# ASSOCIATION AMONG AEROBIC PERFORMANCE, RESTING HEART RATE AND HEART RATE VARIABILITY IN PHYSICALLY ACTIVE COLLEGE-AGED ADULTS

by

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ABSTRACT

The purpose of this study was to determine the relationship between smartphone-derived heart rate measures (resting heart rate [RHR] and heart rate variability [HRV]) and performance on an aerobic performance test. Seventeen male college students performed 55-second HR measures in the seated position every morning for 5 days. The root mean square of successive normal-to-normal interval differences (RMSSD) was used as the HRV metric. The weekly mean and coefficient of variation of RHR ($RHR_M$ and $RHR_{CV}$, respectively) and RMSSD ($RMSSD_M$ and $RMSSD_{CV}$, respectively) were determined. Participants completed the 2 mile run (2MR) on the last day of the week. Intra-class correlations (ICC) were used to determine the stability in the heart rate measures across the 5-day period. Pearson correlations were performed to determine the relationship between 2MR and $RHR_{CV}$, $HR_M$, $RMSSD_M$ and $RMSSD_{CV}$. RHR (ICC = 0.87 [0.74 to 0.95], $p < 0.05$) displayed better stability over the 5-day period relative to the RMSSD (ICC = 0.66 [0.32 to 0.86], $p < 0.05$). $RHR_M$ was very strongly correlated with 2MR ($r = 0.63$), as was $RMSSD_{CV}$ ($r = 0.55$). Conversely, neither $RHR_{CV}$ nor $RMSSD_M$ correlated significantly to the 2MR. Therefore, both $RHR_M$ and $RMSSD_{CV}$ may be useful objective heart rate indicators to reflect aerobic performance.

Key words: heart rate, heart rate variability, aerobic performance, fitness

DEDICATION

This thesis is dedicated to my wife, Rhonda, and my children, Bryan, Aaron and Kayla. Thank you for enduring me while I completed this manuscript.

LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ECG | electrocardiogram |
| R to R | distance between the R waves of an ECG |
| HRV | heart rate variability |
| $HRV_M$ | mean for HRV recorded over 5 consecutive days |
| $HRV_{CV}$ | coefficient of variation for HRV recorded over 5 consecutive days |
| HR | heart rate |
| RMSSD | Root mean of the successive R-R interval differences |

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# INTRODUCTION

While it has long been understood that the sinoatrial node and nodal system which permeates the myocardium intrinsically controls heartbeat, early observations stimulated study into the degree to which the autonomic nervous system affects heart rate and rhythm (6). Heart rate variability (HRV) is defined as the time variations that occur between successive heart beats or R-R intervals (28) (Figure 1). Because HRV is mediated by parasympathetic and sympathetic nervous activity, it has been primarily considered a non-invasive marker of cardiovascular-autonomic regulation (28). However, HRV is influenced by a number of physiological responses, such as circulatory, pulmonary, and endocrine changes (1,16). Thus, day-to-day fluctuation of HRV has been considered a marker of perturbation in homeostasis (7,28).

Much of the previous research has focused on the ability of HRV to detect outcomes of chronic cardiac diseases (7). However, HRV has recently been identified as a promising objective physiological indicator of recovery from, and readiness for, physical training (3). HRV appears to have the potential to identify individuals who will respond more favorably to physically demanding tasks (16,27). A higher resting vagal tone has been shown to correlate to higher serum testosterone levels and therefore a more adaptive allosteric reaction (27). For example, relationships between vagal activity and serum testosterone have been observed in soldiers during military service (27). Additionally, HRV has been suggested as a predictor of combat readiness (16). Of particular importance, HRV may be a useful metric in pre-deployment screenings geared toward the prevention and treatment of post-traumatic stress disorder (20,21).

It appears that if HRV, which it is believed can be influenced with exercise, has a relationship to serum testosterone, which has been shown to correlate to better resiliency, then HRV should be an indicator of better resiliency. That would tell us that exercise should improve resiliency.

Traditionally, HRV could only be measured with an electrocardiogram (ECG) using specialized software. However, this requires expensive equipment not commonly found in field settings. Fortunately, newer technology allows HR data to be recorded with convenient mobile devices. For instance, smart phone applications have been developed that allow for the detection of blood flow through the capillaries of a fingertip via "photoplethysmography". These methods have been shown to provide excellent agreement with traditional, laboratory-derived HRV (9) and have allowed for data acquisition in field settings for monitoring athletes (11,12).

Large day-to-day fluctuation of HRV has been previously reported (25). Therefore, for monitoring responses to exercise training, daily measures of HRV that are averaged throughout a week (i.e., the weekly mean HRV) are preferred over isolated recordings (23). The weekly mean average value represents overall cardiovascular-parasympathetic modulation, while the coefficient of variation (CV) is purportedly a marker of homeostatic perturbation during training (22). Indeed, both the mean and CV of HRV may be related to level of physical fitness and training status (7). For instance, an increased mean and decreased CV of weekly HRV has been shown to coincide with an increase in aerobic fitness and may be indicative of positive adaptation (13).

