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Investigating the Effects of Endurance Training on Heart Rate Variability in Female Swimmer Athletes

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INVESTIGATING THE EFFECTS OF ENDURANCE TRAINING ON HEART RATE VARIABILITY IN FEMALE SWIMMER ATHLETES

by

JOSHUA G. BECK

(Under the Direction of John Dobson)

ABSTRACT

It is important for elite endurance athletes to have practical and reliable means of measuring fatigue throughout their training. Variations in Autonomic Nervous System activity (ANS) may provide an effective marker of fatigue and of recovery. ANS control of heart rate is well known to be affected by exercise training, and those adaptations can be determined using measures of heart rate variability (HRV). Previous research has examined the effect of training on HRV and ANS control of heart rate in males, there is a lack of any comprehensive studies that address adaptations in female athletes. Therefore, the purpose of this study was to investigate the changes in HRV and ANS fluctuations in female swimmer athletes throughout an entire collegiate swim season. 9 Division I female swimmers (Age: 20.6 ± 1.01) were used to determine HRV at three different points in their competitive training: pre-season, mid-season, and post-season. During each testing session, HRV was measured both at rest and during a maximal 400 yd freestyle swim. Heart rate values were determined using Polar™ heart rate monitors, and the HRV analyses was conducted using Kubios 2.0 HRV analysis software. Global ANS balance was shown to significantly shift towards Sympathetic (SNS) predominance during the mid-season testing and significantly shift towards parasympathetic (PNS) predominance during post-season testing. HRV analysis appears to be an appropriate tool to monitor the effects of physical training loads on performance and fitness in female athletes, and it can be used to help identify and prevent overtraining states.

INDEX WORDS: Heart Rate Variability, Endurance, Swimming, Female, Autonomic Nervous System

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VARIABILITY IN FEMALE SWIMMER ATHLETES

by

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DEDICATION

To the 2013-2014 Georgia Southern University Women's Swimming and Diving Team Coaching Staff and Athletes. Thank you for welcoming me on deck and making this experience one that I will never forget.

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My deepest and sincerest thanks to those who have helped me through this whole process. Above all, thank you to my committee, mentors, friends, and coaching staff. But most importantly, thank you Mom and Dad for always believing in me, I love make you proud.

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CHAPTER 1

INTRODUCTION

Intrigue has sparked researchers in the investigation of the relationship between the cardiovascular system and its response to exercise stress (Aubert, Seps, & Beckers, 2003). The Autonomic Nervous System (ANS) has majority control over the cardiovascular system through the activity of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), (Aubert et. al., 2003; Sloan et. al., 2009; Carter et. al., 2003). It has been shown that participation in extensive amounts of endurance exercise, which can be defined as activity of at least 20 minutes at 60-80% of one's max heart rate (Carter, Banister, & Blader, 2003), causes changes in the ANS influence, which, in turn, may alter cardiovascular function at rest.

Heart rate variability (HRV) is a relatively new technique that is an increasingly common means of assessing an individual's ANS activity and training status (Pichot et. al., 2000; Berkoff et. al., 2007; Garet et. al., 2004; Iellamo et. al., 2007). HRV provides an all-inclusive and noninvasive means by which to rapidly and accurately measure any individual's ANS activity on the heart at rest or during various physiological conditions (Tulppo, Makikallio, Seppanen, Laukkanen, & Huikuri, 1998). HRV is a term that is used to describe variations in R-R interval sets (RRi), or better said, amount of time (in milliseconds) between ventricular contractions over a set time frame (Sloan et. al., 2009; Carter et. al., 2003; Berkoff et. al., 2007). HRV may be determined by using an ECG, or a heart rate monitor system (e.g., Polar™), to measure consecutive R waves typically within time and frequency domains (Aubert et. al., 2003; Carter et. al., 2003). Evidence

indicates that frequency domains can be used to determine both SNS vs PNS influence on heart rate during any point in time and fluctuations in ANS modulation based upon the changes in frequency bands (Aubert et. al., 2003; Reyers et. al., 2012). These pertinent bodies of literature have suggested that RRi of higher frequencies (HF), which they define as (0.15-0.50Hz), are representative of PNS influence on the heart, while RRi of lower frequencies (LF), which they define as (0.04-0.15Hz), are representative of a complex combination of SNS and PNS influence (Sloan et. al., 2009; Carter et. al., 2003; Aubert et. al., 2003). The use of LF/HF ratios represents an evaluation of the ANS balance between SNS and PNS influence (Pichot et. al., 2000; Galetta et. al., 2005; Pichot et. al., 2002). Studies have also suggested that the use of normalized LF (LFnu) and HF (HFnu) values are helpful in delineating SNS influence from PNS influence (Pichot et. al., 2000). That said, it is important to note that other factors influence lower frequencies and research has shown that very low frequency (VLF) components ($\leq 0.04\text{Hz}$) do not contribute to any physiological mechanisms (Carter et. al., 2003)

