COMPARISON OF WEEKLY HRV MEASURES COLLECTED FROM TWO DIFFERENT
RECORDING TIMES AND THEIR RELATION TO PERFORMANCE IN COLLEGIATE
FEMALE ROWERS

by

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ABSTRACT

INTRODUCTION: Root-mean-square difference of successive RR intervals (RMSSD) is a common heart rate variability (HRV) metric used in the realm of athletic monitoring. Time constraints in a collegiate sport environment and irregular practice hours are challenges that make obtaining the mean value (RMSSDM) and coefficient of variation (RMSSDCV) of daily RMSSD assessment difficult. It is unclear whether the time of day (i.e., measured immediately upon waking versus immediately prior to morning practice) influences these metrics and their relationships to performance. PURPOSE: To compare HRV values when recorded immediately upon waking to values recorded later in the morning prior to practice, and to determine the associations of HRV measures with performance outcomes in competitive female rowers.

METHODS: Thirty-one NCAA Division I rowers were monitored for six consecutive days. Two seated RMSSD measurements were obtained on at least three mornings using a photoplethysmography application. Each 1-minute RMSSD measure was recorded following a 1-minute stabilization period. The first (T1) measurement occurred at the athlete’s home following waking, the second (T2) upon arrival at the team’s boathouse immediately before practice. From the daily measures, RMSSD mean and CV were calculated. Rank was determined by the coaches based on performance for that week. Two objective performance assessments were conducted on an indoor rowing ergometer on separate days: timed 2000m and distance covered in 30 minutes. Paired samples t-test was used to assess the potential differences between T1 and T2. Bivariate correlations were assessed using an intraclass correlation coefficient (ICC). Statistical significance assessed using α-level, p<0.05. RESULTS: No differences in RMSSDM and
RMSSD\textsubscript{CV} were observed between T1 and T2 (p=0.73, p=0.66, respectively). RMSSD\textsubscript{M} at T1 and T2 were strongly correlated (ICC=0.82, 95% CI=0.63 to 0.92), as well as RMSSD\textsubscript{CV} at both times (ICC=0.75, 95% CI=0.48 to 0.88) (both p<0.01). RMSSD\textsubscript{M} at T1 and T2 was moderately associated with athlete rank (r=-0.55, r=-0.46, respectively), 30-min distance (r=0.40, r=0.41, respectively), and 2,000m at T1 (r=−0.37). No significant correlations were observed for RMSSD\textsubscript{CV}. **CONCLUSIONS:** Ultra-short RMSSD can be measured immediately upon waking or prior to practice, however assessing HRV immediately upon waking yielded stronger correlations with performance.
DEDICATION

This project would not exist without the confidence of Michigan State University Women’s Rowing Coaches, Matthew Weise and Katie Bitz. It is not the finite details of the sport that you so diligently taught which resonate with me, but the restoration of confidence in my own abilities far beyond the likes of athletics and academics. Thank you pushing us past that inevitable brick wall and believing in us during the chaos that follows it. You will never quite understand the impact you have made on the lives of so many strong women out there, but know that they are limitless.

This project definitely would not exist without the likes of those who always believed in me more than I could have ever believed in myself, even if they wanted to slam the door in my face after about the millionth question. Dr. Michael Fedewa and Dr. Mike Esco, thank you for diligently guiding me through this project, offering insightful expertise each step of the way. Thank you, Dr. Hayley MacDonald, for sharing your passion of research and tireless dedication to each and every one of your students, always. Your patience has kept me on track throughout this whole project, and instilled a quiet assurance in my academic abilities. There is not a specific value on the amount for which the three of you have passed on and I will forever be grateful for all that you have done.

Last but definitely not least, Dr. Karin Allor Pfeiffer: mentor, professor, “academic mom”, and friend. If I can inspire others in even an ounce of the tenacity that you have instilled
in me, I will chalk that up to success. This is the first, and hopefully not the last, but it wouldn’t be possible without all of you, so thank you and this one is for you—Cheers.
# LIST OF ABBREVIATIONS AND SYMBOLS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ANS</td>
<td>Autonomic nervous system</td>
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<tr>
<td>BMI</td>
<td>Body mass index (kg/m²)</td>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<tr>
<td>CV</td>
<td>Coefficient of variation</td>
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<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
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<tr>
<td>hr</td>
<td>Hour</td>
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<tr>
<td>HR</td>
<td>Heart rate</td>
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<tr>
<td>HRV</td>
<td>Heart rate variability</td>
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<tr>
<td>Hz</td>
<td>Hertz</td>
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<tr>
<td>ICC</td>
<td>Intraclass correlation coefficient</td>
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<tr>
<td>kg</td>
<td>Kilograms</td>
</tr>
<tr>
<td>LnRMSSD</td>
<td>Natural logarithm of the root-mean-square of successive R-R intervals</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>min</td>
<td>Minute</td>
</tr>
<tr>
<td>ms</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>NCAA</td>
<td>National Collegiate Athletic Association</td>
</tr>
<tr>
<td>PNS</td>
<td>Parasympathetic nervous system</td>
</tr>
<tr>
<td>PPG</td>
<td>Photoplethysmography</td>
</tr>
<tr>
<td>$r$</td>
<td>Pearson product-moment correlation</td>
</tr>
<tr>
<td>RMSSD</td>
<td>Root-mean-square difference of successive RR intervals</td>
</tr>
<tr>
<td>s</td>
<td>Seconds</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
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</table>
SNS  Sympathetic nervous system
T1  First HRV measurement which occurred at the athlete’s home
T2  Second HRV measurement taken upon arrival at the team’s boathouse immediately before practice
α  Alpha
Δ  Change
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I am incredibly grateful to the University of Alabama Women’s Rowing Team athletes, and coaching staff, particularly head coach Larry Davis, assistant coaches Derek and Tabitha Tuten, and James Mulcahy, and manager Logan O’Neil, for whom placed their trust in me to pursue implementation of the HRV monitoring program throughout their Spring 2018 Season. Thank you to the athletic training, medical, and strength and conditioning staff, Megan Toth, Macy Franklin, Dr. Rodney Brown, Dr. James Robinson, and Jim Hamner who tirelessly devote their time and energy into the health and endurance of their athletes, and then shared essential insight into how this would alter our study. This team was the first of any female collegiate rowing team of their caliber to implement and allow such a study and I cannot thank them enough for their time and dedication to make sure it was completed as smoothly as possible.

A professor once told me that choosing a graduate program is more about choosing the people and the “fit” than anything else. This individual could not have made a better point. I have been blessed with a cohort within the Exercise Science department at the University of Alabama that have made my experience all that is has been- awesome. Thank you to Clifton Holmes and Björn Hornikel for waking up at the crack of dawn to help collect data and provide a helping hand to this project. Thank you to Zackary Cicone for taking the time to explain the minute details of research to your fellow colleagues. Finally, a very special thank you to Ward Dobbs for being a fantastic mentor and role model throughout this project and beyond, for me
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CHAPTER 1

A REVIEW OF LITERATURE ON THE CHAOS OF HEART RATE VARIABILITY

Introduction

Monitoring of the autonomic nervous system (ANS) function has been of interest to researchers and practitioners alike for decades. Afferent and efferent pathways of the ANS play a vital role in regulation of organ function in order to maintain a state of dynamic stability in response to changes in the internal and external environment of the body \(^1\). The complexity of the ANS has provided a challenge to locate a single protocol that accurately and reliably reflects the function of either the Parasympathetic Nervous System (PNS) or the Sympathetic Nervous System (SNS) \(^2\).

Heart rate variability (HRV), a tool traditionally measured from the ‘gold standard’ of electrocardiogram (ECG) recordings, has offered insight into the capacity of an individual to function with optimal efficiency across many settings \(^3\). HRV is the beat-to-beat fluctuations between successive ventricular contractions. Tracking this measure in conjunction with other markers of recovery or adaptation may be useful for monitoring the effects of various stimuli on the system as a whole. Because heart rate (HR) and rhythm are largely under the control of the ANS, these HR measures are a non-invasive, inexpensive, time-efficient tool to monitor individual ANS function, particularly parasympathetic modulation \(^3,4\). The purpose of this literature review is twofold: First, to describe the evolution of portable HRV devices as a
convenient tool for monitoring the ANS; Second, to explore the utility of these devises for the purposes of athletic monitoring.

**Autonomic Nervous System Function**

*Parasympathetic and Sympathetic Innervation*

The complete unit of the heart holds the primary responsibility of proper profusion of blood throughout the vasculature. This muscle pump is richly innervated, and thus regulated, by the ANS. The PNS innervates the sinoatrial node (SA node) and atrioventricular node (AV node) through the vagus nerve. The SNS innervates these points as well, but is more uniformly distributed to the major components of the heart, concentrating primarily in the ventricles. In healthy individuals, the SA node is under tonic influence of both the PNS and SNS systems; however, the parasympathetic predominates at rest.

Reciprocal changes in PNS and SNS stimulation can cause increases or decreases in HR at varying speeds. Sympathetic stimulation increases the rate of conduction throughout the heart (thus, HR), while parasympathetic influence slows the conduction rate. PNS activation is immediate; specifically, removal of vagal influence would cause an immediate increase in HR. Conversely, sympathetic stimulation results in a more gradual increase and decrease in rate upon stimulation. Cardiac rhythm disturbances, dysrhythmias, can be indicative of disease or a maladaptation to a certain stimulus.

**Monitoring Tools**

The electrical activity of the heart is measured by an ECG, which has been a valuable clinical tool since the late 1880’s. During an ECG recording, electrodes are placed on the surface of the skin to provide an average of the intricate myocardial contraction and relaxation actions. Although modern technology has made significant changes since this time, the basics of
interpretation have not strayed far from the Dutch physiologist, Willem Einthoven’s original method and interpretation.

Quantitative Approach for Measuring Heart Rate Variability

HRV is generally quantified by three methods: time domain, frequency domain, and non-linear measurements (see Figure 1.1, Appendix A). Time domain measures are the more crude and consistent analysis of the two components. Common time domain variables include standard deviation of the normal R-R intervals (SDNN) and the root mean squared differences of successive normal R-R intervals (RMSSD). ‘NN’ referring to normal-to-normal intervals, which is all intervals between adjacent QRS complexes resulting from sinus node depolarization.

Time Domain Analysis

Standard Deviation of the Normal R-R Intervals (SDNN)

Intervals recorded over longer periods (i.e., 24 hours) result in more complex statistical analyses, derived from direct measurements of N-N intervals. SDNN is a measure of total variability, but is dependent on the length of the recording period, therefore is not a well-defined statistical quantity. In practice, it is inappropriate to compare SDNN measures from recordings of different periods since the total variance of HRV increases with the length of analyzed recording.

Root Mean Squared Differences of Successive Normal R-R Intervals (RMSSD)

The most common time domain measure, RMSSD, is a measure of high-frequency variations, or vagal modulation, less influence by respiration. RMSSD is readily accessible to the general public, as it does not require any sophisticated software, and can be calculated using a Microsoft Excel 2016 (Redmond, WA, USA) spreadsheet. The percentage of successive
normal R-R intervals greater than 50 ms (pNN50) is another measurement that is correlated with RMSSD. However, pNN50 is extremely sensitive to uneven beat detection or incorrect beat labeling. Therefore, RMSSD is preferred as it typically provides a more robust, comprehensive assessment of vagal tone.

Geometrical Methods

A series of N-N intervals can also be converted into geometric patterns for analysis of time domain measures. For these measurements, a simple formula is used to judge the variability based on the geometric and/or graphic properties of the resulting pattern. Geometrical methods are highly sensitive to abnormal data and correspond to total power (variance of R-R intervals during 5-min segments) of the distribution. Thus, most geometric methods require the R-R sequence to be measured on or converted to a discrete scale in order to create a stable histogram.

