY QUESTIONNAIRE

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

   _____ **days per week**

   ☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

   _____ **hours per day**
   _____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

   _____ **days per week**

   ☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

   _____ **hours per day**
   _____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

   _____ **days per week**

   ☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

    _____ **days per week**

    ☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

    _____ **hours per day**
    _____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

    _____ **days per week**

    ☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

    _____ **hours per day**
    _____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical

activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

    _____ **days per week**

    ☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

    _____ **hours per day**
    _____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** aerobic physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

    _____ **days per week**

    ☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** aerobic physical activities in your leisure time?

    _____ **hours per day**
    _____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** aerobic physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

    _____ **days per week**

    ☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** aerobic physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

These questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

Part 6: Resistance Training

These questions are about the time you spend doing resistance training. This includes lifting weights and body weight exercises.

28. During the **last 7 days**, on how many days did you do **resistance training**?

_____ **days per week**

☐ No resistance training → ***Skip*** **to end of questionnaire**

29. How much time did you usually spend on one of those days doing **resistance training**?
_____ **hours per day**
_____ **minutes per day**

30. How many resistance training exercises did you perform on each of those days?

_____ **exercises**

31. How many sets and repetitions of each exercise did you perform on each of those days?

_____ **sets** _____ **repetitions per set**

32. What amount of weight did you lift on each of those days (please check one)?

☐ **low** ☐ **moderate** ☐ **high**

This is the end of the questionnaire, thank you for participating.

APPENDIX I: PRETEST INSTRUCTIONS

Pretest Instructions

Before your appointment, please:

- Do not eat for at least 3 hours
- Do not exercise for at least 24 hours
- Do not consume caffeine or alcohol for at least 4 hours
- Stay normally hydrated
- Do not use tobacco products at all
- Do not use any cold medicines for at least 24 hours, especially those containing pseudoephedrine (e.g., Sudafed, Dayquil, Theraflu, Mucinex D, Zyrtec-D, Aleve D, Benadryl Plus)
- Do not use marijuana or be exposed to marijuana smoke for 48 hours

When you come in, please:

- Wear appropriate athletic shoes and clothing
- Use the restroom before coming to your appointment
- Make sure that your cell phone is set to silent mode
- Arrive a few minutes early and wait in the waiting room
- Keep your voice down so as not to disturb other subjects while they are being tested

APPENDIX J: SUBJECT RECRUITMENT FLYER

HUMBOLDT
STATE UNIVERSITY

Volunteers Wanted

for

Research Study

To qualify:

- Healthy, nonsmoking males, ages 18-25 years
- Normal blood pressure
- All fitness levels welcome

What you will do:

- 3 visits, 1-2 hours each
- **FREE** aerobic fitness test on a stationary bike, body fat test, and blood pressure, all *valued at $250*

Interested? For more information, contact:

Cassie Winczura, B.S., ACSM-HFS, USAW
Candidate, MS in Kinesiology
Phone: (907)529-2120
Email: clw66@humboldt.edu

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APPENDIX K: UNIVERSITY OF HOUSTON NONEXERCISE VO_{2MAX} PREDICTION QUESTIONNAIRE

Use the appropriate number (0 to 7) That Best Describes Your General Activity Level for the Previous Month (circle one)

Do not participate regularly in programmed recreation, sport, or heavy physical activity.

0 Avoid walking or exertion, e.g., always use elevator, ride when possible instead of walking

1 Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration

Participate regularly in recreation or work requiring modest physical activity, such as gymnastics, horseback riding, calisthenics, table tennis, softball, baseball, weight lifting, yard work

2 Spend 10 to 60 minutes per week in these types of physical activity.

3 Spend over 1 hour per week in these types of physical activity.

Participate regularly in heavy physical exercise, e.g., running or jogging, swimming, cycling, rowing, jumping rope, or engaging in vigorous aerobic activity type exercise such as tennis, basketball, soccer, or other similar sports activities.