Resting heart rate (RHR) has been used for monitoring aerobic training responses for a long period of time. The relationship between HRV and RHR typically displays a strong inverse correlation (3). However, it is not clear as to which of the two metrics provides the most robust information for monitoring training and changes in fitness. For example, non-functional overreaching and 10-km performance show similar relationships with HRV (r = 0.88 and 0.76, respectively) and RHR (r = 0.81 and 0.73, respectively) (3). Therefore, further research is needed to help clarify how weekly measures of HRV and RHR should be used and interpreted when monitoring physically fit individuals. Hence, the purpose of this study was two-fold: 1) to determine the stability of RHR and HRV across a 5-day period; and 2) to determine which 5-day heart rate measure was most related to a 2-mile run (2MR) measured from a field test in physically active college-aged males.

# METHODS

*Experimental Approach to the Problem*

Seventeen students enrolled in a military prep school were tested for 5 days. RHR and HRV were recorded daily. Statistical procedures were performed to determine the stability (i.e., reliability) of each measure throughout the 1-week period. In addition, the mean and CV of RHR and HRV were compared to the results of a timed 2MR.

*Subjects*

A convenience sample of 17 male college freshmen and sophomores participated in this study. The subjects were enrolled in a military prep school. All participants were on a supervised physical fitness regimen for at least one academic year. The regimen was not identical for all participants, but contained a cardiovascular and muscular endurance aspect, closely resembling standard military training practices. Table 1 outlines a typical 1-week training microcycle that was followed during the study duration. All participants completed a health-history questionnaire (Appendix A), which indicated that everyone was apparently healthy, free from cardiopulmonary, metabolic, and orthopedic disorders. The participants provided written informed consent. Data collection occurred on Monday through Friday during the morning hours from 5:30am to 7:00am. This study was approved by the Institutional Review Board for Human Subjects. Subjects' mean age was 18.5 (+/- .71) years, mean height was 179.6 (+/- 7.32) cm, and mean weight was 85.5 (+/- 12.06) kg.

The subjects in the current study originally numbered 21 and contained 4 female volunteers. The data from these students had to be excluded after the final results were computed. The reason for this is that their HRV numbers had not considered their menstrual cycle and former tests had indicated that this may distort findings.

*Procedures*

**Heart Rate Data Collection**

A portable smartphone application device (see htp://www.hrv4training.com/) was used to record RHR and HRV data. The application recorded pulse rate information from the fingertip using the smartphone's camera system. The type of phone used was a Samsung Android (version 7.0, Samsung, Suwon, Gyeonggi-do, South Korea). The root mean square of the normal to normal intervals (RMSSD) was the HRV metric recorded in the study. Data collection methodology in the current study followed the same procedures as previous research that validated the device and showed it to provide a perfect correlation (r = 1.00) to ECG for root mean square of the normal to normal intervals (RMSSD) determination (24).

A comparison was conducted between the Samsung Android phone used in this study and a reading from an ECG. The resultant data were very similar between the phone and the ECG. Because of this, only phones of that type (Samsung Android) were used in the current study.

Heart rate data were collected for 5 consecutive week-days. During each of the 5 days, the participants recorded their RHR and HRV at the training facility at 5:00am, as close to awakening as possible. The RHR and HRV recordings took place while participants rested comfortably and motionless in a seated position on a back-supported chair. A one-minute stabilization period preceded the one minute of heart rate measurement, which has previously been shown to provide acceptable agreement with traditional recording timeframes of longer duration (8). The RMSSD was displayed on the smartphone screen and recorded to a data collection sheet. This was the only HRV parameter recorded in the study since it has been suggested as the preferred metric to collect in field settings (3). The RHR and RMSSD weekly mean ($RHR_M$ and $RMSSD_M$, respectively) and associated CV ($RHR_{CV}$ and $RMSSD_{CV}$, respectively) were calculated from the 5-day recordings.

**Two-mile run**

On the last day of the 5-day period, all participants completed a timed 2 mile run (2MR) that followed the last heart rate measure. The subjects jogged to the track from the gym (approximately 1/4 mile) as their warm up, and did a series of lower body stretches for 2 to 4 minutes. The 2-mile run was performed outdoors on a running track. Timing was maintained manually with a stopwatch by a trained technician. The test was conducted in a manner to which the cadets were accustomed. Runners were instructed to complete the course as fast as possible. The time in which each participant crossed the 2-mile mark was recorded as the 2MR time.

*Statistical Analyses*

Data were analyzed with SPSS Statistics version 22.0 (IBM, Chicago, IL). Data normality was evaluated with a Shapiro-Wilk test, which determined that the assumption of normality was violated for the absolute RMSSD ($p < 0.05$). Therefore, natural log (ln) transformations were applied to RMSSD data. Due to the skewed absolute values and the preference of log-transformed HRV measures for athletic monitoring (15), only ln values were analyzed.