The Triangular Index is the total number of all N-N intervals recorded during a 24-hour period divided by the height of the histogram of all N-N intervals (i.e., the density distribution). The Triangular Interpolation of N-N Intervals (TINN) is the baseline width of the distribution measured by the minimum square difference of a triangle. It approximates the N-N distribution by the curve of the highest peak on the histogram of all N-N intervals over a 24-hour period. TINN is the method recommended by the 1996 Task Force as an accurate analysis of overall HRV via time-domain assessment by geometrical means. Geometric methods are relatively insensitive to the analytical quality of the series of N-N intervals, requiring a reasonable number of N-N intervals to construct the geometric pattern (at least 20 minutes, preferably 24 hours).
Nonlinear Methods

A Poincaré Plot is a nonlinear method that can highlight the correlational characteristics of HRV. It is the ratio of the standard deviation (SD1) along the perpendicular axis to the standard deviation (SD2) along the parallel axis. SD1 is based on successive differences or short-term HRV, and SD2 is based on the summation of successive RR intervals or the long-term HRV. Poincaré Plots can be indicators of vagal activity and reduced cardiac vagal control, which are associated with physiological strain and stress. Generally, these parameters are calculated by commercially available HRV statistical software such as Kubios® (Biomedical Signals Analysis Group, University of Kuopio, Finland), Polar® Precision Performance software (Polar® Electro, Kempele, Finland), and Nevrokard® software (Nevrokard® Medistar, Ljubljiana, Slovenia). However, some caution is required regarding nonlinear indices and their utility to predict physiological phenomena. Thus, it is recommended that they be used in complement with other HRV indices.

Frequency Domain Analysis

Frequency domain measures express HRV as a function of frequency, rather than time. The analysis requires filtering the signal into different bands, since different spectral power components of HRV relate to different elements of cardiac autonomic activity. Frequency analysis occurs through evaluation of the spectral power of the R-R variability in relation to the rate of the oscillation. An example of a schematic of power spectral density is displayed in Figure 1.2 (see Appendix A).

Frequency Bands

The ultra-low frequency (ULF) band (<0.0033 Hz) reflects various physiological adaptations such as circadian oscillations, core body temperature, and metabolism. However,
ULF is only meaningful in recordings assessed over 24 hours and is difficult to interpret \(^5,^{15}\). Similarly difficult to interpret, the very-low frequency (VLF) band (between 0.0033 and 0.04 Hz) captures the magnitude of underlying oscillations in heart rate pattern, which represent long-term regulation mechanisms like thermoregulation and hormonal mechanisms \(^9,^{15}\). The low-frequency (LF) band (between 0.04 and 0.15 Hz) is considered a marker of either sympathetic modulations on the SA node or a combination of both SNS and PNS influences; however, the exact interpretation of LF is still somewhat controversial \(^5,^9,^{15}\). High-frequency (HF) oscillations (0.15 to 0.4 Hz) are mediated by the parasympathetic influence on the SA node \(^3\). HF is also called the respiratory band because it directly corresponds to the heart rate variations impacted by the respiratory cycle (i.e., breathing rates) \(^9\). Since vagal activity has an immediate effect on the R-R interval (increases interval), and cessation of vagus nerve activity works in opposition (decreases interval), total vagal activity can be characterized by HF power \(^5\). HF power frequency is highly correlated with the aforementioned time domain, RMSSD interval for reflection of vagal tone \(^5,^9,^{15}\). Together, all of these frequencies make up the total power of the HRV spectra.

**LF/HF Ratio**

Bearing in mind the circumstances for which the recording was taken (i.e., stationary, 24 hour, etc.), it is important that the method of HRV analysis measure the degree of autonomic modulations, rather than the level of autonomic tone per se as the relationship between the PNS and SNS systems is not always reciprocal \(^3\). The standardized capacity of LF and HF emphasizes the controlled and balanced behavior of the two branches of the ANS \(^3,^5\); Therefore, the ratio of LF/HF may be more important when considering sympathovagal balance and dominance \(^5\). Recent studies \(^16,^{17}\) in clinical patient populations have found that the computationally less
difficult ratio of SDNN/RMSSD can also accurately represent a reliable surrogate for the LF/HF ratio.

**Brief History of HRV**

Monitoring HRV is not a new concept as clinicians and physicians have observed variation in HR for centuries. It is only in the last 150 years that more specific methods and mechanisms have appeared to support the complex method 3,8,18.

*Emergence of HRV as a Clinical Tool*

Clinical relevance of HRV was first appreciated by scientists, Hon & Lee 19 in a study of fetal ECG’s in 1965. The pair observed reduced beat-to-beat variation of the fetal heart was associated with distress before any other detectable symptoms, including raw HR itself. Their findings are still readily utilized in many obstetric units today 3,18. This monitoring principle was expanded upon in the 1970’s for diagnostic and research purposes in patients with diabetic autonomic neuropathy using simple bedside tests of short-term R-R interval differences 20. Since that time, beat-to-beat fluctuation (or HRV) has been used to monitor autonomic function in patients with many other cardiovascular conditions 7. In 1977, Wolf et al. 21 found that patients with reduced HRV after a myocardial infarction (MI) had an increased mortality rate of up to three times that of a healthy patient. Further, major breakthrough studies in the 1980’s, particularly by Kleiger et al. 22, demonstrated the role of HRV as an accurate, independent predictor of mortality post MI 3,7,8,18.

Kleiger’s study 22 sparked a critical development in the more recent history of HRV. In 1996, the HRV joint Task Force of the *European Society of Cardiology and the North American Society of Pacing and Electrophysiology* 3 published a consensus statement which established standards of measurement, physiological interpretation and clinical use for HRV. This frequently
cited HRV reference has had no major revisions since its development, asserting its standard for study design \(^{18}\). In fact, a critical review of new HRV analysis methods by Sassi et al. in 2015 \(^{14}\) found that since the HRV Task Force paper in 1996, new methods did not add any additional information concerning the physiological underpinnings of HRV. This clearly indicates HRV’s potential to provide valuable insight into physiological and pathological conditions, further enhancing risk stratification and specificity across a variety of populations \(^{3,8,14,18}\).

_Holter ECG Monitors and a New Wave of Technology_

At the time of the Task Force statement, ECG’s were considered the criterion measure for collection of HRV data, and remain that way today. The Task Force \(^3\) recommends two types of recordings for standardization of studies; Short-term recordings of five minutes are to be analyzed using frequency domain methods, while nominal 24-hour recordings are to be assessed by time domain methods.

Though standard ECG devices are restrictive to a clinic or laboratory, Holter monitors are most commonly used as a compact option to record continuous ambulatory ECG’s over a 24-hour period or longer \(^{1,5,7,8}\); however, this option is still not ideal for daily use in the field as they involve electrodes that are attached to either a stationary or portable machine by long wire leads, making them cumbersome, time consuming, and expensive. In more recent years, commercially available HRV field tools have been devised in order to provide accurate R-R interval data. These include, but are not limited to, the Polar® S810, Polar® RS800, and the Suunto T6© HR monitor and chest strap \(^{1,23}\). In addition, smartphone applications such as, ithlete™ (HRV Fit Ltd. Southampton, UK) and Elite HRV©, have been validated \(^{23,24}\) to provide measures of RMSSD. In these devices, HRV data is transferred to an attached smartphone with the corresponding application by a finger sensor connected to the headphone socket. The application then digitizes
and filters the raw files to provide RMSSD, which is displayed on the smartphone screen almost instantly without the bulk of cumbersome ECG machines, wire, or restrictive heart rate straps. Very recently, similar systems such as HRV4Training²⁵ (see: https://www.hrv4training.com/ ) have been developed which use the built-in camera as photoplethysmography (PPG) device within the individual’s smartphone. During these recordings, an individual places their finger on the phone’s camera and takes a video recording with the LED flash turned on. The recording captures the changes in light absorption by the finger as the capillaries fill and empty of blood ²⁶. 

**Position for Measurement**

Movement will immediately affect HRV as both PNS and SNS systems are involved in meeting physical demands placed on the body ⁵,⁹,²⁷. HRV data has been reliably measured in the supine ²⁸-⁴⁴, seated ⁴⁵-⁵⁴, and standing ⁵⁵-⁵⁸ positions. Young & Leicht ⁵⁹ determined that vagal mediated HRV parameters that were recorded during four consecutive 10-minute ECG segments were significantly similar in healthy non-athletic adults when analyzed in those three positions. However, according to one review ⁶⁰, the majority of HRV studies within healthy populations involved recording with the subjects in the seated position- specifically, with their knees at a 90° angle, both of their feet flat on the floor and their hands on their thighs and eyes closed, similar to what is recommended for blood pressure procedures ⁶⁰. Bearing in mind that other postures might be utilized for practical purposes of the specific experimental condition, for example in sleep research ⁶¹. The HRV Task Force ³ guidelines state that for accurate evaluation of the physiological mechanisms underlying HRV, the measurement needs to be taken free of movement. Explicit interpretation of vagal tone will be extremely difficult under the stress of physical activity; however, alternate methods have been suggested ⁹,⁶²-⁶⁶ if the research question warrants such investigations. It is clear that the chosen posture for the baseline recording should
be the posture that is consistent throughout the entire experiment. The fairly inexpensive and simple nature of this technology is extending the scope of HRV measurement beyond the clinical or research fields.

**Athletic Monitoring**

In recent years, HRV monitoring has gained popularity among coaches and athletes as a simple, non-invasive mechanism to monitor cardiac autonomic regulation simultaneously in large athletic populations. It is well known that HR rises acutely during dynamic exercise due to the initial effects of parasympathetic withdrawal. Thus, studies have shown that during intense training periods, vagal indices of HRV decrease acutely and rebound beyond their pre-training level during subsequent recovery, coinciding with homeostasis restoration. This rebound of HRV has been shown to be associated with improved performance in both recreationally trained and well-trained athletes.

Other tools such as monitoring of saliva and specific blood variables, the use of psychometric questionnaires, or changes in blood lactate have also been implemented for athletic monitoring purposes. However, these tools tend to be invasive, and it is uncertain whether they can appropriately inform on fatigue per se. Thus, they are inconvenient for frequent monitoring. Sports scientists utilize HRV as an objective physiological marker to assist in training management as a means to optimize adaptation and performance in athletes.

Arai et al. were the first to test the modulation of cardiac autonomic activity through exercise. The 1989 study considered 43 healthy volunteers who exercised until maximal exhaustion and their original research has been validated by other researchers. Since that time, several studies have investigated HRV indices measured during both aerobic and anaerobic exercise settings. Their findings suggest that endurance athletes have greater parasympathetic
modulation when compared to power athletes. The literature is also dense in a range of sporting populations, with cycling the most common mode employed according to one review by Michael et al. in 2017. In a recent, unpublished systematic review by the author, HRV was utilized in the following team-sports (descending order): Soccer (‘football’ or futsal) (n=32), Swimming (n=16), Rowing (n=9), Track & Field (n=7), Rugby (Australian Rules, Union, League, Sevens) (n=5), Basketball (n=4), Volleyball (n=3), Ice-Hockey (n=3), Handball (n=3), Badminton (n=2), Baseball (n=2), Wrestling (n=1), Gymnastics (n=1), Field Hockey (n=1), and Hockey (type was not specified) (n=1). Where some articles investigated more than one team sport.

Proper Data Acquisition

There is a variety of methods to assess HRV measurement of athletes in the field. Time domain measures of HRV, in particular RMSSD and SD1 (from Poincaré plots), are less sensitive to respiratory patterns, and only require a short recording time that is essential in sporting practices. Particularly with the rise of previously mentioned smartphone applications, the ease of accessibility and validity make RMSSD the preferred measure for daily use with athletes in the field. Often researchers will take the natural logarithm (Ln) of RMSSD (LnRMSSD) for statistical analysis because it distributes the RMSSD into a ‘normalized’ range of values that reliably and practically measure day-to-day variations in HRV. LnRMSSD weekly average consisting of a minimum of three (randomly selected) measures of LnRMSSD per week, and/or a seven-day running average will accurately identify any vagal-related changes. Furthermore, it is suggested that training adaptation is robustly
related to weekly mean values of HRV compared to single recordings, primarily due to high day-to-day variability, or coefficient of variation (CV), in ANS activity\textsuperscript{135}.

A common misconception regarding HRV for use of ANS status in athletes is that there is a direct linear relationship between vagal-related indices of HRV and the parasympathetic influence on heart rate (HR). However, studies have shown\textsuperscript{138,139} that at both low (high HR) and high (low HR) levels of vagal tone, vagal-related HRV indices are reduced, demonstrating a more quadratic relationship with R-R intervals\textsuperscript{73}. This relationship of fatigue and readiness to perform (thus, ANS status) can be represented by the ratio of LnRMSSD to R-R interval for a specific athlete’s makeup (see Figure 1.1, Appendix A).