4 Run less than 1 mile per week or spend less than 30 minutes per week in comparable physical activity.

5 Run 1 to 5 miles per week or spend 30 to 60 minutes per week in comparable physical activity.

6 Run 5 to 10 miles per week or spend 1 to 3 hours per week in comparable physical activity.

7 Run over 10 miles per week or spend over 3 hours per week in comparable physical activity.

APPENDIX L: MEANS AND STANDARD ERRORS OF RAW OUTCOME VARIABLE DATA

Variable	Mean ± *SE*
HF2 Supine (ms^2/Hz)	1.38 ± .55
LF2 Supine (ms^2/Hz)	1.04 ± .37
LF:HF2 Ratio Supine	1.40 ± .28
HFnu2 Supine (ms^2/Hz)	.50 ± .038
LFnu2 Supine (ms^2/Hz)	.50 ± .038
SDNN2 Supine (ms)	151.12 ± 23.56
HF2 Seated (ms^2/Hz)	.58 ± .20
LF2 Seated (ms^2/Hz)	.66 ± .14
LF:HF2 Ratio Seated	2.69 ± .43
HFnu2 Seated (ms^2/Hz)	.36 ± .040
LFnu2 Seated (ms^2/Hz)	.64 ± .040
SDNN2 Seated (ms)	161.87 ± 36.31
HF3 Supine (ms^2/Hz)	.76 ± .24
LF3 Supine (ms^2/Hz)	.62 ± .15
LF:HF3 Ratio Supine	1.43 ± .30
HFnu3 Supine (ms^2/Hz)	.50 ± .039
LFnu3 Supine (ms^2/Hz)	.50 ± .039
SDNN3 Supine (ms)	133.32 ± 19.30
HF3 Seated (ms^2/Hz)	.50 ± .15
LF3 Seated (ms^2/Hz)	.60 ± .13
LF:HF3 Ratio Seated	2.63 ± .58
HFnu3 Seated (ms^2/Hz)	.38 ± .038
LFnu3 Seated (ms^2/Hz)	.62 ± .038
SDNN3 Seated (ms)	118.97 ± 15.14
T30 HRR	122.15 ± 12.25
delta 60 HRR	46.62 ± 2.72

APPENDIX M: HRV AND HRR CORRELATION MATRIX

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
(1) LogHF Supine (ms^2/Hz)													
(2) LogLF Supine (ms^2/Hz)	.84**												
(3) LogLF:HF Supine	-.52**	.026											
(4) HFnu Supine (ms^2/Hz)	.51*	-.038	-1.0**										
(5) LFnu Supine (ms^2/Hz)	-.51*	.038	1.0**	-1.0**									
(6) LogSDNN Supine (ms)	.88**	.73**	-.48*	.47*	-.47*								
(7) LogHF Seated (ms^2/Hz)	.68**	.58**	-.35	.35	-.35	.81**							
(8) LogLF Seated (ms^2/Hz)	.49*	.68**	.16	-.16	.16	.61**	.78**						
(9) LogLF:HF Seated	-.55**	-.19	.72**	-.73**	.73**	-.63**	-.74**	-.16					
(10) HFnu Seated (ms^2/Hz)	.50*	.15	-.69**	.70**	-.70**	.61**	.75**	.17	-.99**				
(11) LFnu Seated (ms^2/Hz)	-.50*	-.15	.69**	-.70**	.70**	-.61**	-.75**	-.17	.99**	-1.0**			
(12) LogSDNN Seated (ms)	.52*	.46*	-.23	.24	-.24	.70**	.80**	.76**	-.44**	.47*	-.47*		
(13) LogT30 HRR	-.40	-.45*	.024	-.030	.030	-.40	-.30	-.32	.12	-.11	.11	-.32	
(14) delta 60 HRR	.24	.32	.075	-.064	.064	.21	.13	.37	.19	-.18	.18	.27	-.68**