Highly-trained athletes are known to have a lower resting heart rate compared to their sedentary counterparts (Carter et. al., 2003; Tulppo et. al., 1998; Galetta et. al., 2005; Aubert et. al., 2003). Endurance training facilitates reductions in resting heart rate by both increasing PNS and decreasing SNS outflow to the heart. Pigozzi et. al. (2001) and Carter et. al. (2003) have theorized that these endurance training-induced changes in ANS outflow are also responsible for the increases in HRV that are typically found in highly trained athletes. When examining the effects during exercise on HRV, it is important to consider that PNS withdrawal is the primary moderator for increasing heart rate up to 60% of the VO_2 max and that any increase above 60% is caused from an

increase in SNS activity (Carter, et. al., 2003; Aubert et. al., 2003). Studies have observed that, with intense training, there is a progressive decline in HRV (Pichot et. al., 2000; Garet et. al., 2004; Iellamo et. al., 2002). The a decrease in heart rate variability, demonstrates a global ANS shift away from PNS activity, to a predominant SNS influence acting on the heart. If the intense training is immediately followed by a period of recovery training (e.g., one week recovery training), then PNS activity will rebound and cause an increase in HRV and demonstrate a shift in ANS activity away from SNS and towards PNS as the primary control factor on heart rate.

Given the important information that it can provide about ANS function and fluctuation, HRV has become an important tool for helping to monitor training in elite athletes (Pichot et. al., 2000; Berkoff et. al., 2007; Garet et. al., 2004; Iellamo et. al., 2002). The use of HRV as an indicator of both training and under recovery has been insightful to the needs of an individual during a recovery phase (Pichot, Busso, Roche, Garet, Costes, Duverney, Lacour, & Barthelemy, 2002). After an intense overreaching training period, which can be referred to as a buildup of training stress that results in a short-term decrease in performance capacity (Bosquet, Merkari, Arvisais, & Aubert, 2008), an elite athlete could take anywhere from 8-23 days to fully recover (Pichot, Busso, Roche, Garet, Costes, Duverney, Lacour, & Barthelemy, 2002). Changes in ANS activity measurements can help to identify the effects of this intense training, which can then be used to optimize individual taper. (Garet, Tournaire, Roche, Laurent, Lacour, Brathelemy, & Pichot, 2004). HRV appears to be a strong indicator of cumulated training loads in elite athletes (Pichot et. al., 2000). Excessive fatigue is counterproductive for athletes as it can lead to a decrease in their performance capacity.

Peak performance in sport requires training loads that will occasionally push the adaptation capabilities of the human body to their limits. This push requires an accumulation of training stress resulting in a short-term decrease in performance capacity, a period of recovery is necessary after this over reaching portion of training. The use of HRV can help to identify individuals who are under recovered, and helps with the implementation of improved recovery, which in turn, can improve performance capacity in individuals above what was achievable after normal training is present (Bosquet et. al., 2008) HRV can be used to identify fatigue by evaluating the fluctuations in ANS. A correlation has been shown between ANS activity and performance. When a decrease in ANS activity was observed, performance also decreased, and when there was a rebound in ANS, there was an increase in performance (Garet et. al., 2004; Pichot et. al., 2000; Iellamo et. al., 2002).

Research that has examined training, ANS activity, and HRV has used mostly male subjects, and few studies have examined gender differences in cardiovascular function following endurance training (Berkoff et. al., 2007). Very little testing has dealt with the effects of training and physiological changes in female athletes (Sloan et. al., 2009; Berkoff et. al., 2007). Among the few studies that have actually compared males and females, Berkoff et. al. (2007) and Carter (2003) have observed that men have a greater LF, which shows increased sympathetic activity. On the other hand, females have a greater HF reflecting an increased parasympathetic influence which demonstrates a characteristic of increased cardiac protection for female athletes during durations of cardiac stress (Carter et. al., 2003; Berkoff et. al., 2007; Aubert et. al., 2003). It is likely that females and males respond to endurance training in similar ways, but the two have

not yet been sufficiently compared and contrasted, and so important differences may exist (Sloan et. al., 2009). For example, it is possible that endogenous sex hormones fluctuations throughout the menstrual cycle could have an influence on adaptations of HRV during endurance training. (Aubert et, al., 2003; Carter et. al., 2003, Berkoff et. al., 2007; Pigozzi et. al., 2001). However, this may not be the case. Due to inadequate studies pertaining to female athletes, it is clear that there is a need to use female endurance athletes to investigate changes in ANS and HRV throughout a competitive season (Berkoff et. al., 2007).