In order to accurately consider HRV from a performance perspective, quantification of the training load\textsuperscript{76} and a thorough analysis of the specific population’s training program\textsuperscript{140} is required. Specifically, higher parasympathetic activity associated with intensified training loads, may compromise cardio-acceleration during exercise\textsuperscript{141}. Reductions of PNS activity and subsequent increases in sympathetic activity result in a faster time to maximal output and may be indicative of an increased readiness to perform\textsuperscript{142}. Therefore, understanding of a particular athlete’s response to training and competition from longitudinal monitoring is critical for prescription of an appropriate, balanced conditioning program\textsuperscript{73}.

HRV has been assessed in athletic populations upon waking\textsuperscript{73,143}, sleeping\textsuperscript{69,72}, during exercise\textsuperscript{144} or during post-exercise recovery phase\textsuperscript{145-147}. Short recordings in a supine position upon awakening in the morning, has shown to be the most reliable measure for this population\textsuperscript{4,133}. The determinants of the different positional heart rate measures are described in further detail in Table 1.2 (see Appendix A).
The standard 10-minute collection procedure may meet resistance from coaches whose practice time is sacred, and result in low compliance from the athletes. Therefore, shorter recording durations are preferred for practical purposes within these time-constraints. Esco & Flatt discovered that RMSSD can be accurately acquired through 60-second recordings. Their data suggest no significant differences when this shorter recording was compared to the standard five-minute recordings. As recording times decreased to less than 60 seconds (i.e., 10 and 30 seconds), error of the values increased while strength of correlations decreased. Other groups have demonstrated similar findings in team-sports players, further enhancing the robustness of the measure for athletic populations.

Esco and Flatt continued their investigations on the five-minute stabilization period that is recommended prior to five-minute recordings. Their results showed that stabilization of RMSSD occurs within the first minute of a five-minute prerecording period. These data indicate that RMSSD can be adequately measured with a one-minute stabilization period followed by a one-minute recording period. Lending initial support to shorter, more convenient HRV data collection in athletes.

**Future Directions and Limitations**

A body of literature demonstrates that regular monitoring of these variables can substantially improve the training process given that the appropriate combination, timing, and methodology of data collection is applied. Measurement of HRV is very sensitive to several methodological aspects, which makes comparisons between studies difficult. Buchheit et al. suggest that HR monitoring is still not accepted as a criterion measure due to this lack of consistency in the literature, despite its popularity in the field. A number of recent studies in both athletic and clinical populations, provide an inconsistent picture as a consequence of differences
in data interpretation and their clinical meaning\textsuperscript{4,150}. Further, the HRV Task Force\textsuperscript{3} advises that the population characteristics and the nature of each investigation always be considered when determining the duration of recording. Due to this sensitivity of specific measurements, it is crucial that subjects be recorded under analogous conditions and environments. Keeping track of potential confounding variables (i.e., outliers) will allow the researcher to exclude participants prior to data collection. A few transient variables have been suggested\textsuperscript{9}, which include, but are not limited to: a normal sleep routine the day before the experiment for the subject\textsuperscript{151}, no intense physical training the day before the experiment\textsuperscript{152}, no meal at least two hours before data collection\textsuperscript{153}, no coffee, caffeinated drinks\textsuperscript{154} or tea\textsuperscript{155} in the two hours before, and no alcohol consumption 24 hours prior\textsuperscript{156} to measurement. Finally, the recording of a true baseline is crucial and should be made as consistent and transparent as possible to ensure comparability of the results across samples, experiments, and laboratories\textsuperscript{157}.

Consumer devices are not without potential drawbacks. They report a proprietary metric rather than a standard metric, and do not always provide access to raw data\textsuperscript{150,158}, leaving the technical details of correction methods blind to the consumer\textsuperscript{158}. The ease of access to HRV collection often obscures the complicated nature of the parameter itself. Thus, it is critical that researchers are aware of the concerns related to measurement so studies can be accurately interpreted\textsuperscript{3,9,158,159}.

Furthermore, there is considerable debate as to the exact relationship between changes in cardiac autonomic activity and interactions between the sympathetic and the parasympathetic divisions of the ANS. This is particularly true with regards to the relationship between LF power and cardiac sympathetic regulation\textsuperscript{67}. As this metric continues to grow its reputation as an effective marker of recovery status and potential marker of illness and injury, added research
should be directed towards understanding its true potential. Future studies should emphasize the effects of acute and chronic HRV monitoring of performance, particularly longitudinally. Other gaps in the literature include: the relationship between HRV and injury, inter-and intra-day reliability of the measure and night vs. morning measures. Finally, there appears to be conflicting evidence with the use of HRV in youth (6-12 years) populations; with some suggesting it is reliable \(^3,^{18}\), and others suggesting otherwise \(^2\). Future research on the validity and reliability of HRV in more specific scopes is therefore vital to maximize the benefits of this metric \(^67\).

**Conclusion**

The purpose of this literature review was to describe the evolution of portable HRV devices as a convenient tool for monitoring of the ANS and then explore their utility for the purposes of athletic monitoring. Because the ANS influences the majority of the heart’s components, simple, noninvasive measurements of HR can expose a large range of valid and reliable indices of ANS function \(^3,^{9,73}\). One-minute recordings \(^2\) following a one-minute stabilization period \(^{149}\) for use in athletic monitoring have evolved from the original, 10-minute clinical recordings \(^3\). Smartphone applications \(^{23,24}\) have progressed from cumbersome ECG readings. While HRV data should be interpreted with appropriate caution (as with any metric), it is clear that there is a method to the madness. Based on the Chaos Theory \(^{160}\), a chaotic system exhibits seemingly random behavior with a subtle but regular underlying pattern. The behavior never quite repeats itself exactly, but is controlled within a range of values making the system stable; it does not wander off into infinity as would a random system \(^8\). It may be awhile before researchers can definitively advocate the use of HRV, but the congruency of data suggests we are pointed in the right direction.
CHAPTER 2

INTRODUCTION

In recent years, sports science technology has been in the forefront of athletic monitoring and performance across numerous sport disciplines\textsuperscript{161}. Among these technologies, is the use of short-term measurements of heart rate variability (HRV), which has gained popularity among coaches and athletes as a simple, non-invasive tool to monitor autonomic function in relation to performance and recovery\textsuperscript{87,161}. HRV reflects central regulation of the heart via autonomic innervation, which was traditionally measured in clinical settings\textsuperscript{162} but can now span further into athletic populations\textsuperscript{163}. Several studies\textsuperscript{68-72} have shown that during intense training periods, vagal indices of HRV decrease acutely and rebound beyond their pre-training level periods of recovery, a pattern that coincides with homeostasis restoration\textsuperscript{161,163}. Observation of this rebound effect with training has been associated with greater performance outcomes for both recreationally and highly-trained athletes\textsuperscript{68,69}, especially among athletes competing in highly strenuous sporting events. For example, endurance-type sports, such as rowing, place excessive demands on both the aerobic and anaerobic systems. Such demands result in major perturbations to homeostasis that are often characterized by significant fluctuations in heart rate (HR), and thus, autonomic function\textsuperscript{164}. Given the unique physiologic profile of rowers and their typically high training volumes, monitoring the day-to-day fluctuations in HRV could provide valuable information regarding recovery and adaptation to training.
Tracking individual trends in HRV (i.e., whether HRV is increasing or decreasing over time) and the degree of fluctuation within each individual, appears to provide valuable insight regarding training volume, recovery status, and readiness to perform that coaching and sports medicine staff can incorporate as another tool to evaluate and monitor athletes’ responses to training. The time-domain HRV parameter, the root mean square of successive R-R intervals (RMSSD), has been proposed as the preferred marker of monitoring resting HRV overtime to obtain a weekly (or rolling) average among athletes under ambulatory or field-based conditions. Because HRV is a reflection of ANS activity, HRV metrics that are used to measure and quantify autonomic function, like RMSSD (and other HRV metrics) are influenced by variety of external and internal factors. Nonetheless, time constraints in a collegiate sport environment (i.e., training scheduling, compliance with National Collegiate Athletic Association [NCAA] regulations; etc.) and irregular practice hours are typical challenges for many varsity sports and make monitoring physiologic adaptations to training difficult. To circumvent these issues, several physiologic monitoring devices, including those that measure resting HRV, have been adapted for use in non-laboratory settings (i.e., home-based setting or training/practice facility). Despite these advances, the practicality of obtaining high athlete compliance and reliable HRV measures in an unsupervised, home-based setting remains a concern among coaches and researchers alike. Performing all resting HRV measures on-site at the beginning of regularly scheduled practice sessions, with oversight from trained researchers, seems to represent the most practical and accurate monitoring solution for collegiate athletics. Yet, based on existing recommendations, it is unclear whether the reliability of short-term HRV measurements is influenced by the timing of when they are performed in the morning hours (i.e., measured immediately upon waking versus immediately prior to morning practice). To our
knowledge, we are unaware of any study that has investigated the within-and between-day reliability of short-term HRV measurements among athletes and its association with athletic performance. Therefore, the primary aim of this study was compare HRV values when recorded immediately upon waking to the values recorded later in the morning, but still prior to practice. In addition, this study sought to determine the associations of these HRV measures with performance outcomes in competitive female rowers.

We hypothesized that home-based HRV measurements taken immediately upon waking (T1) will be different than HRV measurements taken later in the morning at the boathouse prior to practice (T2) due to the increasing number of external and internal factors that could affect the ANS in the time since waking. For these reasons, we also hypothesized that the home-based HRV measurement (T1) will be a more reliable indicator of performance compared to the HRV measurement taken at the boathouse before practice (T2).
CHAPTER 3
METHODOLOGY

Participants

Thirty-nine (n= 39) female, NCAA Division I Collegiate Rowers were recruited from the University of Alabama (Tuscaloosa, AL) Women’s Rowing Team to participate in this study. The athletes were members of the same varsity team with 4.0 ± 2.7 years of competitive rowing experience.

Inclusion and Exclusion Criteria

Existing literature suggests that training adaptation is more precisely reflected by weekly mean values of HRV than to isolated recordings due to daily perturbations characteristic of ANS activity, and thus, HRV. Further, the RMSSD weekly average consisting of three or more measures per week or a seven-day running average has been shown to accurately identify any vagal-related changes in athletes and is considered a criterion measure for tracking weekly changes in autonomic function in response to training. Therefore, only those athletes who complete both measurements (T1 and T2) on at least three of the six recording days were included in the final analysis.

Each of the participants received medical clearance by the university physicians to participate in the strenuous physical demands required by the sport of rowing. None of these individuals had any diagnosed disabilities or diseases that could influence their response to
training. If an injury occurred during, or prior to the testing period, which did not allow the rowers to complete at least two of the three performance measurements, they were excluded from the study. Rowers who were taking medications for hypertension, ADD/ADHD, and/or any other stimulant/depressant that could otherwise influence the cardiovascular system were excluded from the study 166, but this was not the case. Menstrual cycle and contraception use were identified for each of the women, but with little conclusive evidence towards this effect on vagal tone, and thus HRV, in female athletes, they were included in the analysis. The rowers were asked to refrain from alcohol consumption for the entirety of the study to rule out any affects that this could have on their HRV scores 167, and all subjects self-reported this abstinence.

Written informed consent was obtained by each participant after learning of any potential risks associated with their involvement in the study. This study was approved by the University’s Institutional Review Board (see Appendix F), as well as NCAA Compliance personnel.

*Overview of the Study Design*

The rowing athletes were monitored for one-week during the beginning phase of their winter training program (see Appendix B). Athletes reported to campus in early January to begin their training with an intensive seven-day training camp (1/3/2018 - 1/9/2018). Following the training camp, athletes had a four-day rest period in which no formal team practice or training sessions were held. Athletes then began formal, in-season training (20 hours per week) that marked the start of their spring season (01/15/2018). The athletes did not compete in any formal races during the week of data collection, nor in the period leading up to it.
Training Program

The same rowing coach provided the training plan for all rowing athletes. As such, the training program content was similar across rowers and consisted of: on-the-water rowing practice, land-based ergometer training and strength training (see Appendix B). Briefly, on-the-water practices occurred six days per week for three hours: Monday through Friday from 06:00 – 09:00 AM and Saturday from 07:00 – 10:00 AM. All team members met at their on-campus boathouse for practice, and completed an aerobic warm-up before separating into boat pairings for practice. Land-based ergometer training sessions were held on Monday and Friday afternoons, for one-hour and thirty minutes. Strength training was held on Tuesday and Thursday following water practice, lasting approximately one-hour and fifteen minutes. The total training time for the observed week was within the NCAA compliance limit of 20 hours allowed during in-season training per week.