To determine if there were differences in the heart rate measures across the 5-day period, repeated measures analyses of variance were employed. Intraclass correlations (ICC) were used to determine the stability in each heart rate metric. Pearson product-moment correlations were used to quantify the relationships between the aerobic fitness measure and each of the 5-day heart rate measures (i.e., $HR_M$, $HR_{CV}$, $RMSSD_M$, $RMSSD_{CV}$). The ICC and correlation coefficient values were qualified by the Hopkins et al. (11) method wherein an r of 0 to 0.30 was considered small, 0.31 to 0.49 was moderate, 0.50 to 0.69 was large, 0.70 to 0.89 was very large, and 0.90 to 1.00 was near perfect. Statistical significance was considered as $p < 0.05$.

# RESULTS

*Inter-day Stability of the Heart Rate Metrics*

Individual and group mean day-to-day values for each heart rate metric are presented in Table 2. There were no statistically significant differences across the 5-day period for RHR and RMSSD. The ICCs were *very large* for RHR (mean ICC = 0.87 [0.74 to 0.95], $p < 0.05$) and *large* for RMSSD (mean ICC = 0.66 [0.32 to 0.86], $p < 0.05$).

*Relationships between the 2-mile run and 5-day Heart Rate Metrics*

Individual and group mean data for the 2MR is also presented in Table 2. $RHR_M$ was significantly correlated to two mile run performance ($r = 0.63$, $p = 0.007$, *large*), whereas $RMSSD_M$ was not ($r = -0.04$, $p = 0.89$, *small*). However, $RMSSD_{CV}$ was correlated to two mile run performance ($r = 0.55$, $p = 0.023$, *large*), but $RHR_{CV}$ was not ($r = -0.054$, $p = 0.84$, *small*). In addition, there was a non-significant correlation found between $RHR_M$ and $RMSSD_M$ ($r = -0.44$, $p = 0.07$, *moderate*), but a significant relationship was found between $RHR_{CV}$ and $RMSSD_{CV}$ ($r = 0.59$, $p = 0.01$, *large*).

DISCUSSION

The purpose of this study was two-fold: 1) To determine the stability of smartphone derived ultra-shortened heart rate metrics (RHR and RMSSD) across a 5-day period; and 2) to determine which heart rate measure was most related to a field test of aerobic performance in physically active college aged adults. The study demonstrated that RHR had better stability over the 5-day period relative to the RMSSD, as shown by the respective *very large* versus *large* ICC values. In addition, $RHR_M$ and $RMSSD_{CV}$ demonstrated *large* correlations with the aerobic performance indicator of 2MR. Conversely, neither $RHR_{CV}$ nor $RMSSD_M$ correlated significantly to the 2MR.

Previous studies examining the stability of HRV have shown equivocal findings (25). The discrepancy in the literature is mainly due to the wide range of HRV parameters available. The analysis of the variability characteristics of an ECG recording can lead to numerous time, frequency, and non-linear domain measures. Traditional recording standards from the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology gave recommendations on the use of nearly 20 different HRV parameters (28). Since then, advances in research have given way to newer methods of HRV analysis (25). However, of all the available parameters, it appears that RMSSD is one of the more reliable indexes (3). Indeed, RMSSD has been shown to typically display a coefficient of variation of ~12%, while frequency domain measures have been shown to have a CV of up to ~80% (3). Because of this, as well as the ability to acquire within ultra-short recording durations, RMSSD has been suggested as a preferred HRV marker for use in athletes (3). However, the factors that influence the stability of a specific HRV marker, such as RMSSD, are not fully understood.

In clinical cardiovascular patients, HRV has been shown to provide poorer reliability compared to healthy controls (18). On the other hand, "good" (ICC = 0.86) to "almost perfect" (ICC = 0.90) ICC values were shown for all time-domain HRV parameters in a sample of physically active college-age adults (19). Therefore, it is possible that physical fitness may impact the reliability of RMSSD, with higher fit individuals showing lower day-to-day variation. This is supported by the large correlation between 2MR and $RMSSD_{CV}$ found in the current study. Thus, individuals with higher aerobic capacity may be more resilient and have a better ability to recovery quicker from a daily stressor (7). Further, a decrease in $RMSSD_{CV}$ likely occurs with aerobic training. Flatt and Esco (13) demonstrated a very large and significant correlation between the improvement in Yo-Yo performance and $RMSSD_{CV}$ ($r = -0.74$; $p = <0.01$) during the first few weeks of endurance-based training in a group of female soccer players. This finding suggested that a decrease in $RMSSD_{CV}$ in response to training is a favorable outcome, indicative of positive aerobic adaptation. RHR does not seem to display the same degree of daily fluctuation compared to RMSSD, as shown with higher ICC values, and hence $RHR_{CV}$ may not be as sensitive of a marker for reflecting day-to-day perturbation. The lack of correlation between $RHR_{CV}$ and 2MR was likely due to the lack of day-to-day variation in RHR and suggests that this marker (i.e., $RHR_{CV}$) may not be suitable for tracking changes in aerobic performance. Therefore, practitioners monitoring longitudinal adaptation of aerobic performance are encouraged to record RMSSD over a number of days during a given week and calculate $RMSSD_{CV}$.