Note: *$p < .05$, **$p < .01$

APPENDIX N: ADDITIONAL SCATTERPLOTS

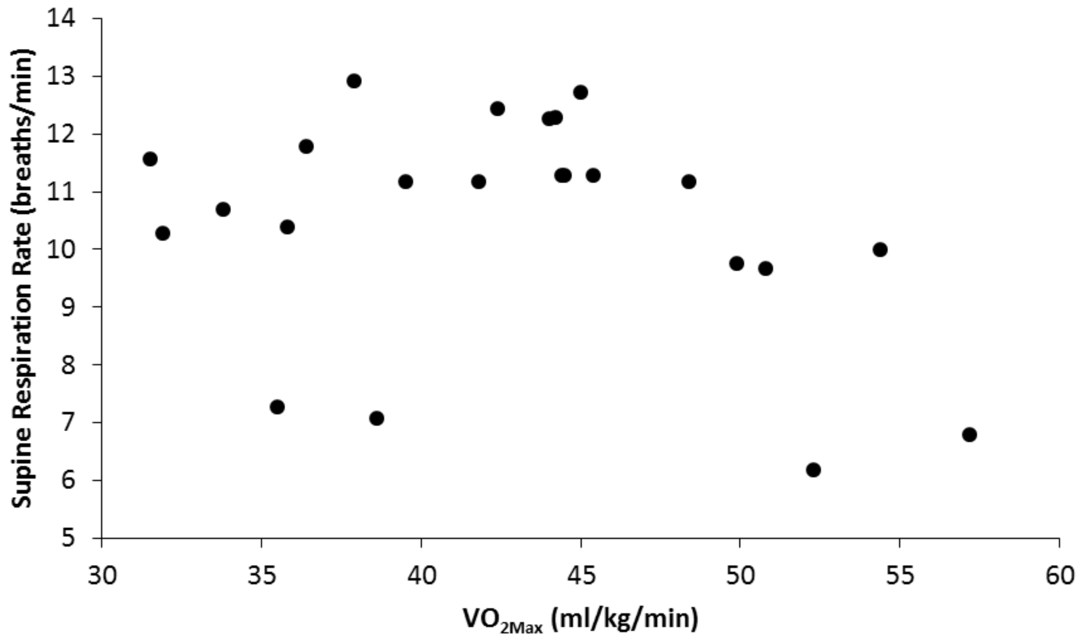

Figure N1. Relationship between fitness and supine resting respiration rate.