Heart Rate Variability Recordings

HRV recordings were obtained using a previously validated photoplethysmography (PPG) smartphone application, HRV4Training (see: https://www.hrv4training.com/) (see Appendix C). The athletes were instructed to remove any phone covers which impede direct contact with the camera sensor so that they would be able to cover the flash of their mobile device completely with their left index finger for all recordings. The PPG device uses the phone’s camera and flash light to illuminate the skin in order to monitor changes in blood volume during a cardiac cycle. Athletes were instructed to assume a seated position for all HRV measurements in an attempt to reduce all possible parasympathetic saturation, a common observation among highly fit individuals with low resting HR. Once seated in a neutral position with their feet on the ground, athletes were instructed to limit any bodily movement and practice
spontaneous breathing before opening the HRV4Training application on their personal mobile device. The same mobile device was used throughout the entire study period for both the T1 and T2 collection points. The rowers then initiated a one-minute stabilization period, which began once their left index finger was completely covering the camera sensor, followed by a one-minute data acquisition period. This ultra-shortened RMSSD metric has been validated in other athletic monitoring studies, and has been shown to be as sensitive as the ten-minute criterion measure defined by the Task Force, which can be impractical in these athletic environments.

The athletes were guided through their first HRV measurement at an introductory session held on the first day of training camp (see Appendix E). This session was also used to download the application onto each of the volunteer’s personal mobile devices. Following this introduction, study participants underwent a three-week familiarization period that allowed the athletes to become accustomed to taking an accurate measure under the supervision of the same three trained graduate research assistants that were present for the duration of the study. During the familiarization period, athletes were instructed to perform daily HRV measurements each morning upon arrival to the team’s on-campus boathouse, prior to the start of practice, in the same aforementioned procedure. The third week of data collection was chosen for this study due to superior compliance, spring race schedules, and research deadlines.

During the week of data collection (01/22/2018 - 01/27/2018), the rowers were asked to complete two morning measurements, each lasting a total duration of two-minutes, using the same personal mobile device with the HRV4Training PPG application. The first HRV measurement (T1) was performed at the athletes home immediately after waking and elimination according to the same procedures used in the three-week familiarization period. Wherein, they
proceeded through their normal, pre-practice morning routine prior to arrival at the boathouse. The second HRV measurement (T2) was obtained within one-hour of the first measurement (T1) upon arriving at the on-campus boathouse for daily practice according to the same procedures used in the familiarization period and earlier that morning. All HRV measurements were collected between 05:30 AM and 06:00 AM in the quiet repair bay area of the boathouse, away from the main boat bay, under the supervision of the same trained graduate research assistants.

The HRV4Training PPG smartphone application was chosen among the plethora of HRV monitoring devices due to the low cost, ease of navigation through the coaching platform, and lack of burdensome additional devices that are generally required by HRV monitoring tools (i.e., HR straps, finger sensors, or ECG leads), and often result in low athlete compliance. The HRV application implements a peak detection algorithm, based on a slope inversion, to determine peak-to-peak intervals \(^{171}\) wherein intervals are corrected for artifacts automatically if they differ by more than 75% from the previous or removing outliers that do not fall within the defined limits \(^{25}\). However, researchers found a slight limitation in the device for the purposes of this study, as currently it only allows one measurement per athlete per day. As such, the data points collected at T1 were exported from the coaching platform to the study database by the same researcher at 05:30 AM each morning, prior to the second collection point (T2). Following T2 data collection, HRV values were appropriately labeled and exported to the same study database. Each of the subject’s names were promptly replaced with their assigned number as to protect the privacy of the participants, and the anonymity of the data.

Following each HRV recording, the subjects answered a few questions which automatically appeared within the application. The questions inquired about injury, diet, mode of transport to the boathouse, alcohol intake, supplements, menstrual cycle, and sickness. These
inquires allowed the researchers to control for the daily tasks performed between the two measurements (i.e., breakfast/caffeine consumed, medications taken, mode of transportation to the boathouse) as to rule out any limitations that could externally impact their performance/HRV measurement overall.

**Performance Metrics**

Rowing ergometers are designed to simulate movement performed by on-water rowing and are widely considered a valuable tool for rowing training, the evaluation of a rower’s sport-specific performance, and the detection of changes in performance. Although ergometer rowing differs somewhat from the on-water training in terms of the skills required, it closely simulates the biomechanical and metabolic demands of on-water rowing. As such, two land-based rowing ergometer tests were included as markers of performance.

The team’s training plan with each individual’s rowing ergometer and on-water performance was collected from the coaches from the onset of data collection and continued throughout the entire study period. The performance metrics, ergometer tests (2,000-m timed-trial and distance covered in 30-min) and team ranking, are described in greater detail next:

Performance records included split and time of completion for each of the athletes’ 2,000 meter ergometer test pieces, with the shorter time to completion indicating a greater performance. This is a common performance metric used in the sport of rowing to objectively quantify a rower’s ability to effectively move their mass through the stroke compared to their teammates and competitors; it also mimics the distance used for Olympic (and most other) rowing events. This test requires an excess of their anaerobic threshold, and an average oxygen consumption of 95% or greater of $\bar{VO}_2\text{max}$ to ensure a successful performance.
The typical collegiate rowing season (in the United States) begins in September with longer race lengths (i.e., 4,000 – 10,000 meters) designed to build an endurance base with technical proficiency for the more anaerobically taxing spring races, generally comprised of 2,000 meters (see Table 3.6, Appendix B & Appendix D for more information). Thus, the winter training period (generally November to March) of the season focuses on the shift from primarily aerobic to anaerobic thresholds. The 30-minute ergometer test reflects the amount of meters pulled on an indoor ergometer over the course of 30-minutes.

The rank of each rower within the team (54 members in total) was determined on a weekly basis at the discretion of the coaching staff. Team ranking reflects the overall performance of each rower that week and is a culmination of:

- Racing performance, including but not limited to; Time trials, small and/or large boat matrices and/or seat racing
- Ongoing ergometer testing
- Factors relevant to crew combination, namely within crew compatibility, as well as individual coachability, technical compatibility, and team balance/harmony
- Assessment of competitive readiness
- Other factors relevant to achieving team objectives (i.e., academic eligibility, injury, etc.)

**Other Outcomes**

Pertinent health histories were collected from the team’s medical staff for all 39 athletes and included the following: birthdate, height, weight, current medication use, and past and current injury reports.

Years of experience, novice/varsity status on the team, and scholarship award were collected directly from the rowing athletes during the introductory session and confirmed by the coaches following compilation for descriptive analysis.
**Statistical Analyses**

*Comparison of RMSSD Measures Collected at Two Different Time-points (T1 and T2)*

The RMSSD mean (RMSSDM) and coefficient of variation (CV) (RMSSDCV) was calculated (CV = [SD/mean] \times 100) for each recording. RMSSDCV values represent the standard error of the estimate (i.e., absolute reliability) within inter-day RMSSD assessments. The mean and CV RMSSD values collected for each athlete at both time-points (i.e., T1, home-based measure and T2, boathouse measure) were compared using paired samples t-tests. Cohen’s $d$ effect size was also calculated to gauge the magnitude of these differences (if any) using a standardized metric. Effect sizes were interpreted using Hopkins’ thresholds\(^{177}\), <0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large. Finally, we calculated the limits of agreement, which were quantified using intraclass correlation coefficients (ICC), to determine the relative reproducibility of the mean and CV RMSSD measures between T1 and T2. The Bland-Altman method\(^{178}\) was utilized for assessing agreement between the difference scores between T1 and T2 for both RMSSDM and RMSSDCV.

*Relationship between the RMSSD Measures and Performance Indicators*

Pearson and Spearman Rho correlational analyses were performed to determine if the HRV parameters (RMSSDM and RMSSDCV) were related to both continuous (i.e., 2,000 meter time and 30-minute meters) and categorical (i.e., rank) measures of performance. The thresholds used to interpret the magnitude or strength of the correlation coefficients (i.e., ICC, Pearson, Spearman Rho) were as follows: <0.10, trivial; 0.10–0.29, small; 0.30–0.49, moderate; 0.50–0.70, large; 0.70–0.89, very large; >0.90, nearly perfect\(^{177}\). Statistical significance was set at an alpha-level of $p < 0.05$. 

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Potential Influence of Confounders

Independent samples t-test was used to determine if the RMSSD parameters (mean and CV) were different across the sample when categorized based on whether they engaged in behaviors that may have confounded or biased within-day HRV measurements taken at T1 versus T2: consumed food, caffeine or medications between measurements (categorized as “yes” or “no”), relied on an active (e.g., walking or biking) or passive (e.g., bus, drove themselves or were driven as a passenger) mode of transportation to the boathouse (active = yes; passive = no). Other variables that may have influenced between-day HRV measurements (but not within-day measures) were also analyzed using independent samples t-test and included: presence of menstrual cycle at any point throughout the week (“yes” or “no”), use of contraceptive or birth control (“yes” or “no”), other medication use, that did not include birth control and was not taken between the two recordings (“yes” or “no”), reported sickness at any point throughout the study period, as confirmed by athletic trainer (“sickness/ill” or “healthy”), reported injury at any point throughout the study period, as confirmed by athletic trainer (“injured” or “healthy”), status within the team (“varsity” or “novice”; see Appendix B), recruitment status from high-school athletics (“recruit” or “walk-on”), and scholarship athletes of any amount, as dictated by coaching staff (“scholarship” or “no funding”). Because average time between each recording (T1 and T2) was a continuous variable, a Pearson correlation coefficient was used to determine if it was related to the difference in the RMSSD values.

Statistical Computing

Analyses were performed using SPSS software (Version 23.0, IBM Corp., New York, NY, USA) and Microsoft® Excel® 2016 (Redmond, WA, USA). Data are presented as mean ± standard deviation (M ± SD). The Shapiro-Wilk test was used to assess the normality of the
studied variables; variables that violated assumptions of normality were log-transformed (Ln). LnRMSSD is a preferred HRV parameter for monitoring athletes in field settings\textsuperscript{2,161,163} as it provides a practical and reliable method for which to distribute the RMSSD into a ‘normalized’ range of values, without the influence of breathing frequency and parasympathetic activity across a shortened time-frame\textsuperscript{164}. Daily RMSSD values were transformed using the natural logarithm (LnRMSSD); mean (LnRMSSD\textsubscript{M}) and CV (LnRMSSD\textsubscript{CV}) RMSSD values were generated and used for all analyses \textsuperscript{2,161,163}. 
CHAPTER 4

RESULTS

Of the 39 participants that were recruited, 31 athletes completed the study and were included in the analyses (the descriptive characteristics of the athletes who completed the study and those that did not are summarized in Table 4.1). Of the eight non-completers, six were excluded for not meeting *a priori* study inclusionary criteria (see Chapter 3 for details) and two athletes sustained injuries during the study and were not able to complete the assigned workouts, despite high study compliance. The completers were not significantly different than the non-completes (see Table 4.1), and thus, the removal of these athletes from our sample did not influence the final results.

**Figure 4.1.** Flow-diagram outlining the complete study participation.

- Total number of rowing athletes on the team who were invited to participate in the study: $n=54$
- Rowers who consented to participate in the study: $n=39$
- Rowers who completed the study within the limits of the inclusion and exclusion criteria: $n=31$
Table 4.1. Comparison of baseline characteristics of study completers versus non-completers.