On the other hand, $RHR_M$ provided a strong relationship to the 2MR performance. This supports the unequivocal findings of the strong correlation between RHR and aerobic fitness (2). It is because of this that RHR has often been used as a simple indicator of monitoring the cardiovascular response to aerobic training. Resting heart rate is typically much lower among individuals with high aerobic fitness (10). This physiological outcome to training is due to a greater plasma volume, increasing end diastolic volume and hence resulting in a longer duration of diastole (14). In other words, the time segment between a typical R-R interval is lengthened to allow for an extended period for appropriate ventricular filling. Therefore, the decrease RHR is an accommodative response to the increase stroke volume following aerobic training (14). In addition, aerobic training has been suggested to increase vagal activity which may be another physiological factor for reducing RHR (26). However, only a moderate non-significant correlation was found between $RHR_M$ and the vagal-indicator of $RMSSD_M$ in the current study. This suggests that other factors may influence RHR rather than parasympathetic activity. In fact, some researchers have suggested that training-induced bradycardia is due to intrinsic (i.e., lower sinoatrial node pacing) rather than extrinsic (i.e., parasympathetic activity) influences. These findings suggest the need for further research addressing the relationships between RHR, HRV, and aerobic performance.

The findings of a lack of correlation between $RMSSD_M$ and 2MR cannot be fully explained. Previous studies have shown a significant correlation between HRV and aerobic fitness. For instance, Cataldo et al. (5) demonstrated a significant correlation between 10 kilometer run times and resting RMSSD ($r = -.71$). Differences in the current study and Cataldo et al. (5) could have been explained by the difference in the distances run. Subjects in Cataldo et al. (5) ran a 10K, which is 6.21 miles. The subjects in the current study only ran 2 miles. Another potential explanation could be the position in which HRV was measured. The current study used the seated position while the supine position was used in Cataldo et al. (5). The effect of body position on HRV's relationship to aerobic performance has not been determined previously.

It should be noted that the study sample was relatively small for a correlation analysis. In addition, the study occurred at end of the subjects' military-specific training period, after each subject passed their physical fitness test. The specific week was part of a "maintenance" or "transition" cycle before beginning the next macrocycle of training. Therefore, the subjects may have been more adapted to the program compared to what would have been found at the beginning of the year. In addition, the level of intensity of training during the week was much lower compared to their standard physical training. Training periods of higher intensity may have produced different results since HRV has been shown to change in response to higher training loads (7). However, the study was only one week in duration which may not be long enough for variation in intensity of training to effect results. Moreover, each subject was taking a series of final exams during the data collection week. Because psychological stress influences HRV, the study should have incorporated some sort of validated psychometric survey. Future research should determine if the reliability of RHR and HRV are influenced by psychological stress.

*Practical Applications*

Though subjective measures have been shown to be useful for monitoring athletes in response to training (17), HRV has been proposed as an objective indicator that may be valuable when used with traditional approaches (3,4). Under the conditions of this study, when using heart rate metrics as performance predictors, $RHR_M$ and $RMSSD_{CV}$ were closely correlated to the aerobic performance test of 2MR. The findings support previous research that weekly measures of heart rate data are preferred over isolated recordings (3,23). However, because of the findings of better stability of RHR compared to RMSSD, and lack of association between $RMSSD_M$ and 2MR, RHR may be useful for tracking changes in aerobic performance if only an isolated (e.g., 1-day) measure is possible. However, the findings of a strong relationship between weekly $RMSSD_{CV}$ and 2MR performance suggests less daily perturbation in cardiac-parasympathetic modulation among aerobically fit individuals. Therefore, practitioners are encouraged to record heart rate data during as many days as possible throughout a 1-week period, as calculation of $RMSSD_{CV}$ with only one isolated measure cannot be performed. Further, the usefulness of $RMSSD_M$ is somewhat less important relative to the power of $RMSSD_{CV}$ when tracked over multiple days or even weeks, and the usefulness of $RHR_M$ in tracking physical fitness adaptation is well understood and accepted.