Sloan et. al., (2009) suggested that during the follicular phase a shift occurs in the ANS towards SNS activity. However, an additional study showed that, throughout normal cyclic variations in all endogenous sex hormone levels and despite increased heart rate during the ovulation phase, there was no HRV measurement that was significantly different between each phase. (Leicht, Hirning, & Allen, 2002). Furthermore, Kondo et. al. (1989) examined ANS activity throughout five different points within the menstrual cycle (e.g. menstrual, follicular, ovulatory, luteal, and premenstrual phases) and found that there were no noticeable differences in the RRi between any of the phases at rest. Also, Cooke et. al. (2002) investigated potential changes in RRi during a normal menstrual cycle in healthy, young, females using measurements from the carotid-cardiac baroreflex. The investigators found that, while hormone fluctuation was substantial, neither the RRi nor the ANS changed significantly over the course of the normal menstrual cycle. Therefore, the bulk of evidence indicates that it is not necessary to account for differences in menstrual cycle phase when investigating training-induced variations in ANS or HRV.

The aim of this study was to gain a better understanding of the influences swim training has on the physiological changes associated with HRV in female swimmers. Swimmers were chosen because of their prolonged practices in the water and extensive training regimen during a full season, involved intense overreaching periods mixed with periods of recovery. Due to the strenuous training that is involved in the sport of swimming, these athletes were, theoretically, exposed to greater changes in ANS activity. However, it is important to point out that swimmers may not demonstrate the typical responses to intense training due to the unique nature of their training environment. For example the unique environment of water, swimmers physiologically respond differently to exercise within the pool as compared to land based exercises such as running (Troup, 1999). The cardiovascular responses are altered due to the elevated pressure on the surface of the body, caused from water immersion (Troup, 1999). Swimmers also perform in a supine position in the water which causes an increase in the venous filling (end diastolic volume), which in turn, both increases stroke volume and lowers heart rate at any given cardiac output (Troup, 1999). This information brings to question, how will season training of swimmers affect the heart rate or HRV? Therefore, the purpose of this study was to investigate the changes in resting and submaximal heart rate variability in female swimmers throughout an entire collegiate swim season.

CHAPTER 2 METHODS

Participants

Thirty collegiate female swimmers were recruited for this study from a NCAA Division 1 University swim team. The swimmers' participation in the study was completely voluntary. Nine swimmers between the ages of 19-24 participated. As is very typical of competitive swimmers, the participants trained primarily in one of three groups (sprint, middle-distance, or distance groups).

Instrumentation

Polar Heart Monitor. The Polar Team 2 heart monitor system was used. This system consisted of 30 Team 2 transmitters with Wearlink and straps and charger (Polar Electro Oy, Professorintie 5, Kempele, Finland). The system was capable of assessing multiple heart rates at once with the use of the Polar Team 2 heart monitors and software for PC. The heart monitors were waterproof and they instantaneously measured heart rate, RR interval sets and training load while participants were active in the water.

Kubios HRV 2.0. This software was used for HRV analysis. This software was developed by Mika P. Tarvainen, J. P. Niskanen, J. A. Lipponen, P. O. Ranta-aho, & P. A. Karjalainen in the Department of Physics at the University of Kuopio, Finland. This program had the ability to instantly calculate the time and frequency domains that were necessary for the comprehensive analysis of HRV signals (Reyes et. al., 2012).

Procedure

Swim Training: The training that was implemented to the swim team was developed exclusively by the varsity swim coaches. Consequently, the participants trained in a manner that was typical for collegiate swimmers and the researchers did not have influence over the workouts or training plan. Given that there was no control over the training and the full details of training were not known, in general, normal training of collegiate swimmers consisted of high intensity, fast interval training paired with anaerobic type exercise (e.g. underwater sets, sprints with no breath...etc) middle distance training, stroke specific training and finally sprint training. Also, competitive swimmers often periodically engaged in recovery training (e.g., light intensity, long distant swims with long periods of rest between sets) throughout their season. That said, an effort was made to collect some evidence as to the quantity and quality of the participants' training. Weekly distances swam were obtained from the coaching staff and weekly rating of perceived exertion (RPE) scores were collected for each session from each swimmer via a private email. The RPE scale used was the Borg CR10 scale. Training load was calculated by multiplying the training group's weekly average RPE score by the distance swam by each group (Wallace et. al., 2008).

Heart Rate Testing: HR and HRV was assessed during three different periods (i.e., days) throughout the season: pre-season, mid-season, post-season. The pre-season assessment occurred at the very beginning of the training period when swimmers were considered detrained. At the beginning of each of the three data collection periods, the Polar Team 2 heart monitors were handed out as swimmers arrived at practice.