<table>
<thead>
<tr>
<th>Group Statistics</th>
<th>Completers (n=31)</th>
<th>Non-Completers (n=8)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (in)</td>
<td>67.91 ± 2.00</td>
<td>67.25 ± 2.28</td>
<td>0.426</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.06 ± 12.63</td>
<td>72.94 ± 10.58</td>
<td>0.299</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.30 ± 4.04</td>
<td>24.99 ± 2.66</td>
<td>0.393</td>
</tr>
<tr>
<td>Age (yrs.)</td>
<td>19.74 ± 1.18</td>
<td>19.50 ± 0.76</td>
<td>0.587</td>
</tr>
<tr>
<td>Tot. Rowing Exp. (yrs.)</td>
<td>3.97 ± 2.80</td>
<td>4.13 ± 2.53</td>
<td>0.886</td>
</tr>
</tbody>
</table>

Statistics are summarized as mean ± SD unless stated otherwise. SD, standard deviation; in, inches; kg, kilograms; m, meters; yrs, years; BMI, Body Mass Index; Tot., total; Exp., experience; bpm, beats per minute.

All of the rowers (100%) were of Caucasian descent and two of the girls were from outside of the United States (i.e., New Zealand and United Kingdom), recruited to the university for athletics. Of the girls that completed the study, 13 were starboard (right side) sweep rowers, ten port (left side) sweep rowers, and eight were ambidextrous sweep rowers (i.e., were able to row on both sides of the boat; see Appendix D). Eight of the rowers were in their novice (or first) year of rowing at the collegiate level, while the other 23 were members of the varsity squad, with >1 years of competitive rowing experience. 48.4% of the sample were recruited by the coaching staff to join the team based on their rowing performance in high school and 54.8% of the 31 rowers were on scholarship for their athletic abilities.
Table 4.2. Summary of independent sample t-tests of potential confounders of HRV recordings taken at T1 versus T2.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Yes/No (n rowers)</th>
<th>LnRMSSD_M Mean ± SD</th>
<th>p</th>
<th>LnRMSSD_CV Mean ± SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Potential Confounders between HRV Recordings at T1 and T2 (within-day variability)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumed food between measures</td>
<td>Yes (n=15)</td>
<td>0.02 ± 0.39</td>
<td>0.499</td>
<td>-0.04 ± 2.75</td>
<td>0.558</td>
</tr>
<tr>
<td></td>
<td>No (n=16)</td>
<td>-0.08 ± 0.43</td>
<td></td>
<td>0.71 ± 4.18</td>
<td></td>
</tr>
<tr>
<td>Type of transportation from home to boathouse</td>
<td>Active (n=10)</td>
<td>0.02 ± 0.41</td>
<td>0.642</td>
<td>0.16 ± 2.96</td>
<td>0.837</td>
</tr>
<tr>
<td></td>
<td>Passive (n=21)</td>
<td>-0.06 ± 0.41</td>
<td></td>
<td>0.44 ± 3.83</td>
<td></td>
</tr>
<tr>
<td>Consumed caffeine food between measures</td>
<td>Yes (n=5)</td>
<td>-0.09 ± 0.47</td>
<td>0.724</td>
<td>1.77 ± 3.68</td>
<td>0.335</td>
</tr>
<tr>
<td></td>
<td>No (n=26)</td>
<td>-0.02 ± 0.40</td>
<td></td>
<td>0.08 ± 3.50</td>
<td></td>
</tr>
<tr>
<td>Medication use between measures</td>
<td>Yes (n=10)</td>
<td>-0.10 ± 0.49</td>
<td>0.515</td>
<td>-0.50 ± 3.22</td>
<td>0.365</td>
</tr>
<tr>
<td></td>
<td>No (n=21)</td>
<td>0.00 ± 0.37</td>
<td></td>
<td>0.75 ± 3.67</td>
<td></td>
</tr>
<tr>
<td><strong>Potential Confounders of Daily HRV Recordings (between-day variability)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Menstruation status</td>
<td>Yes (n=13)</td>
<td>-0.08 ± 0.36</td>
<td>0.613</td>
<td>-0.25 ± 2.87</td>
<td>0.430</td>
</tr>
<tr>
<td></td>
<td>No (n=18)</td>
<td>-0.00 ± 0.45</td>
<td></td>
<td>0.78 ± 3.95</td>
<td></td>
</tr>
<tr>
<td>Contraceptive use</td>
<td>Yes (n=15)</td>
<td>-0.07 ± 0.45</td>
<td>0.670</td>
<td>-0.23 ± 3.18</td>
<td>0.382</td>
</tr>
<tr>
<td></td>
<td>No (n=16)</td>
<td>0.00 ± 0.37</td>
<td></td>
<td>0.90 ± 3.84</td>
<td></td>
</tr>
<tr>
<td>Other medication use</td>
<td>Yes (n=10)</td>
<td>-0.23 ± 0.53</td>
<td>0.133</td>
<td>0.60 ± 2.88</td>
<td>0.787</td>
</tr>
<tr>
<td></td>
<td>No (n=21)</td>
<td>0.06 ± 0.30</td>
<td></td>
<td>0.23 ± 3.85</td>
<td></td>
</tr>
<tr>
<td>Health status</td>
<td>Sick/Ill (n=6)</td>
<td>0.10 ± 0.21</td>
<td>0.380</td>
<td>-0.81 ± 4.31</td>
<td>0.379</td>
</tr>
<tr>
<td></td>
<td>Healthy (n=25)</td>
<td>-0.07 ± 0.44</td>
<td></td>
<td>0.63 ± 3.35</td>
<td></td>
</tr>
<tr>
<td>Injury status</td>
<td>Injured (n=12)</td>
<td>0.01 ± 0.38</td>
<td>0.603</td>
<td>2.03 ± 2.98</td>
<td>0.027*</td>
</tr>
<tr>
<td></td>
<td>Healthy (n=19)</td>
<td>-0.06 ± 0.43</td>
<td></td>
<td>-0.71 ± 3.48</td>
<td></td>
</tr>
<tr>
<td>Collegiate rowing status</td>
<td>Varsity (n=23)</td>
<td>-0.10 ± 0.45</td>
<td>0.051</td>
<td>0.41 ± 3.68</td>
<td>0.884</td>
</tr>
<tr>
<td>Scholarship status</td>
<td>Novice (n=8)</td>
<td>Recruited (n=15)</td>
<td>Walk-on (n=16)</td>
<td>No funding (n=14)</td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------------</td>
<td>------------------</td>
<td>---------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.14 ± 0.20</td>
<td>-0.13 ± 0.47</td>
<td>0.06 ± 0.32</td>
<td>-0.05 ± 0.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.19 ± 3.26</td>
<td>0.36 ± 3.07</td>
<td>0.34 ± 4.01</td>
<td>-0.27 ± 3.50</td>
<td></td>
</tr>
<tr>
<td>On scholarship (n=17)</td>
<td>-0.02 ± 0.43</td>
<td>0.200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No funding (n=14)</td>
<td></td>
<td></td>
<td>0.823</td>
<td>0.86 ± 3.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.387</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically Significant (p <0.05)

HRV, heart rate variability; M, mean; CV, coefficient of variation; SD, standard deviation; T1, home (1st) measurement; T2, boathouse (2nd) measurement; Active (e.g., walking or biking) or passive (e.g., bus, drove themselves or were driven as a passenger); Collegiate rowing status: varsity, 1+ years of collegiate rowing experience; novice, <1 years of collegiate rowing experience.
Potential Influence of Confounders

Three athletes were tri-annually injected with a birth control hormone, one had a vaginal ring inserted, while the other 11 were taking an oral contraceptive to provide birth control. 10 of the women were prescribed and were taking medications that did not include birth control; Such medications included allergy (n= 6), and pain/anti-inflammatory medications (n= 4). Six (n= 6) girls reported being sick during the testing period, as confirmed by their team physician, 12 of the girls were seeing an athletic trainer for an injury that still allowed them to practice to their full abilities. Injuries included tendonitis of wrist (n= 1), shins (n= 2), knees (n= 2) and Achilles Tendon (n= 1), lower back pain (n= 3), lateral ankle sprain (n= 1), and Iliotibial Band weakness (n= 2).

Table 4.2 investigates the difference scores for each individual participant between the means of their T1 and T2 measurements as they influence potential confounders to the study. The total sample (n= 31) average difference of the LnRMSSD\(_M\) between the two time points was -0.03 ± 0.41. The minimum difference for the LnRMSSD\(_M\) was -1.14 and maximum, 0.59. The total sample average difference within the LnRMSSD\(_C\) was 0.35 ± 3.52 where the minimum difference was -7.35 and maximum, 6.73.

Comparison of RMSSD Measures Collected at Two Different Time-points (T1 and T2)

Table 4.3. Comparison of the means between home and boathouse LnRMSSD measurements.

<table>
<thead>
<tr>
<th>Measure</th>
<th>ES</th>
<th>ICC</th>
<th>Bias</th>
<th>1.96*SD</th>
<th>Lower</th>
<th>Upper</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.06</td>
<td>0.82</td>
<td>0.03</td>
<td>0.80</td>
<td>-0.76</td>
<td>0.83</td>
<td>0.63-0.92</td>
</tr>
<tr>
<td>T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Statistically Significant (p < 0.05)

T1, home (1\(^{st}\)) measurement; T2, boathouse (2\(^{nd}\)) measurement; SD, standard deviation; ES, effect size
As shown in Table 4.3, changes in LnRMSSD$_{M}$ and LnRMSSD$_{CV}$ were not associated with the time between T1 and T2 within the current sample ($r = -0.166$, $p = 0.372$, small; $r = -0.008$, $p = 0.964$, trivial, respectively). The mean of the differences between daily recordings of T1 and T2 was $2,013.90 \pm 800.93$ seconds ($33.57 \pm 13.35$ minutes).

Figure 4.2. A Bland-Altman plot is graphed in the figure above, where the middle line represents the mean bias (as seen in Table 4.3, above), 0.03 between the home (T1) and boathouse (T2) measurements. The upper limit of agreement is represented in the top line at 0.83 and the lower limit of agreement is represented in the bottom line at -0.76.
Table 4.4. Comparison of the CV (%) between home and boathouse LnRMSSD measurements.

<table>
<thead>
<tr>
<th>Measure</th>
<th>ES</th>
<th>ICC</th>
<th>Bias</th>
<th>1.96*SD</th>
<th>Lower</th>
<th>Upper</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>-0.09</td>
<td>0.75</td>
<td>-0.35</td>
<td>6.91</td>
<td>-7.26</td>
<td>6.56</td>
<td>0.63-0.92</td>
</tr>
<tr>
<td>T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CV, coefficient of variation; T1, home (1st) measurement; T2, boathouse (2nd) measurement; SD, standard deviation; ES, effect size

Table 4.4 investigates the agreement (p= 0.584) of the LnRMSSD<sub>CV</sub> between the home measurements (T1) and boathouse measurements (T2) for the thirty-one rowers. The effect size of -0.09 qualitatively indicates a very trivial impact (<0.2) on the measures.

Figure 4.3. Bland-Altman method comparing the differences against the means for T1 and T2 LnRMSSD<sub>CV</sub> measurements
Figure 4.3. A Bland-Altman plot is graphed in the figure above where the middle line represents the mean bias (as seen in Table 4.4), -0.35, between the home (T1) and boathouse (T2) measurements. The upper limit of agreement is represented in the top line at 6.56 and the lower limit of agreement is represented in the bottom line at -7.26.

*Relationship Between the RMSSD Measures and Performance Indicators*

*Table 4.5.* Summary of HRV parameters (LnRMSSDM and LnRMSSDCV) at T1 and T2 as well as performance outcomes for the 31 participants.