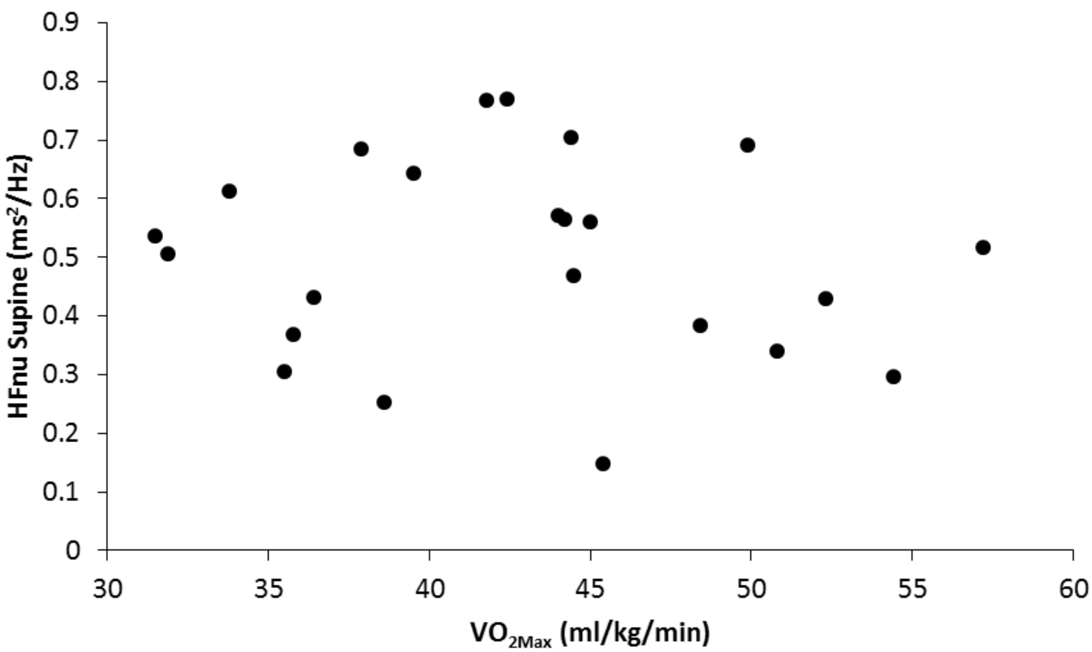

Figure N2. Relationship between fitness and HFnu Supine HRV.

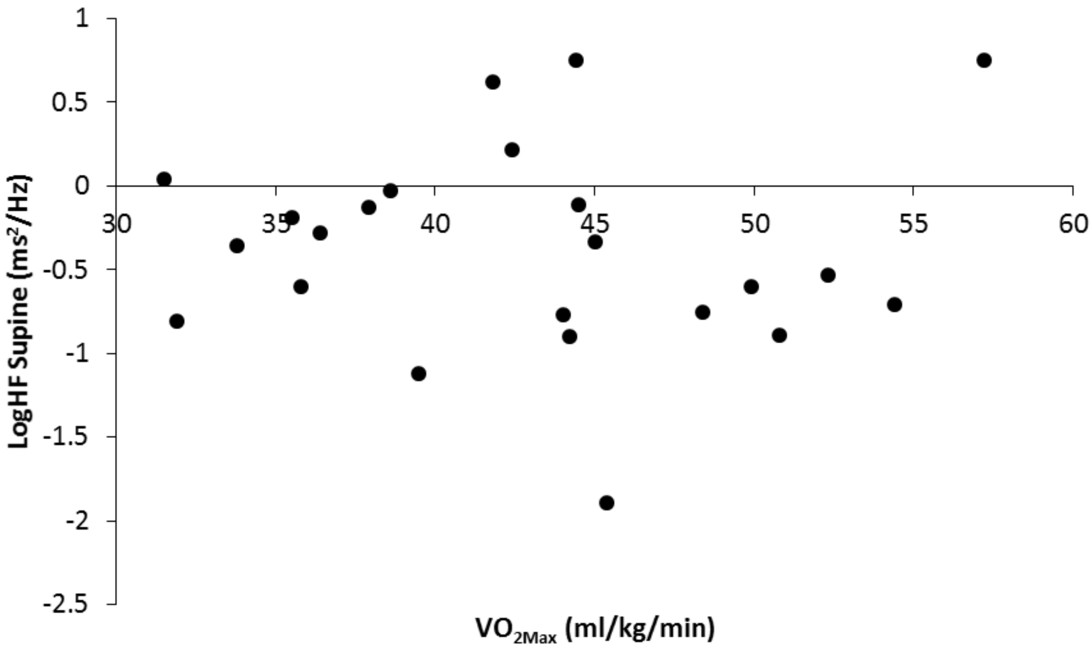

Figure N3. Relationship between fitness and LogHF Supine HRV.