Swimmers were asked to wear the heart monitor under their swimsuits. Resting heart rate (RHR) was recorded after the participant had sat in a comfortable position for at least five minutes. After recording the RHR, the participants were then told to complete the proper warm-up that the coach had requested (e.g., 400 yard swim, 300 yard kick, 200 yard pull, 100 yard drill). Upon completion of warm-up, swimming heart rates were monitored using the Polar Team 2 system and while the participants perform a 400 yard timed freestyle swim. Garet et. al. (2004) demonstrated that the 400 yard distance could be used as an effective means of eliciting maximal aerobic power. This distance gave ample time for swimmers' heart rate response to achieve a steady-state with fewer variations of submaximal heart rate during the 400 yard swim. A whistle signaled the swimmer to begin the race at which point the swimmer swam with as much intensity as possible for the entire 400 yard distance, the HR monitors were then collected at the completion of the 400yd swim. The data from HR monitors were uploaded to the Polar Team 2 computer software and eventually analyzed by Kubios, which determined frequency domains of LF, HF, and LF/HF ratio.

Statistical Analysis

Statistical differences in resting and submaximal HR and HRV values (e.g., LF, HF, and LF/HF ratio) were determined using repeated measures (pre-season vs. mid-season vs. post-season) ANOVAs. Statistical significances was set at $P = 0.05$, but values of up to $p = 0.07$ will also be discussed. Data are expressed as mean \pm standard deviation

CHAPTER 3

RESULTS

Participants

Participants included 9 female members of the Georgia Southern University women's swimming team; two were sprinters, four were middle distance swimmers and three were distance swimmers. Basic demographics are shown below in Table 1.

Training Load

Throughout each week of the swim season, the distance training group averaged a weekly total ($45,292 \pm 19148$ yards), Mid Distance training group averaged a weekly total ($41,489 \pm 18447$ yards), and Sprint training group averaged a weekly total ($37,070 \pm 16507$ yards). The exact weekly yardage covered by each group is displayed in Figure 1. The mean RPE throughout the season for the Distance group was 6.53 ± 1.67 , 6.0 ± 1.90 , and 4.63 ± 2.21 , for the Distance, Mid Distance and Sprint groups, respectively. RPE is depicted in Figure 3, and mean TTLs are depicted in Table 4

Heart Rate Variability Analysis

HRV analysis was completed while individuals were at rest and while swimming a 400 yd front-crawl. Resting values of HR, LF, HF and LF/HF ratio from pre, mid, and post season tests are displayed in table 4. A repeated measures ANOVA indicated the LF/HF ratio varied significantly throughout the season $F(2,16) = 4.46$, $P = 0.03$, $\eta_p^2 =$

0.36. Post hoc tests revealed there was not a statistical difference between the pre-season and post-season values $F(1,8) = 0.64$, $P = 0.45$, but post-season values were significantly $F(1,8) = 5.48$, $P = 0.04$, $\eta_p^2 = 0.41$ lower than those of the mid-season. The difference between pre-season and mid-season LF/HF ratios missed statistical significance $F(1,8) = 4.67$, $P = 0.06$

The HR, LF, HF, LF/HF ratio values that were collected during the pre-season, mid-season, and post-season 400 yard swims are listed in Table 5. A repeated measures ANOVA indicated the heart rate during the 400 varied significantly throughout the season $F(2,16) = 6.26$, $P = 0.01$, $\eta_p^2 = 0.44$. Post hoc tests revealed these heart rate values increased significantly $F(1,8) = 5.69$, $P = 0.04$, $\eta_p^2 = 0.42$ between the pre-season and mid-season and they increased significantly $F(1,8) = 13.06$, $P = 0.01$, $\eta_p^2 = 0.62$ between pre-season and post-season.

CHAPTER 4

Discussion

This study investigated the effects of intense endurance training on heart rate variability in collegiate female swimmers. Results indicated there were significant differences in the resting LF/HF ratio and the heart rate during the 400 test, which corresponded with the variations in training intensity and periods of recovery throughout the season. Also, near significant trends were obtained in the resting heart rate and the resting HFn.u. measures ($P = 0.06$ and $P = 0.07$, respectively) which could also be related to training intensity and recovery periods.

Frequency Domain Analyses

Frequency domain indexes of heart rate variability, can provide noninvasive markers of autonomic nervous system modulation of heart rate (Pigozzi et. al., 2001; Iellamo et. al., 2002; Pichot et. al., 2002) In this study, subjects demonstrated frequency domains of LFn.u to be nearly significant throughout the season ($P = 0.08$), however, values measured during the pre-, mid-, and post-season showed similar trends as found in previous research (Perini & Veicsteinas, 2003; Iellamo et. al., 2002; Pichot et. al., 2002). During the pre-season to mid-season measurements, LFn.u. values at rest (58.56 to 70.57) trended towards an increase. This increasing trend could signify a shift in predominance of sympathetic modulation during the overload period. During the mid-season to post-season, the measurement of LFn.u values were trending toward a decrease (70.57% to 48.12%) which could imply a decrease in SNS modulation strength, below that of