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Rank</th>
<th>Ergometer Tests</th>
<th>Heart Rate Variability Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2,000-m Time (s)</td>
<td>30-min Distance (m)</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
<td>453</td>
<td>7258</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>445.2</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>471</td>
<td>7077</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>435</td>
<td>7653</td>
</tr>
<tr>
<td>5</td>
<td>17</td>
<td>450.4</td>
<td>7264</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>468.6</td>
<td>7118</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>445.1</td>
<td>7362</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>451</td>
<td>7254</td>
</tr>
<tr>
<td>9</td>
<td>29</td>
<td>462.9</td>
<td>7153</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>475.2</td>
<td>6953</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>456.6</td>
<td>7061</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
<td>457</td>
<td>7162</td>
</tr>
<tr>
<td>13</td>
<td>32</td>
<td>471.7</td>
<td>7058</td>
</tr>
<tr>
<td>14</td>
<td>40</td>
<td>458</td>
<td>7116</td>
</tr>
<tr>
<td>15</td>
<td>34</td>
<td>467.7</td>
<td>6837</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>434.7</td>
<td>7361</td>
</tr>
<tr>
<td>17</td>
<td>9</td>
<td>437</td>
<td>7409</td>
</tr>
<tr>
<td>18</td>
<td>51</td>
<td>448.6</td>
<td>-</td>
</tr>
<tr>
<td>19</td>
<td>38</td>
<td>467.3</td>
<td>6987</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>449.2</td>
<td>7340</td>
</tr>
<tr>
<td>21</td>
<td>48</td>
<td>477.6</td>
<td>6878</td>
</tr>
<tr>
<td>22</td>
<td>49</td>
<td>485.7</td>
<td>6722</td>
</tr>
<tr>
<td>23</td>
<td>43</td>
<td>484.3</td>
<td>6884</td>
</tr>
</tbody>
</table>
Table 4.5. There were 12 total recordings (six days × two recordings) that could have been completed and 32.3% of the subject’s fulfilled these requirements, while 16.1% met the minimum criteria of six total recordings in three days. The average 2,000 meter score for the team was 458.59 seconds or 07:38.59 minutes. The average meters rowed during the 30-minute test on the indoor rowing ergometer was 7,143.17 ± 234.63 meters or 4.44 ± 0.15 miles.

Table 4.6. Correlation coefficients between the LnRMSSD M and CV values and performance variables.

<table>
<thead>
<tr>
<th></th>
<th>LnRMSSD_M T1</th>
<th>LnRMSSD_M T2</th>
<th>LnRMSSD_CV T1</th>
<th>LnRMSSD_CV T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank</td>
<td>-0.55*</td>
<td>-0.46*</td>
<td>-0.25</td>
<td>-0.06</td>
</tr>
<tr>
<td>2,000m</td>
<td>-0.37*</td>
<td>-0.33</td>
<td>-0.32</td>
<td>-0.20</td>
</tr>
<tr>
<td>30min</td>
<td>0.40*</td>
<td>0.41*</td>
<td>0.37</td>
<td>0.15</td>
</tr>
</tbody>
</table>

*Statistically significant (p < 0.05)

M, mean; CV, coefficient of variation; T1, home (1st) measurement; T2, boathouse (2nd) measurement.
Table 4.6. Moderate-to-large correlations were observed for LnRMSSD_M and performance outcomes at both time-points: Rank (T1: p= 0.002, large and T2: p= 0.009, moderate), 2,000 meter (T1 only: p= 0.044, moderate) and 30-minute meters (T1: p= 0.032, moderate and T2: p= 0.027, moderate). There were no significant correlations observed for LnRMSSD_CV and performance markers at any time-point. Very large and significant (p < 0.01) intra-class correlations were found between LnRMSSD_M for T1 and T2 (ICC= 0.82, 95% CI= 0.63 to 0.92), as well as between LnRMSSD_CV for T1 and T2 (ICC= 0.75, 95% CI= 0.48 to 0.88).
CHAPTER 5
DISCUSSION, CONCLUSION, & PRACTICAL APPLICATIONS

The purposes of this study were to compare RMSSD values when recorded immediately upon waking to values recorded later in the morning prior to practice, and to determine the associations of these measures with performance outcomes in competitive female rowers. In contrast to our initial hypothesis, we found no difference in LnRMSSD values (mean and CV) when measured upon immediately waking versus later in the morning prior to practice. Moreover, we found that the LnRMSSD_M value, but not LnRMSSD_CV, was moderately associated with rowing performance for this sample.

While not statistically significant, the status or experience level of the rower (i.e., varsity vs. novice) tended to influence LnRMSSD_M values in our sample. The change in LnRMSSD_M values at T1 vs. T2 was lower for varsity than novice rowers (p= 0.051), suggesting that varsity rowers were more accustomed to their training program than their novice counterparts (i.e., experienced less perturbation to homeostasis). This would make sense given the repetitive nature of this sport, however, further investigation into the influence of years of experience and meters rowed on RMSSD are warranted before any further conclusions can be drawn.

Physical injury (mainly musculoskeletal overuse injuries) relating to the sport was the only variable that significantly influenced the LnRMSSD_CV values taken at T1 versus T2 (p= 0.027). It is well accepted that multiple factors contribute to the development, progression, and healing of athletic injuries, but the exact pathophysiology, and dynamic role of the ANS on
such injuries remains a debated topic. However, considering this dynamic communication pathway between the central and peripheral nervous system, monitoring the body’s response to stress and recovery at the ANS level may have the potential to reveal early signs of injury.

Daily RMSSD assessment in athletes is growing in popularity for tracking individual trends related to performance outcomes. The Task Force recommends that subjects should be recorded under fairly similar conditions and environment while obtaining HRV measures, but does not specify when is most appropriate. This is the first study of its kind to investigate the reproducibility of LnRMSSD mean and CV across an entire week (i.e., six days) among competitive (Division I) collegiate female rowers, which represent an understudied population. Our findings suggest that athletic monitoring of HRV (i.e., mean and CV LnRMSSD values) can be performed either at home, upon waking in a fasted state (T1) or later in the morning prior to practice at the rowing facility (T2). Mean LnRMSSD values obtained at both time-points correlated with the performance indices, with T1 recordings correlating more strongly than those at T2. Interestingly, the CV of daily LnRMSSD values, which generally represents perturbations to cardiac-autonomic homeostasis (i.e., the day-to-day fluctuations of HRV), were not correlated with any performance indices at either time point. The lack of correlation between LnRMSSD and performance markers is not surprising given the considerable variation in the daily training programs (i.e., type of training and volume) and the training schedule during the week of data collection (see Appendix B). Nonetheless, our findings seem to support that both time-points, when utilized consistently, can accurately assess adaptation to a training stimuli in female collegiate rowers. Given the time constraints and difficulty with compliance when administering such monitoring programs- that was even apparent in our sample, where only 31
of the 54 total rowers volunteered and completed the study to its length- we recommend that coaches and practitioners consider using the most practical method of pre-practice recording measures taken at the training facility (i.e., T2 in this study).

Cardiac autonomic regulation is sensitive to a variety of stimuli, particularly in athletes whom are engaged in various daily training sessions along with other sources of stress. Research within athletic populations suggests that averaged weekly morning resting RMSSD measures provides a consistent representation of actual changes in an athlete’s autonomic balance. For example, Nakamura et al. demonstrated superior interday and intraday reliability between LnRMSSD measures in elite rugby union players, but only investigated trends within the first training day of the week, and took place in the same location and position with only 10 minutes between each recording. Upon investigation of the relationships between positional groups of a collegiate football team and training load parameters, Flatt et al. recorded RMSSD measures using a smartphone device while the subjects were in the athletic training facility, on a training table, 60-90 minutes before training and at least 90-minutes after team breakfast. However, these studies used a single LnRMSSD recording across multiple days, which offers limited insight regarding the effects of circadian-induced variation in cardiac autonomic nervous control in apparently healthy individuals, especially among female athletes.

Limitations and Strengths

This study is not without limitations. First, the agreement between ultra-short-term HRV (i.e., one-minute LnRMSSD) and the criterion five-minute data acquisition has been previously demonstrated, however, it was not done so using the PPG sensor, nor the HRV4Training smartphone application. Furthermore, much of the HRV research has been conducted in athletic
populations consisting of elite (i.e., Olympic or National Team level), male athletes and thus, is not generalizable to the current study sample or other studies involving female athletes. It is unclear how this may have influenced our results, if at all. Second, this study was conducted in a competitive, collegiate (NCAA Division I) university setting where the athletes may have been exposed to stressors that may not have affected other individual rowers (e.g., academic, family, and social stressors). Studies involving different sports disciplines and populations, as well as other HRV tools are warranted in order to extend its use within the athletic realm, and beyond.

This study has several strengths, most notable is the unique study population. The research conducted to date mainly involves elite male athletes and does not take into consideration the interaction between the menstrual cycle and autonomic function. Our study did not find any significant changes between those who were menstruating and those who were not in terms of the two time points (see Table 4.1); however, we did not collect specific information regarding phase of menstrual cycle or type of contraceptive used. The existing literature on the effects of menstrual cycle hormone fluctuations on exercise performance is equivocal. Future research should consider these variables in both short- and long-term study designs and their interactions with weekly individual training adaptation. Furthermore, this study also utilized a unique approach to HRV monitoring as it was designed to represent the real-life daily activities of the rowers over time and with limited interruption. We closely monitored and documented their behaviors, but did not interfere with their habitual daily routines to ensure the practical applications of our findings. Despite these efforts, none of the variables collected in this study had a significant impact on the mean or CV of RMSSD between the two time points in our sample. This was surprising given the findings of prior investigations into HRV and autonomic
control, which highlight the complexity of the ANS and its sensitivity to both internal and external stimuli. Prospective studies aimed at quantifying external influences on HRV measurements, particularly in real-life, every-day situations, are warranted.

**Conclusion**

Tracking individual trends in HRV and the degree of fluctuation within each individual, appears to provide valuable information regarding training volume, recovery status, and readiness to perform that coaching and sports medicine staff can use to evaluate and monitor athletes' responses to training. This study answers an important methodological question regarding the time point for which HRV measurements should be taken, and may address prior equivocal findings and misunderstandings around HRV data/interpretation in previous research. While readers should be aware of the potential decreased sensitivity of later in the morning measures when attempting to monitor performance readiness, our data may lead these practitioners, coaches, and trainers to ponder if this decreased sensitivity is more important than overall compliance and absolute accuracy of the measurements in terms of effective autonomic athletic monitoring.
REFERENCES


46. Buchheit M, Al Haddad H, Millet GP, Lepretre PM, Newton M, Ahmaidi S. Cardiorespiratory and Cardiac Autonomic Responses to 30-15 Intermittent Fitness Test in


APPENDIX A

LITERATURE REVIEW TABLES AND FIGURES

Tables

Table 1.1. Summary of the main heart rate variability parameters and their physiological origin.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variable</th>
<th>Description</th>
<th>Physiological Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Domain</td>
<td>SDNN</td>
<td>Standard deviation of all R-R intervals</td>
<td>Cyclic components responsible for HRV</td>
</tr>
<tr>
<td></td>
<td>RMSSD</td>
<td>Root mean square of successive differences</td>
<td>Vagal tone</td>
</tr>
<tr>
<td></td>
<td>LnRMSSD</td>
<td>Natural logarithm of RMSSD</td>
<td>Vagal tone</td>
</tr>
<tr>
<td></td>
<td>pNN50</td>
<td>Percentage of successive normal sinus R-R intervals more</td>
<td>Vagal tone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>than 50 ms</td>
<td></td>
</tr>
<tr>
<td>Time Domain –</td>
<td>Triangular</td>
<td>Total number of N-N intervals divided by the number of</td>
<td>Relationship of total interval; alternate to more</td>
</tr>
<tr>
<td>Geometric Measures</td>
<td>Index</td>
<td>N-N intervals in the modal bin of a histogram</td>
<td>complicated statistical parameters</td>
</tr>
<tr>
<td></td>
<td>TINN</td>
<td>Baseline width of the minimum square differences triangular interpolation of the highest peak of the histogram of all N-N intervals.</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>ULF</td>
<td>Ultra-low frequencies</td>
<td>Circadian oscillations, core body temperature, metabolism and the renin-angiotensin system</td>
</tr>
<tr>
<td>Domain</td>
<td>VLF</td>
<td>Very-low frequencies</td>
<td>Long-term regulation mechanisms, thermoregulation and hormonal mechanisms</td>
</tr>
<tr>
<td></td>
<td>LF</td>
<td>Low frequencies</td>
<td>Mix of sympathetic and vagal activity, baroreflex activity</td>
</tr>
<tr>
<td></td>
<td>HF</td>
<td>High frequencies</td>
<td>Vagal tone</td>
</tr>
<tr>
<td></td>
<td>LF/HF</td>
<td>Low/high frequency ratio</td>
<td>Mix of sympathetic and vagal activity</td>
</tr>
<tr>
<td></td>
<td>SD/RMSSD</td>
<td>Suggested[^17] to be a less difficult surrogate to LF/HF ratio</td>
<td></td>
</tr>
<tr>
<td>Nonlinear Indices</td>
<td>SD1 - Poincaré plot crosswise</td>
<td>Successive differences in R-R intervals</td>
<td>Unclear, depicts quick and high frequent changes in HRV</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------</td>
<td>----------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>SD2 - Poincaré plot lengthwise</td>
<td>Summation of differences in R-R intervals</td>
<td>Unclear, depicts long-term changes in HRV</td>
<td></td>
</tr>
</tbody>
</table>