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Table 1. Basic structure of the physical training program for military cadets across the studied week.

| MONDAY | TUESDAY | WEDNESDAY | THURSDAY | FRIDAY |
|---|---|---|---|---|
| 3 mile run at self-selected pace<br><br>RT session:<br>- 100 push-ups*<br>- 200 sit-ups*<br>- 30 pull-ups*<br><br>Cool-down with 10 minutes of static stretching | ½ mile jog as warm-up<br><br>3 sets of repeat interval sprints across 200 to 400 yards<br><br>Cool-down with 10 minutes of static stretching | 5 mile run at self-selected pace<br><br>RT session:<br>- 100 push-ups*<br>- 200 sit-ups*<br>- 30 pull-ups*<br><br>Cool-down with 10 minutes of static stretching | 1 mile run as a 5-7 member team while carrying a log<br><br>RT session:<br>- 50 sit-ups<br>- 30 overhead presses**<br><br>Cool-down with 10 minutes of static stretching | Cardio run: 2 mile run for time.<br><br>Max set push-ups<br>Max set sit-ups<br>Max set pull-ups<br><br>Cool-down with 10 minutes of static stretching |

RT = Resistance training

*The targeted total of repetitions were accumulated in as many sets as needed per participant.

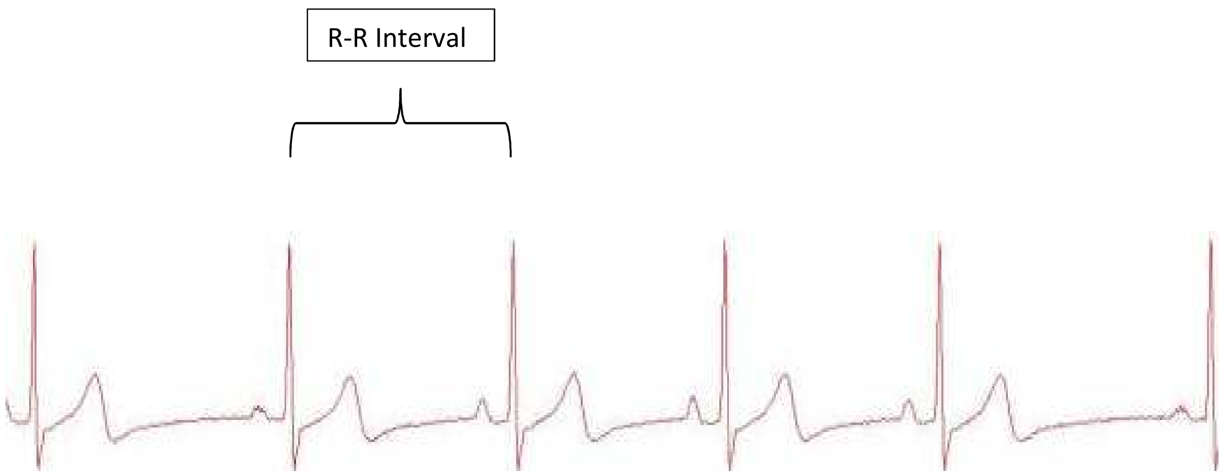
** Repetitions were to be performed with log in 5 to 7 member groups.

Table 2. Individual and mean values for the studied variables.