baseline values (58.56%, respectively). Frequency domains of HFn.u values at rest demonstrated nearly significant differences throughout the season ($P= 0.07$), however, values measured during pre-, mid-, and post-season showed opposite trends of that seen in LFn.u. During pre- to mid-season, at the peak of training loads, HFn.u measurements (41.07 % to 29.46%) could imply a predominant shift in ANS tone to sympathetic dominance. This trend corresponds with that of Perini and Veicsteinas (2003) whom also observed similar fluctuations of parasympathetic withdrawal in relation to increased intensity. A large and nearly significant rebound of HFn.u was measured from mid-season to post-season (29.46% to 51.88%) which could signify a predominance of parasympathetic modulation during the recovery period. The PNS modulation showed a trend that increased in strength at the post-season compared to baseline (41.07% to 51.88%, respectively) which may give insight to individuals being in a rested and recovered state as stated by Pichot et. al., (2000). These findings, even though not significant, follow similar trends from previous studies that did find statistical significance in both fluctuations of the LFn.u and HFn.u measurements as intensity was increased and decreased (Pichot et. al., 2002; Iellamo et. al., 2002; Garet et. al., 2004).

Although no significant differences were observed in LFn.u and HFn.u values during the season, subjects demonstrated a significant progressive increase in heart rate variability from mid-season to post-season, as demonstrated in the LF/HF ratio at rest (5.87 to 1.77, respectively). These modifications correspond to a progressive increase in vagal modulation and decrease in sympathetic modulation on the sinoatrial node. The LF/HF ratio measurement changes are consistent with previous research (Pichot et. al.,

2000; Pichot et. al., 2002; Garet et. al., 2004) which demonstrated a progressive increase in the LF/HF ratio at rest when training intensities were at their highest level, and LF/HF ratio values decreased when intensity and duration were lowered (i.e., during a recovery period). Practically, this can be translated to a basic assumption that the athletes were demonstrating an imbalance toward a predominance of sympathetic activity during the mid-season; the LFn.u value at mid-season adds strength to this assumption, when training intensity was at the highest value. Upon the completion of the mid-season training and as taper was being initiated, the autonomic nervous system tone shifted its imbalance toward a predominance of parasympathetic activity by the post-season, which can be related back to the fluctuations observed in HFn.u values from mid-season to post-season. These findings from resting values of the LF/HF ratio are similar to trends Perini and Veicsteinas (2003) observed, who found that when at rest, the LF/HF ratio could detect the modification in ANS activity caused by prolonged exercise. This relationship can correspond to the nonsignificant progressive bradycardia that is demonstrated from pre-season to post-season values (see Table 4). Thus, these findings show consistency with that of previous research of resting HR values (Pigozzi et. al., 2001; Pichot et. al., 2002; Pichot et. al., 2000). In addition to the changes observed in HRV, this study lacked the ability to give an explanation in regards to the differences in gender and the role it plays in HRV fluctuations caused by intense training, this is also true with previous research; therefore, further research is necessary to investigate the differences between gender adaptations to aerobic exercise.

The transition from rest to exercise of varying intensities depends on the interactions of LF and HF rhythms necessary for the body to achieve steady-state via the cardiopulmonary system. The HR response during exercise leading up to 30% of an individual's VO_2 max is based solely on the reduction of vagal modulation (Perini & Veicstenias, 2003). Any activity that takes place at medium-high intensity, the increased sympathetic influence is the second mechanism and overlaps vagal withdrawal to cause further HR increases up to steady-state values (Perini & Veicstenias, 2003). To achieve steady-state, the respiratory system must increase effort to maintain intensity, and in doing so, plays part in influencing the parasympathetic modulation. This interaction is known as the respiratory sinus arrhythmia (RSA). The RSA is caused when inhalation inhibits vagal activity and exhalation causes vagal activity to resume. The mechanical effect of increased respiratory activity has been shown to be responsible for HF fluctuations during exercise, and that increased HF powers above 60-65% VO_2 max, when LF predominance should be the primary frequency, demonstrates that this mechanism is important (Perini & Veicstenias, 2003). The autonomic response has been related to the ventilatory threshold during dynamic muscular movements. The parasympathetic activity was shown to decrease from a rest to exercise transition up till 60% ventilatory threshold followed by a substantial increase after 60%. Sympathetic activity was shown to be statistically unchanged up till 100% ventilatory threshold, and then it increases significantly at 110% ventilatory threshold (Yamamoto et. al., 1992). Swimming is very demanding on the respiratory system and limits the swimmers' rate of breathing when compared to land based exercises. Additionally, swimmers must strictly