\(^{9}\text{greatest use in athletic populations, often calculated directly on smartphone application}

Adapted from Laborde et al.’s *Heart Rate Variability and Cardiac Vagal Tone in Psychophysiological Research-Recommendations for Experiment Planning, Data Analysis, and Data Reporting*\(^{9}\).

| **Table 1.2.** Determinates of different heart rate variability measures and their application to general health and fitness. |
|--------------------------------------------------|---------------------------------------------------------|----------------------------------------------------------|
| **HRV Measure** | **Determinants** | **Monitoring variable(s)** |
| **Sleep** | Circadian changes in ANS activity | ANS regulation & PNS dysregulation, somatic restoration, and essential function of sleep\(^ {192}\) |
| **Resting HR** | Cardiac morphology, plasma volume, ANS and baroreflex | Wellness, fitness, readiness to perform |
| **Resting vagal-related HRV indices** | Genetics, plasma volume, ANS and baroreflex | Wellness, fitness, readiness to perform |
| **Exercise HRV** | Intensity-dependent: ANS<VT1, respiration >VT2 | Aerobic fitness (in theory) |
| **Post-exercise vagal-related HRV indices** | ANS and baroreflex, but the metaboreflex has the greater effect | In theory, wellness, fitness and readiness to perform in practice, more fitness because of its link with relative exercise intensity |

HRV, heart rate variability; ANS, autonomic nervous system; PNS, parasympathetic nervous system; HR, heart rate; VT, ventilatory threshold

Adapted from Buchheit’s *Monitoring Training Status with HR measures: do all Roads Lead to Rome?*\(^ {4}\)
Figure 1.1. Visual representation of the relationship between adaption to training load and autonomic nervous system activity (e.g., LnRMSSD; R-R interval). Adapted from D.J. Plews et al., *Training Adaptation and Heart Rate Variability in Elite Endurance Athletes: Opening the Door to Effective Monitoring*[^73].

Footnote: Example of the relationship between the R–R interval and the natural logarithm of the square root of the mean sum of the squared differences between R–R intervals (LnRMSSD) in a subject with increasing bradycardia. Here, a saturation of heart rate variability is seen with long R–R intervals. Note how at shorter R–R intervals there is a linear relationship between LnRMSSD (dotted line), which becomes disassociated as the duration of the R–R interval increases, indicating heart rate variability saturation.

LnRMSSD, Natural logarithm of the root mean square of successive differences; R–R interval, where R is the point corresponding to the peak of the QRS complex of the ECG wave, RR is the interval from the peak of one QRS complex to the peak of the next as shown on an electrocardiogram; ms, milliseconds
Figure 1.2. Visual representation of the degree of power components by frequency (Hz). Adapted from the 1996 Joint Task Force Statement from the European Society of Cardiology and the North American Society of Pacing and Electrophysiology³.

Footnote: Example of an estimate of power spectral density obtained from the entire 24-h interval of a long-term Holter recording. Only the LF and HF components correspond to peaks of the spectrum while the VLF and ULF can be approximated by a line in this plot with logarithmic scales on both axes. The slope of such a line is the $\alpha$ measure of HRV.

ULF, Ultra-low frequency; VLF, Very-low frequency; LF, Low frequency; HF, High frequency; Hz, Hertz; ms, milliseconds; HRV, heart rate variability; $\alpha$, alpha
**APPENDIX B**

**TRAINING INFORMATION**

**Table 3.1.** Winter training program: A sample week with the inclusion of two heart rate variability assessments.

<table>
<thead>
<tr>
<th>Time Point</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
<th>Sunday</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1: Perform HRV measurement at home (unsupervised) →</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2: Perform HRV measurement at boathouse (within 1-hr of first measurement) →</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6:00-8:00 AM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rest</td>
</tr>
<tr>
<td>Water Practice →</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9:30-10:45 AM</td>
<td>Strength Training</td>
<td>Strength Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3:30-5:00 PM</td>
<td>Land-based Ergometer Training</td>
<td>Land-based Ergometer Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2. Schematic of the training schedule and study collection period across the entire rowing season.

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of Days</th>
<th>Training Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 3 – 9</td>
<td>6</td>
<td>Winter Training Camp</td>
<td>Familiarization Period; Intensive camp held during students Winter Break</td>
</tr>
<tr>
<td>Jan. 10 – 14</td>
<td>4</td>
<td>No Scheduled Team Practices</td>
<td>Familiarization Period; Part of NCAA mandate for a certain allotment of “days-off”</td>
</tr>
<tr>
<td>Jan. 15 – Feb. 23</td>
<td>6 weeks</td>
<td>Winter Training Period</td>
<td>20-hours of training per week</td>
</tr>
<tr>
<td>Jan. 22 – 27</td>
<td>6</td>
<td>Study Collection Period</td>
<td>12 total recordings per person (two per day)</td>
</tr>
<tr>
<td>Feb. 24</td>
<td>1</td>
<td>First Spring Regatta, Home Dual Meet</td>
<td>Official start to main, spring season</td>
</tr>
<tr>
<td>Feb. 24 – May 12</td>
<td>13 weeks</td>
<td>Spring Season</td>
<td>Spring training (in-season) period</td>
</tr>
</tbody>
</table>

Table 3.3. Total minutes of work performed by each athlete throughout the study.

<table>
<thead>
<tr>
<th>Date</th>
<th>Land Training</th>
<th>Water Training</th>
<th>Erg Training</th>
<th>Strength Training</th>
<th>Total Training Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/22/2018</td>
<td>12</td>
<td>61</td>
<td>8</td>
<td>0</td>
<td>81</td>
</tr>
<tr>
<td>1/23/2018</td>
<td>12</td>
<td>40</td>
<td>0</td>
<td>60</td>
<td>112</td>
</tr>
<tr>
<td>1/24/2018</td>
<td>12</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>52</td>
</tr>
<tr>
<td>1/25/2018</td>
<td>22</td>
<td>40</td>
<td>0</td>
<td>60</td>
<td>122</td>
</tr>
<tr>
<td>1/26/2018</td>
<td>12</td>
<td>100</td>
<td>55</td>
<td>0</td>
<td>167</td>
</tr>
<tr>
<td>1/27/2018</td>
<td>12</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>112</td>
</tr>
</tbody>
</table>
Table 3.4. Full daily workout routine completed by each rowing athlete throughout the study.

<table>
<thead>
<tr>
<th>Date</th>
<th>Daily Workouts</th>
</tr>
</thead>
</table>
| Monday 1/22/2018 | **Aerobic Warm Up Run:** 12'  
**Water Workout AM:** 24' outbound, 5-7' recov., 30' return; both @18/20spm, alt. every 2'  
**Erg Workout PM:** 2,000m Time Trial |
| Tuesday 1/23/2018 | **Aerobic Warm Up Run:** 12'  
**Water Workout AM:** 4x10' w/ 3.5' recovery; @16/18/20/22 spm, alt. every 4'/3'/2'/1'  
**Strength Workout AM:** Goal= ~60% 1RM- Box Jumps (3x5); Front Squat (2x6); Back Squat (3x8); Low Box Step Up (3x5); RDL's (3x6) |
| Wednesday 1/24/2018 | **Aerobic Warm Up Run:** 12'  
**Water Workout AM:** 4x1.5m w/ 5' recov. btwn.; (format: 1000m @24-26spm, 500m @30spm rate cap but must drop split). Each piece with static scrimmage start (1 stroke & go) |
| Thursday 1/25/2018 | **Aerobic Warm Up Run:** 22'  
**Water Workout AM:** 10 x (3' on/1' off) w/ 5'-7' recov. btwn. piece 5 & 6; pieces 1-5 @24spm & pieces 6-10 @26spm  
**Strength Workout AM:** Goal= ~60-70% 1RM- Clean Pull (3x5 & 2x3); Scalp Retractions (3x5); Bench Press (3x6); DB Incline Bench (3x5); DB Row (3x5); Upright Row (3x5) |
| Friday 1/26/2018 | **Aerobic Warm Up Run:** 12'  
**Water Workout AM:** 60’ drill; 30'-40' SS row; both @20-24spm  
**Erg Workout PM:** 55’ x (40” on/ 20” off), building speed & rate throughout each 40” of pressure |
| Saturday 1/27/2018 | **Aerobic Warm Up Run:** 12'  
**Water Workout AM:** 60’ of drill/SS @20-24spm; 2 x 2m w/ equal recov.; (format: 1500m @26spm; 500m drop split, rate cap @30spm) |

spm, strokes per minute; ', minute; ", second; m, meter; btwn., between; w/, with; ~, around; DB, dumbbell; RM, repetition maximum; alt., alternating; SS, steady state; cap, maximum rate possible; split, rate per 500m; recov., recovery
Table 3.5. The University of Alabama Women’s Rowing racing schedule for the 2017-2018 season.

<table>
<thead>
<tr>
<th>Date</th>
<th>Race Title</th>
<th>Location</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Fall Season</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/17/2017</td>
<td>Chattanooga Head Race</td>
<td>Chattanooga, TN</td>
<td>5,000</td>
</tr>
<tr>
<td>10/21/2017</td>
<td>Head of the Charles</td>
<td>Cambridge, MA</td>
<td>4,800</td>
</tr>
<tr>
<td>11/4-5/2017</td>
<td>Head of the Hooch</td>
<td>Chattanooga, TN</td>
<td>5,000</td>
</tr>
<tr>
<td>11/11/2017</td>
<td>Dual Meet with Central Florida</td>
<td>Tuscaloosa, AL</td>
<td>9,500</td>
</tr>
<tr>
<td></td>
<td><strong>Spring Season</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/24/2018</td>
<td>Dual Meet with Eastern Michigan</td>
<td>Tuscaloosa, AL</td>
<td>4,000(^a)</td>
</tr>
<tr>
<td>3/3/2018</td>
<td>Dual Meet with Southern Methodist University</td>
<td>Tuscaloosa, AL</td>
<td>4,000(^a)</td>
</tr>
<tr>
<td>3/24/2018</td>
<td>Crimson Tide Invitational</td>
<td>Tuscaloosa, AL</td>
<td>4,000(^b)</td>
</tr>
<tr>
<td>4/7/2018</td>
<td>BIG 12 Double Dual</td>
<td>Kansas City, KS</td>
<td>4,000(^b)</td>
</tr>
<tr>
<td>4/14-15/2018</td>
<td>Lake Natoma Invitational</td>
<td>Sacramento, CA</td>
<td>6,000(^a)</td>
</tr>
<tr>
<td>4/28/2018</td>
<td>Longhorn Invitational</td>
<td>Austin, TX</td>
<td>4,000(^b)</td>
</tr>
<tr>
<td>5/12-13/2018</td>
<td>BIG 12 Championships</td>
<td>Oak Ridge, TN</td>
<td>2,000</td>
</tr>
</tbody>
</table>
Two 2,500 meter races were conducted, followed by three 1,500 meter races with rest in between race pieces.

Four 1,000 meter races were conducted, with rest in between each piece.

One 2,000 meter race, followed by two 1,000 meter races with rest in between each piece.

Two 2,000 meter races were conducted, with rest in between each piece.

Three 2,000 meter races were conducted, two on Saturday and one on Sunday, with rest in between each piece.

m, meters

More information can be found at: https://rolltide.com/index.aspx?path=wrow
APPENDIX C
HRV4TRAINING SMARTPHONE APPLICATION*

Figure 3.1. HRV4Training camera acquisition and measurement screen.
Figure 3.2. HRV-based daily advice screen within HRV4Training application

Footnote: HRV4Training provides advice based on objective assessment of physical condition and your subjective scores. HRV over the last week is used to determine your baseline (at least 4 days of measurements are required), while the past 2 months of data are used to determine what your normal HRV values are. The daily advice aims at helping you in making small daily adjustments to your training program, by keeping in consideration not only how your score changed from yesterday's, but also with respect to your past 7 days moving average (i.e. the baseline), your normal values, and factoring in your subjective scores and recent trends (when enough data is present).
Figure 3.3. History and training annotations screen within the HRV4Training application.