| Subject | HR1 | HR2 | HR3 | HR4 | HR5 | $HR_M$ | $HR_{CV}$ | RMSSD1 | RMSSD2 | RMSSD3 | RMSSD4 | RMSSD5 | $RMSSD_M$ | $RMSSD_{CV}$ | 2MR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 57.0 | 54.0 | 55.0 | 55.0 | 63.0 | 56.8 | 6.4 | 4.5 | 4.3 | 4.6 | 5.0 | 4.8 | 4.6 | 6.1 | 14.0 |
| 2 | 67.0 | 48.0 | 76.0 | 48.0 | 61.0 | 60.0 | 20.3 | 4.7 | 3.8 | 3.7 | 5.9 | 4.8 | 4.6 | 19.9 | 13.4 |
| 3 | 93.0 | 78.0 | 92.0 | 80.0 | 70.8 | 82.8 | 11.5 | 2.8 | 5.5 | 3.5 | 3.0 | 4.2 | 3.8 | 28.2 | 31.0 |
| 4 | 62.0 | 66.0 | 67.0 | 58.7 | 66.0 | 63.9 | 5.5 | 4.0 | 4.3 | 4.2 | 4.4 | 4.3 | 4.3 | 3.5 | 17.5 |
| 5 | 70.0 | 71.0 | 70.1 | 72.0 | 72.0 | 71.0 | 1.4 | 4.0 | 4.3 | 4.1 | 4.0 | 4.0 | 4.1 | 3.3 | 15.4 |
| 6 | 52.0 | 60.0 | 64.0 | 60.0 | 55.0 | 58.2 | 8.1 | 4.1 | 3.9 | 3.8 | 3.4 | 4.4 | 3.9 | 9.0 | 14.1 |
| 7 | 56.0 | 51.0 | 54.0 | 61.0 | 61.0 | 56.6 | 7.8 | 4.2 | 4.3 | 4.5 | 4.1 | 4.2 | 4.3 | 3.7 | 14.2 |
| 8 | 76.0 | 64.0 | 70.0 | 60.0 | 67.0 | 67.4 | 9.0 | 3.9 | 4.7 | 3.7 | 4.7 | 4.5 | 4.3 | 11.3 | 14.3 |
| 9 | 74.0 | 73.0 | 72.0 | 75.0 | 69.0 | 72.6 | 3.2 | 3.2 | 3.0 | 3.3 | 3.4 | 3.3 | 3.2 | 5.3 | 13.6 |
| 10 | 74.0 | 75.0 | 86.0 | 55.0 | 70.0 | 72.0 | 15.6 | 3.7 | 3.8 | 3.2 | 3.8 | 3.8 | 3.7 | 7.1 | 15.0 |
| 11 | 61.0 | 78.0 | 76.0 | 73.0 | 70.0 | 71.6 | 9.3 | 4.6 | 4.1 | 3.8 | 3.8 | 4.2 | 4.1 | 7.9 | 14.5 |
| 12 | 72.9 | 60.1 | 66.6 | 67.0 | 67.3 | 66.8 | 6.8 | 4.3 | 4.9 | 3.7 | 4.7 | 4.2 | 4.3 | 11.0 | 13.4 |
| 13 | 69.1 | 78.3 | 71.2 | 69.9 | 74.0 | 72.5 | 5.2 | 4.8 | 4.5 | 4.5 | 4.2 | 4.4 | 4.5 | 4.8 | 18.3 |
| 14 | 72.9 | 65.0 | 74.8 | 78.0 | 74.2 | 73.0 | 6.6 | 4.0 | 4.0 | 5.1 | 3.8 | 4.6 | 4.3 | 12.3 | 31.2 |
| 15 | 61.0 | 56.0 | 64.4 | 55.0 | 61.5 | 59.6 | 6.6 | 3.9 | 4.2 | 3.9 | 4.0 | 4.1 | 4.0 | 3.0 | 12.0 |
| 16 | 68.3 | 68.3 | 77.8 | 55.8 | 69.6 | 68.0 | 11.6 | 3.9 | 3.7 | 4.2 | 4.5 | 4.1 | 4.1 | 7.9 | 12.2 |
| 17 | 70.0 | 73.0 | 77.2 | 74.0 | 75.0 | 73.8 | 3.6 | 4.4 | 3.9 | 4.0 | 3.8 | 4.0 | 4.0 | 5.4 | 19.2 |
| Mean | 68.0 | 65.8 | 71.4 | 64.6 | 67.4 | 67.4 | 8.1 | 4.1 | 4.2 | 4.0 | 4.2 | 4.2 | 4.1 | 8.8 | 16.6 |
| SD | 9.6 | 9.7 | 9.6 | 9.7 | 5.6 | 7.3 | 4.6 | 0.50 | 0.55 | 0.50 | 0.69 | 0.36 | 0.35 | 6.6 | 5.7 |

HR1 = heart rate (HR) on day 1, HR2 = HR on day 2, HR3 = HR on day 3, HR4 = HR on day 4, HR5 = HR on day 5, $HR_M$ = mean of HR over the 5 day period, $HR_{CV}$ = coefficient of variation of the HR over the 5 day period, RMSSD1 = root mean of the successive R-R interval differences (RMSSD) on day 1, RMSSD2 = RMSSD on day 2, RMSSD3 = RMSSD on day 3, RMSSD4 = RMSSD on day 4, RMSSD 5 = RMSSD on day 5, $RMSSD_M$ = mean of RMSSD over the 5 day period, $RMSSD_{CV}$ = coefficient of variation in RMSSD over the 5-day period.

Figure 1.  Representative ECG describing R-R intervals.



APPENDIX A

(This page completed by Research Subjects)

Please Print

Name: ___________________________________________________________
Last                                        First                                        MI

Have you had, or do you now have, any of the following? If YES, please explain under "Remarks."