control their breathing (e.g., breathing every 3 or more strokes while swimming the crawl) in a manner that increases the amount of time air is being exhaled out and limits the amount of time air is being brought in. Though it would have been ideal for the RSA to be accounted for in this study, it was not possible to collect information of respiration. In addition to RSA, previous research has also shown that, individuals who exercise in water demonstrate different respiratory patterns caused by the pressure exerted on the chest due to immersion in water (Perini & Veicstenias, 2003). This increased pressure on the body, in addition to the altered respiratory pattern, caused larger HF central frequencies during dynamic muscle movement while immersed in water (Perini & Veicstenias, 2003). According to this evidence, HRV is not an accurate means of assessing ANS activity during dynamic muscular activity, especially when the influences of respiration are not accounted for. Nevertheless, HRV data was collected during the 400 yard freestyle swim, in this study in an attempt to focus on how this data changed within individuals as the season progressed. Data indicated significant changes in the mean submaximal heart rate observed during the 400 yard freestyle swim from pre- to mid- and pre- to post-season (175 to 180 bpm, and 175 to 182 bpm, respectively). The absence of significant differences in LFn.u., HFn.u., and LF/HF ratio are in agreement with previous research (Perini & Veicsteinas, 2003).

Limitations of the Study

One major limitation of this study was the sample size. At the start of this study, a total of 15 participants were recruited (Sprint group = 4, Mid Distance group = 8, Distance group = 4) and during the post-season data collection 9 subjects remained (Sprint group = 2, Mid Distance group = 4, Distance group = 3). The majority of participants that dropped out of the study did so because of injury. Due to small subject size, a great deal of variance was observed in nearly all measures, and in some cases, the standard deviations were much greater than the mean values. Second, a potential limitation of this study includes the indirect method used to assess changes in autonomic function. The polar heart monitors that were used may have caused additional variance. These heart monitors were easily shifted while swimming and in some instances, crucial HRV measurements may have been lost or not recorded. Due to lost or unrecorded R-R intervals, Kubios 2.0 HRV analysis software may have added to the increased variance. Research has shown that measurements of HRV during the daytime have increased potential of being affected by environmental factors (Pichot et. al., 2002) such as, stressors from school, personal life issues, stressors occurring within the team, etc. Ideally, HRV should also be measured during sleep to provide an indicator of accumulated strain of both training and other sources of stress on the athlete while environmental stressors exert very little influence on ANS activity (Garet et. al., 2004). Although power spectral analysis is not able to accurately explain ANS activity during exercise due to respiration, it has been shown to accurately estimate ANS activity during recovery due to the return of cardiovascular control mechanisms to pre-exercise

conditions (Perini & Veicsteinas, 2003). This leaves a possibility of further research for the recovery rate of ANS, and whether it would differ during a collegiate swim season.

Conclusions

This study investigated the effects of intense exercise training on the heart rate variability in collegiate female swimmer athletes, at the beginning, middle and end of a full collegiate swim season. Heart rate variability, thus, appears to be a potentially strong indicator of accumulated stress experienced by swimmers who train continuously. Constant monitoring of athletes in such a way can help determine optimal training volumes, and potentially yield the highest possible performance. This study has partially succeeded in increasing the understanding of autonomic fluctuations in female collegiate swimmers during an entire swim season. More research is needed to understand changes of ANS activity throughout different phases of training and while monitoring normal sleep cycles. Additional research involving both male and female subjects could also be geared towards demonstrating ANS activity during recovery after bouts of intense exercise. This could result in improved individualized training profiles and may help in the prevention of overtraining states.

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Viveiros, L., Costa, E., Nakamura, F., & Aoki, M. (2011). Training load monitoring in judo: Comparison between the training load intensity planned by the coach and the intensity experienced by the athlete. *Revista Brasileira de Medicina do Esporte*, 17(4), 266-269.

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APPENDIX A

RESEARCH QUESTIONS, LIMITATIONS, DELIMITATIONS, ASSUMPTIONS, AND DEFINITIONS

Research Questions

1. Will swim training have an effect on female resting and submax heart rate variability?

Limitations

1. Sample is recruited from GSU athletics for convenience which means there will be a small number of participants and non-randomization
2. The ability to generalize this information to the swimming population will be difficult
3. Participants will not be familiar with this in-water testing

Delimitations

1. Only female participants
2. The study will be done using NCAA Division I elite female swimmers between the ages of 18-24 years of age who all compete on the Georgia Southern Swim Team
3. Only using specific information from the 400 yard swim test and polar heart monitor

Assumptions

1. Each participant will take the task seriously

2. Each participant will put forth great effort for each test

APPENDIX B
ANNOTATED BIBLIOGRAPHY

Aubert, A., Seps, B., & Beckers, F. (2003). Heart rate variability in athletes. *Sports Medicine* , 33(12), 889-919.

The purpose of this review was to examine the influences on HRV indices in athletes from training status, different types of exercise training, sex and ageing, presented from both cross-sectional and longitudinal studies. They stated that the predictability of HRV in over-training, athletic conditioning and athletic performance is also included.

Berkoff, D., Cairns, C., Sanchez, L., & Moorman, C. (2007). Heart rate variability in elite american track-and-field athletes. *The Journal of Strength & Conditioning Research*, 21(1), 227-231.