Footnote: Once you've got some data, use the history tab to browse through it and look at the different features that were extracted during the test. You'll also be able to see the impact of some of your tags (e.g. travel, alcohol intake, injuries, etc.) on your physiological stress level. The Baseline page helps you in going beyond short daily variability, and get a better overview of your physical condition. The blue line is a 7 days moving average, which captures the global trend of your HRV, without being too affected by daily swings. At the bottom you can see annotated trainings as well.

Figure 3.4. HRV trends analysis within HRV4Training application.
Footnote: HRV4Training is also the first app that combines multi-parameter data to help you better understand the big picture. Look at baseline changes on multiple parameters relevant to your physical condition (e.g. HRV, HRV, coefficient of variation, training load), etc. The app can automatically determine if your recent HR or HRV trend is changing in a trivial way, or if the change is something to take more seriously, based on your historical data.

[*Figures included from: https://www.hrv4training.com/quickstart-guide.html ]
APPENDIX D
GLOSSARY OF ROWING TERMS*

**Bow:** The forward section of the boat. The first part of the boat to cross the finish line. The person in the seat closest to the bow, who crosses the finish line first.

**Coxwain (Cox):** Member of the crew who generally sits stationary in the boat facing the bow. While the coxswain’s main job is to steer the shell with a tiny rudder, they also help motivate the crew to carry out the race strategy.

**Ergometer:** Rowers call it an “erg”; it is a rowing machine that closely approximates the actual rowing motion used for land fitness training. The rowers’ choice is the Concept II, which utilizes a flywheel and a digital readout so that the rower can measure spm and the distance covered.

**Head Race:** Generally held in the fall, between 4-10,000 meters, and the boats are started in their respective divisions separately at different intervals. They are usually conducted on a river with an assortment of bridges and turns that can make passing a challenge. The winner is the crew that had the shortest elapsed time between the start and finish lines, with any additional time included for penalties.

**Novice:** Any rower during their first season of competition.

**Piece/Time Trial:** A specific workout with an equivalent distance race simulation performed by an individual rower for a recorded time.

**Port Side:** Left side of the boat, while facing forward, in the direction of the movement.
**Regatta:** A competition with events for different boat types and status athletes usually involving heats, semi-finals and finals for each event. Boats compete side by side from a standing start.

**Spm:** strokes per minute, also called “rate”; the rowing cadence set for that particular workout or the number of times a blade goes into the water each minute.

**Starboard Side:** Right side of the boat, while facing forward, in the direction of movement.

**Stern:** The rear of the boat; the direction the rowers are facing.

**Stroke:** The complete cycle of the oar (or flywheel on an erg) going from the catch back to the catch through the series of forceful movements designed to propel the boat through the water.

**Sweep:** One of the two disciplines of rowing – the one where rowers use only one oar on one side of the boat. Pairs (for two people), fours (for four people) and the eight are sweep boats.

Pairs and fours may or may not have a coxswain. Eights always have a coxswain.

HRV Rowing: Instructions, Tips, and Guidelines

What is Heart Rate Variability?
Heart rate (HR) is usually interpreted as an average in beats per minute or “bpm”. For example you might have a resting HR of 60 bpm. HR is not uniform or metronomic; there is variation in the time intervals between each individual beat. The period between heartbeats varies from beat to beat, thus, heart rate also varies beat to beat

HR is controlled by the autonomic nervous system (ANS) which is comprised of two divisions:
- Sympathetic = Fight or Flight; Increase HR & Decrease HRV
- Parasympathetic = Rest and digest; Decrease HR & Increase HRV

High HRV is correlated with good general health while low HRV is linked to different cardiovascular diseases. In recent years, HRV has become an indicator of fatigue and recovery. This is widely important for monitoring athletes due the many physiological and psychological stressors they are put through in training and competitions. The HRV4Training will allow us to take daily measures of each athlete and track how each individual is responding and adapting to the various training throughout the season.

Getting Started
1. Open “App Store” application in smartphone
2. Scroll to the bottom until you see the “Redeem” button and select it
3. You will be asked to Sign-In to iTunes Store using your password
4. Select “You can also enter code manually”
5. Enter code
6. Download “HRV4Training”

Syncing with Coaching app
1. You will receive a “data sharing request” from the Coach’s app
2. Select the “three gray stacked bar” icon in the top left corner for menu options
3. Go to “Settings”
4. Scroll down and select “Data sharing settings for HRV4Training Coach”
5. Accept the request by selecting “Yes” to share data
6. Also, select “Set daily Tags picked by your coach”

Taking a Measurement
1. Void bladder and bowels
2. Get into a seated position and relax for approximately one minute
3. Remove the case on your phone
4. Place your LEFT HAND index finger (aka pointer finger) on the camera and light
5. Select “Measure HRV”
6. Sit still, breathe normally, and do not talk
7. Your phone will vibrate when the measurement is complete
8. The app will notify you if the measurement was “optimal” or not; if it is optimal then select “store measurement”; if it is not, redo the measure
9. Complete the questionnaire to the best of your ability
10. Select “Save Measurement” at the bottom of the page
11. View your score and close the app

*At home measurements will only be done when instructed by the researchers*

Exporting Data
1. Go to your Contacts app and create a new contact:
a. First Name: HRV
b. Last Name: Rowing
c. Email: uawomensrowinghrv@gmail.com

2. Save contact
3. Open the HRV4Training app and select the “three gray stacked bar” icon in the top left corner for menu options
4. Select “Data export”
5. Select “Send by email”
6. Send the email to the “HRV Rowing” contact you just created

*Exporting data will only occur on Sunday. You will receive weekly reminders.*

Quick Insights into HRV4Training

- **Heart Rate**: Average resting HR at the time of each measure

- **rMSSD**: rMSSD is computed as the square root of the mean squared differences of successive RR intervals. When computing rMSSD, we look at *beat to beat differences*, thus the rMSSD feature is associated with short term changes in the heart. rMSSD is considered a solid measure of vagal tone and parasympathetic activity.

- **Recovery Points**: rMSSD values are transformed so that the values are a bit more readable and user friendly. The result is a number approximately on a scale between 1 and 10, with higher values representing higher parasympathetic activity, lower stress, better recovery (in general).

- **Questionnaire** (Don’t press the “Configure Tags”):
  1. **Wakeup Time**: Best Guess
  2. **Bedtime**: Best Guess
     - Knowing the hours of sleep you’re getting on average will allow us to see what the optimum number of hours are needed for you to recover from training
3. **Sleep Quality**: Sliding scale with “Green” being good and “Yellow” being bad
4. **Training**: Rest, Easy, Average, or Intense
5. **What Sport**: Always pick “Rowing”
6. **Performance**: Sliding scale with “Green” being good and “Yellow” being bad
   - How well did you complete the tasks given to you in practice? Did you meet expectations or fall short?
7. **Rated Perceived Exertion**: The higher the number, the more effort needed to perform
   - How much effort did it take to complete the task
8. **Training Distance**: Measured in “miles”
   - We’ll get this information from your coaches but give your best estimate
9. **Motivation**: Sliding scale with “Green” being high and “Yellow” being low
   - Are you ready and excited for training today?
10. **Training Duration**: Measured in “minutes”
    - We’ll get this information from your coaches but give your best estimate
11. **Physical Condition**: Sliding scale with “Green” being good and “Yellow” being bad
    - How are you feeling? Any abnormal pains or any feelings of being “off”?
12. **Mental Energy**: Sliding scale with “Green” being high and “Yellow” being low
    - Are you focused on training or are you stressed out from other things that are distracting you from training?
13. **Muscle Soreness**: Sliding scale with “Green” being low and “Yellow” being high
    - Think about the most sore you’ve ever been and compare it to that; how painful is regular physical activity
14. **Fatigue**: Sliding scale with “Green” being low and “Yellow” being high
    - How tired or exhausted are you?
15. **Injury**: If you’re not injured then leave it blank
    - We’ll be in contact with your athletic trainer
16. **Diet**: Briefly describe the breakfast you had prior to coming to the facility; leave blank if no breakfast was consumed

80
Knowing what you had prior to the HRV measurement will let us know how it might affect your scores

17. **Current Lifestyle**: Sliding scale with “Green” being good and “Yellow” being bad
18. **Traveling**: Yes or No
19. **Alcohol Intake**: Nothing, A little, and Too Much
   - Please be honest because alcohol has been shown to generate fatigue and inhibit recovery
20. **Sick**: Yes or No
21. **Supplements**: Comment; Ex: protein, creatine, glutamine, pre-workout, etc.
22. **Menstrual Cycle**: Yes or No
23. **Comment**: Any additional details that isn’t covered in the questionnaire but is important to your score
24. **Medication**: 0 = Not on medication, 1= Yes I took it, 2 = No I didn’t take it

- “Home” screen is where you take measures, see previous measures, and see what your baseline is (only seen after 4 days of measurements)

- “History” screen allows you to see your Recovery Points, HR, rMSSD, Sleep, Energy, Soreness, and Training scores from previous weeks

- “Baseline” screen gives you a trend line of your Recovery Points, HR, and rMSSD

- “Population Comparison” screen allows you to see how your measures stack up to other HRV4Training users.
APPENDIX F

UNIVERSITY INSTITUTIONAL REVIEW BOARD AUTHORIZATION

THE UNIVERSITY OF
ALABAMA
Office of the Vice President for Research & Economic Development
Office for Research Compliance

October 11, 2016

Andrew A. Platt
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB # 14-OR-431-ME-R2 “Monitoring Training Effects with Smartphone-Derived HRV in Collegiate Swimmers”

Dear Mr. Platt:

The University of Alabama Institutional Review Board has granted approval for your renewal application. Your renewal application has been given expedited approval according to 45 CFR part 46. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your application will expire on October 10, 2017. If your research will continue beyond this date, complete the relevant portions of the IRB Renewal Application. If you wish to modify the application, complete the Modification of an Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, complete the appropriate portions of the IRB Study Closure Form.

Please use reproductions of the IRB approved informed consent form to obtain consent from your participants.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,

[Signature]

Director & Research Compliance Officer
Office of Research Compliance

358 Rose Administration Building | Box 870127 | Tuscaloosa, AL 35487-0127
205-348-8461 | Fax 205-348-7189 | Toll Free 1-877-820-3066
To the University of Alabama Research Compliance Office:

I (Andrew Flatt) am currently listed as the primary investigator for the approved study, "Monitoring Training Effects with Smartphone-Derived HRV in Collegiate Athletes" (IRB #14-OR-431-ME-R2). As the protocol is up for renewal, I would like to transfer the primary investigator title to my doctoral advisor, Dr. Michael Esco (Associate Professor in the Department of Kinesiology). I would like to make this transfer of title because I have completed my doctorate at the University of Alabama and have taken a faculty position elsewhere. Should you need any additional information, I can be contacted via email at [redacted] Dr. Esco can be contacted at [redacted]

Thanks,

Andrew Flatt PhD

Dr. Michael Esco,

This letter serves as my approval for your study "Monitoring training effects with Smartphone-derived heart rate variability in collegiate athletes, IRB Protocol ID 6253" that involves the University of Alabama Rowing team.

Thanks,

[Signature]
Larry Davis
Head Coach, Women's Rowing

THE UNIVERSITY OF ALABAMA®
October 13, 2017

Michael Esco, Ph.D.
Assistant Professor
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB # 14-OR-431-ME-R3 “Monitoring Training Effects with Smartphone-Derived HRV in Collegiate Swimmers”

Dear Dr. Esco:

The University of Alabama Institutional Review Board has granted approval for your renewal application. Your renewal application has been given expedited approval according to 45 CFR part 46. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your application will expire on October 12, 2018. If your research will continue beyond this date, complete the relevant portions of the IRB Renewal Application. If you wish to modify the application, complete the Modification of an Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, complete the appropriate portions of the IRB Study Closure Form.

Please use reproductions of the IRB approved informed consent form to obtain consent from your participants.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.

Sincerely,

[Name]
Director & Research Compliance Officer
Office of Research Compliance

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