| YES | NO | CHECK EACH ITEM | YES | NO | CHECK EACH ITEM |
|---|---|---|---|---|---|
| | | Dizziness, loss of consciousness, or fainting | | | Eating disorder (anorexia, bulimia, etc) |
| | | High blood pressure or stroke | | | Eye problems or vision changes |
| | | Hay fever or seasonal allergies | | | Wears glasses or contact lenses |
| | | Reactions to medications, foods, or insect bites | | | Hearing loss or recent ear infections |
| | | Surgery; or visited a surgeon | | | Visit to Rheumatologist (arthritis, lupus, etc) |
| | | Concussions, head injuries or extremity numbness | | | Frequent persistent cough |
| | | Frequent or severe headaches, migraines | | | Sinus infections/sinusitis |
| | | Dental pain, tooth or gum problems, dental braces, bridges, or plates | | | Mouth or nose problems |
| | | Epilepsy, seizures, rheumatic fever | | | Wisdom teeth have not been removed |
| | | Scarlet fever, rheumatic fever, Mononucleosis | | | Thyroid or throat problems |
| | | Tumor, cyst, unusual growth or cancer | | | Males: Problems with/testicles, scrotum, penis |
| | | Visit to cardiologist/heart specialist | | | Females: problems with/menses, breast, Paps |
| | | Chest pain or pressure, palpitations (pounding heart) | | | Muscle weakness, paralysis or lameness |
| | | Heart problems (murmur, abnormal rhythm, etc) | | | Painful or swollen joints; ankle, wrist, fingers, knee, etc |
| | | Shortness of breath with exercise (use an inhaler) | | | Dislocation or trick shoulder, elbow, or knee |
| | | Asthma (reactive airways) recurrent wheezing | | | Bone problems (pain, pins, plates, fracture in last 5 yrs) |
| | | Chronis cough, lung disease, or recurrent bronchitis | | | Back or neck pain (severe or recurrent) |
| | | Tuberculosis (TB) or close contact with TB patient | | | Wears a brace or a splint |
| | | Diabetes, blood sugar too high or too low | | | Bone or joint deformity |
| | | Stomach, liver, or gallbladder problems, gallstones | | | Frequent leg cramps or persistent foot problems |
| | | Hepatitis, jaundice, or liver problems | | | Attempted suicide, and/or recurrent thoughts of suicide |
| | | Gastro-esophageal reflux/GERD, irritable bowels | | | Clinical depression, excessive worry or anxiety |
| | | Intestinal disease (Crohn's disease, ulcerative colitis) | | | Bipolar disorder, schizophrenia, other psychosis |
| | | Coughed up or vomited blood | | | ADD/ADHD, learning disability, or speech problem |
| | | Hemorrhoids, or rectal disease | | | Visit to a psychiatrist, Psychologist, or counselor |
| | | Black or tarry stools | | | Excessive bleeding, easy bruising or blood disorders |

| | | | | | |
|---|---|---|---|---|---|
| | | Kidney stones, kidney or bladder infections/problem | | | Visit to hematologist or oncologist |
| | | Frequent or painful urination, or blood in the urine | | | Skin problems (psoriasis, eczema, severe acne) |
| | | Hernia or rupture | | | Any illness lasting more than one week |
| | | Heat exhaustion, heat stroke, other heat related problem, dehydration requiring medical treatment | | | Injuries requiring medical attention ( neck, knee, ankle)<br>Broken bones, fractures, use of protective equipment or braces |
| | | Missing organs or limbs (eye, kidney, testicle, leg, arm) | | | Other significant illness or surgery not listed above |

**Family History**

| Yes | No | Check Each Item |
|---|---|---|
| | | Is there any history of family or genetic disease |
| | | Has any family member had a stroke at less than 55 years of age? |
| | | Has any family member died suddenly at less than 40 years of age of causes other than an accident? |

Remarks (Explain each "YES" above):

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________

*This applies to active conditions which could affect participation in military, athletic and/or academic programs, as well as past medical or psychiatric conditions.*

Subject Signature:__________________________________________________ Date: ____________

APPENDIX B

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

March 27, 2017

Darrell Martin
Department of Kinesiology
College of Education
The University of Alabama
Box 870312

Re: IRB # 17-OR-112-ME: "Evaluation of Heart Rate Variability (HRV) as a Predictor of Performance in College Freshmen and Sophomores"

Dear Mr. Martin,

The University of Alabama Institutional Review Board has granted approval for your proposed research. Your application has been given expedited approval according to 45 CFR part 46. Approval has been given under expedited review categories 4 and 7 as outlined below:

*(4) Collection of data through non-invasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves; and*

*(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 approval will expire on March 26, 2018.** If the study continues beyond that date, you must complete and submit the Renewal Form within e-Protocol. If you modify the application, please submit the Revision 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, please complete the Final Report Form. Please use the IRB-approved (stamped) consent form.

Should you need to submit any further correspondence regarding this application, please include the assigned IRB approval number. Good luck with your research.

Sincerely,

[redacted]

ɜ | Box 870127 | Tuscaloosa, AL 35487-0127
-348-7189 | Toll Free 1-877-820-3066

**Consent to Participate in a Research Study**

**Study Title:** **The relationship between smartphone-derived HRV and physical performance in military Cadets**

**Investigators:**

Darrell Martin, B.S.
Graduate Student
Department of Kinesiology

Michael R. Esco, Ph.D.
Assistant Professor
Department of Kinesiology

Phillip Bishop, Ed.D.
Professor Emeritus
Department of Kinesiology

Mark Richardson, Ph.D.
Professor
Department of Kinesiology

Jonathan Wingo, Ph.D.
Associate Professor and
Chair
Department of Kinesiology

**Funding Source**: None

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EXPIRATION DATE: 3/26/2018

**You are being asked to participate in a research study.**

**Is the researcher being paid for this study?**

No

**Is the researcher developing a product that will be sold, and if so, will the researcher profit from it?**

No

**Does the researcher have any conflict of interest in this study?**

No

**What is this research study about?**

The purpose of this study is to determine the relationship between resting heart rate variability and physical performance in military Cadets.