The purpose of this study was to investigate the differences in the heart rate variability in endurance trained track athletes compared to the anaerobically trained track athletes. The investigators hypothesized that the HRV measurements would be dramatically different between the two groups. What they did find was that between groups, there was not a large difference. But what they did find to have a large difference was between genders.

Bosquet, L., Merkari, S., Arvisais, D., & Aubert, A. (2008). Is heart rate a convenient tool to monitor overreaching? a systematic review of the literature. *British Journal of Sports Medicine* , 42(9), 709-714.

This is a meta-analysis which was conducted on the effect of overload training on resting HR, submaximal and maximal HR, to determine whether these measures can be used as valid markers of overreaching. This analysis found that the small to moderate amplitude changes in HRV were seen to fall within the day to day variability. They stated that correct interpretation of HR or HRV fluctuations during the training process requires the comparison with other signs and symptoms of overreaching to be meaningful.

Carter, J., Banister, W., & Blader, A. (2003). Effect of endurance exercise on autonomic control of heart rate. *Sports Medicine* , 33(1), 33-46.

This article consists of multiple article reviews that deal with heart rate and how the HR can be regulated by PNS and SNS. This article also goes in detail as to how long-term endurance training has significant influences on how the autonomic nervous system controls the heart functions. It also has stated that parasympathetic activity increases due

to endurance training and decreases the sympathetic activity which then can cause a decrease in resting heart rate.

Castello, V., Simoes, R., Bassi, D., Catai, A., Arena, R., & Borghi-Silva, A. (2011). Impact of aerobic exercise training on heart rate variability and functional capacity in obese women after gastric bypass surgery. *Obesity Surgery*, 21(11), 1739-1749.

The purpose behind this study was to examine whether a 12 week aerobic exercise training program influence the HRV and functional capacity in a positive manner for patients that just underwent gastric bypass surgery in a female group. The results showed that the 12 week aerobic exercise training program had improved the cardiac autonomic modulation as well as the functional capacity four months after GBS.

Cooke, W., Ludwig, D., Hogg, P., Eckberg, D., & Convertino, V. (2002). Does the menstrual cycle influence the sensitivity of vagally mediated baroreflexes?. *Clinical Science*, 102(6), 639-644.

The purpose of this study was to examine the changes that could occur during the female menstrual cycle and if it could possibly play a role in the influence of the autonomic regulatory mechanisms. The investigators studied the carotid-cardiac baroreflex in ten healthy young females on four occasions over the course of their menstrual cycle. While their hormones fluctuated substantially, they found that the beat-to-beat (R-R interval) does not change over the course of the normal menstrual cycle.

Galetta, F., Franzoni, F., Femia, R., Roccella, N., Pentimone, F., & Santoro, G. (2005). Lifelong physical training prevents the age-related impairment of heart rate variability and exercise capacity in elderly people. *Journal of Sports Medicine and Physical Fitness*, 45(2), 217-221.

The aim of this study was to have a better understanding of the effects age has on the reduction of HRV and the working capacity. They evaluated a group of elite master athletes and their lifelong history of endurance running and the effects it has on their HRV and work capacity. What the investigators found was that long term endurance training had caused

Garet, M., Tournaire, N., Roche, F., Laurent, R., Lacour, J., Barthelemy, J., & Pichot, V. (2004). Individual interdependence between nocturnal activity and performance in swimmers. *Medicine and Science in Sports and Exercise*, 36, 2112-2118.

The purpose of this study was to investigate the relationship between variations in autonomic nervous system activity and the variations in performance. There were a total of 7 subjects (4 male, 3 female) that performed a maximal aerobic performance of a 400 yard freestyle race before and after a 3-wk intensive training period, and following a 2-

wk tapering period. The decrease in ANS activity during intensive training is correlated with the loss in performance, and the rebound in ANS activity during tapering tracks with the gain in performance. Interestingly, the speed of the rebound during the tapering period was quite different between swimmers. ANS activity measurement may be useful to design and control individual training periods and to optimize the duration of tapering.

Idellamo, F., Legramante, J., Pigozzi, F., Spataro, A., Norbiato, G., Lucini, D., & Pagani, M. (2002). Conversion from vagal to sympathetic predominance with strenuous training in high-performance world class athletes. *Circulation*, 105(23), 2719-2742.

This study was done to test the hypothesis that strenuous endurance training, as seen with high-performance athletes, would increase sympathetic activity and decrease parasympathetic activity. Subjects were 7 male members of the Italian junior national rowing team. Investigators monitored subjects roughly 3 months apart 3 times through the training season before taper was implemented. This study showed that during the peak training, the heart is influenced by a higher sympathetic activity with a decrease in parasympathetic demonstrating an indicator of fatigue.