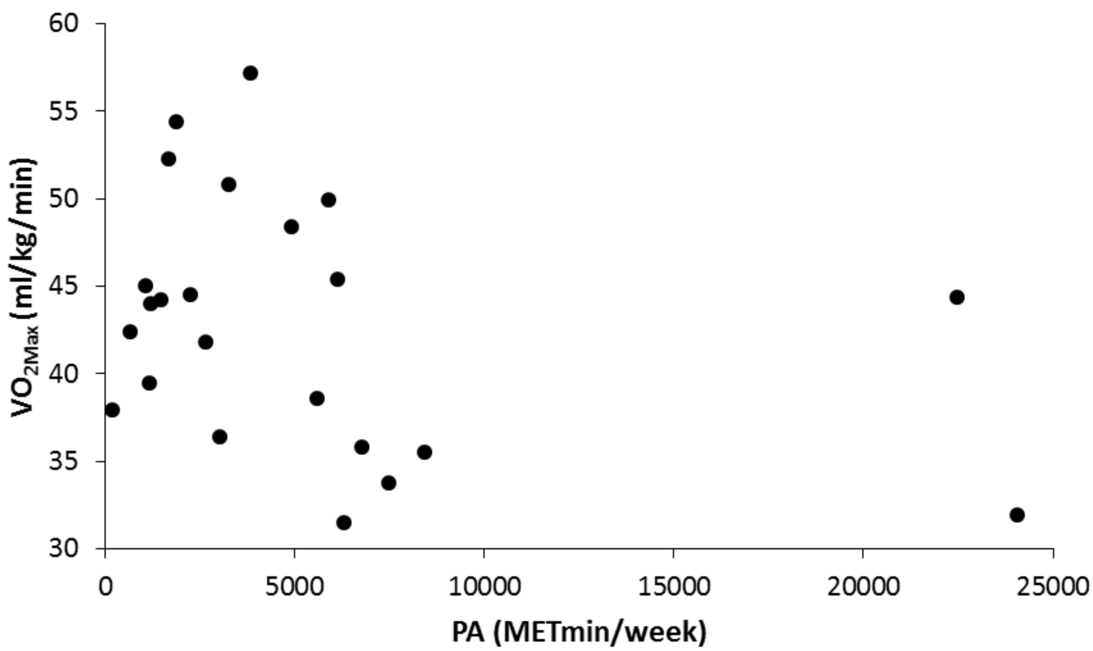

Figure N4. Relationship between physical activity and fitness.

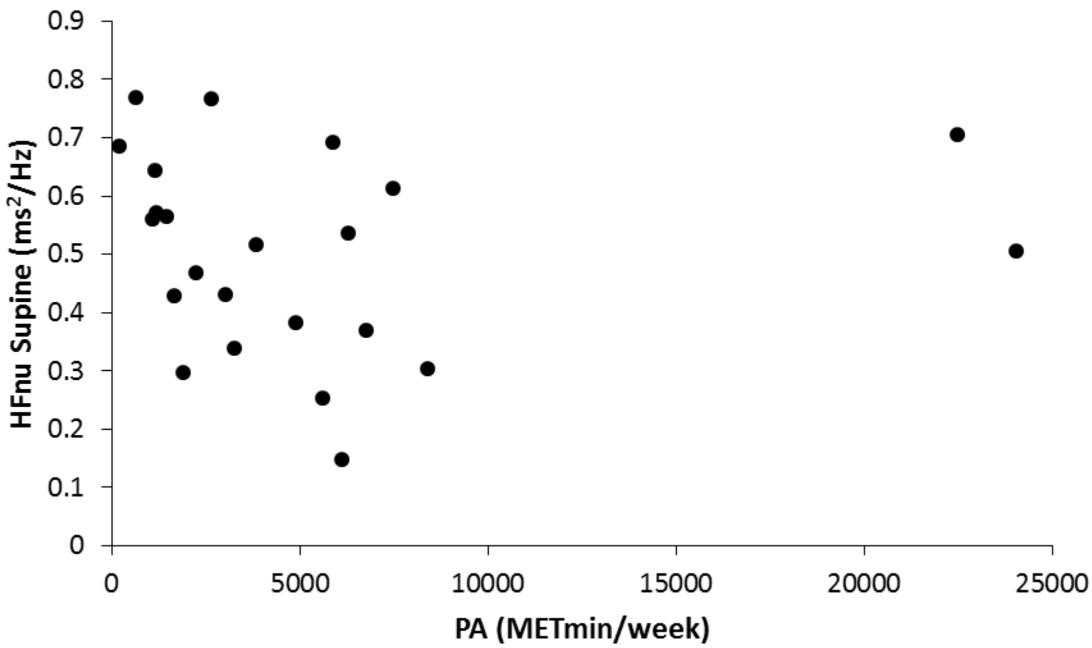

Figure N5. Relationship between physical activity and HFnu Supine HRV.