**Why have I been asked to be in this study?**

You have been asked to be in this study because you are a military Cadet 18 years of age or older. Your participation is requested because you are involved in a program in which you will perform a military physical fitness test.

**How many people will be in this study?**

There will be approximately 60 people in this study.

**What will I be asked to do in this study?**

You will be asked to report to the gymnasium and have your heart rate recorded every day for 5 days, in addition to the regular physical training (PT) that you will be conducting during that time as a part of your cadet PT program. The researchers will use a smartphone application and a pulse-wave finger sensor. You will be asked to perform a 55-second, seated resting heart rate test with this device. Following the heart rate test you will be asked to respond to a "Wellness" questionnaire which will have you rate your perceived level of sleep quality, fatigue, soreness, nutrition, mood and stress on a sliding, numeric scale.

The researchers will not play a part in the planning or manipulation of your training program. It will remain under complete control of your military college personnel. You or your cadre will however, provide us with training information such as rating of perceived exertion and PT results.

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**How much time will I spend being in this study?**

Each heart rate measure will take approximately 90 seconds to complete and the questionnaires will take approximately1 minute to complete. Therefore, less than 5 minutes each day will be required for data collection. The time spent waiting on other cadets to have their HRV recorded may be 10 to 15 minutes per day. Cadets will be brought in for HRV recording in a "staggered" manner so as not to waste too much of their time. Each day less than 15 minutes will be required from each student. The entire duration of the study will be 5 days, so the study will require less than 75 minutes.

**Will being in this study cost me anything?**

Only 60 to 75 minutes of your time.

**Will I be paid for being in this study?**

No

**Can the researcher take me out of the study?**

Yes, the researchers can take you out of the study if you choose not to perform daily heart rate measures.

**What are the benefits (good things) that may happen to me if I take part in the study?**

You will be given access to some of the latest technology for athlete monitoring. We will provide you with a summary of what we observed about your status if you desire. You may find this of interest, or you may not.

**What are the benefits to scientists or society?**

This study will help provide scientists, coaches, and athletes information regarding the practical utility of smartphone-derived heart rate information which may lead to better athlete management, superior training, increased performance and reduced overtraining potential.

**What are the risks (dangers or harms) to me if I am in the study?**

There are minimal risks in performing the daily heart rate measures and responding to the questionnaire. We are not asking that you change your physical activity in any manner.

**How will my confidentiality be protected?**

All information about you will be kept strictly confidential. Any identifying information (such

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as your name) will be omitted from any publications or presentations that result from this study. The information gathered from you, that we will use in the study, will be stored in a spreadsheet on a personal computer. Your personal information will not be maintained. Only study personnel will have access to your information and data.

**What are my alternatives to being in this study? Do I have other choices?**

You may freely choose not to participate. Your cadre has agreed that your choice NOT to participate will not affect your training or competitions in any way.

**What are my rights as a participant in this study?**

Taking part in this study is voluntary. You can refuse to be in the study. If you start the study, you can stop at any time. Deciding not to participate, or withdrawing participation at any point will not affect your relations with Marion Military Institute (MMI) or your chain of command. The University of Alabama Institutional Review Board (IRB) is the committee that protects the rights of participants in this research study. The IRB may review study records from time to time to be sure that those involved as participants in research studies are being treated fairly and that the study is being carried out as planned.

**Care for Research-Related Injury**

It is almost impossible that participation in this research could result in injury; however, in the event that this research activity results in an injury, treatment will be available, including first aid and emergency treatment as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. Neither the PI, MMI, nor the University of Alabama has made provision for payment of costs associated with any injury resulting from participation in this study.

**Whom do I call if I have questions or problems?**

All questions regarding the study can be directed to the primary investigator, Darrell Martin via email (dwmartin3@crimson.ua.edu or dmartin@marionmilitary.edu), or in person in his office on the MMI campus. Additionally, the supervising faculty advisor can be contacted via email (mresco@ua.edu) or by phone at (205) 348-2151. If you have questions about your rights as a person taking part in a research study you may call Ms. Tanta Myles, the Research Compliance Officer for The University of Alabama at (205) 348-8461 or toll free at 1-(877) 820-3066.

You may also ask questions, make suggestions, or file complaints or concerns through the IRB outreach website at http://osp.ua.edu/site/PRCO_Welcome.html. You may email them as well at participantoutreach@bama.ua.edu.

After you participate, you are encouraged to complete the survey for research participants that is online at the outreach website or you may ask the investigator for a copy of it. Mail it back to:

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The University of Alabama Office for Research Compliance, Box 870127, 358 Rose Administration Building, Tuscaloosa, AL 35487-0127.

*I have read this consent form. I have had an opportunity to ask questions. I understand what I will be asked to do. I freely agree to take part in the study. I will receive a copy of this consent form to keep.*

[redacted]

Signature of R[redacted] Date

Signature of Investigator Date

[redacted]

Signature of Witness Date

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