Kondo, M., Hirano, T., & Okamura, Y. (1989). Changes in autonomic nerve function during the normal menstrual cycle measured by the coefficient of variations of rr intervals. *Nihon Sanka Fujinka Gakkai zasshi*, 41(5), 5

The purpose of this study was to determine if there is a change in ANS function during the menstrual cycle. There were 20 female subjects (average age 26.1 ± 4.6 yrs) with a normal menstrual cycle. R-R intervals was measured to investigate autonomic function in the menstrual, follicular, ovulatory, luteal, and premenstrual phases. The investigators found that there was no noticeable difference in R-R interval among the 5 phases of the menstrual cycle.

Leicht, A., Hirning, D., & Allen, G. (2002). Heart rate variability and endogenous sex hormones during the menstrual cycle. *Experimental Physiology*, 88(3), 441-446.

The purpose of this study was to examine the association between normal endogenous levels of oestrogen, progesterone, luteinising hormone and follicle stimulating hormone and heart rate variability. The investigators found that, despite a significantly greater heart rate was present at ovulation and normal cyclic variations in all endogenous sex hormone levels; there was no measure of HRV that was significantly different between menstrual phases. This finding demonstrates that the normal cyclic variations in endogenous hormone levels during the menstrual cycle were not significantly associated with changes in cardiac autonomic control as measured by HRV.

Nagai, N., & Moritani, T. (2004). Effect of physical activity on autonomic nervous system function in lean and obese children. *International Journal of obesity*, 28(1), 27-33.

The point of this study was to explore the ANS activity in lean and obese children, the focal point being on the variation in physical activity levels. The investigators recruited a total of 24 physically active and 24 physically inactive obese children were chosen for this study and 24 lean-active and 24 lean-inactive children. The results showed that obese children have a reduced SNS as well as PNS activity compared to lean children with a similar activity level. The study showed that with physical activity there can be an increase in the overall ANS activity in both lean and obese children.

Perini, R., & Veicsteinas, A. (2003). Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. *European journal of applied physiology*, 90(3-4), 317-325.

The purpose of this review was to examine the differences of LF and HF frequencies that occur during different positions of the body during rest and during different exercise in various physiological conditions. They also examined the respiratory activity and the effects it plays on the autonomic activity during exercise on land as well as while being submerged in water.

Pichot, V., Busso, T., Roche, F., Garet, M., Costes, F., Duverney, D., Lacour, J., & Barthelemy, J. (2002). Autonomic adaptations to intensive and overload training periods: A laboratory study. *Medicine and Science in Sports and Exercise*, 34(10), 1660-1666.

The purpose of this study was to examine the possibility of using heart rate variability as a possible marker of fatigue that is practical and can easily assess the ANS and the changes that occur. The investigators studied six sedentary subjects, whom participated in 2 months of rigorous intensive training and 1 month of overload training. They found that during the intense physical training, performance increased significantly as well as significant shifts in ANS modulation from SNS to more of a PNS activity. When the subjects performed the overload training, PNS ceased to increase and the ANS shifted to SNS activity. During the week of recovery, there was a substantial rebound of the PNS activity

Pichot, V., Roche, F., Gaspoz, J., Enjolras, F., Antonidais, A., Minini, P., Costes, F., & Busso, T. (2000). Relation between heart rate variability and training load in middle-distance runners. *Medicine and Science in Sports and Exercise*, 32(10), 1729-1736.

The purpose of this study was to investigate the reliability of using HRV as a indicator for overall physical fatigue in middle distance runners. The investigators chose to use the ANS activity using HRV in seven middle distance runners during a 4 week time period, three of which were heavy training followed by a resting week. The results

showed that heavy training shifted the cardiac autonomic balance to a increase in SNS activity and away from PNS activity. This showed that the runners were physically fatigued. The use of HRV was more reliable than the use of resting heart rate, VO_{2max} , and hormone balance.

Pigozzi, F., Alabiso, A., Parisi, A., Disalvo, V., Diluigi, L., Spataro, A., & Iellamo, F. (2001). Effect of aerobic exercise training on 24 hr profile of heart rate variability in female athletes. *The Journal of Sports Medicine and Physical Fitness*, 41(1), 101-107.

This study was used to investigate the effects of exercise training on the autonomic regulation of heart rate under daily life conditions. Twenty-six healthy female athletes were used during the study. A five week aerobic exercise training program was implemented and HRV was monitored daily and nightly. The investigators found that that relative night-time increases the LF and decreased in the day-night difference in time domain indexes for the heart rate variability.

Sloan, R., Shapiro, P., DeMeersman, R., Bagiella, E., Brondolo, E., McKinley, P., Slavov, I., & Fang, Y. (2009). The effect of aerobic training and cardiac autonomic regulation in young adults. *American Journal of Public Health*, 99(5), 921-928.

This study was conducted to test the effects of aerobic exercise on the autonomic regulation of the heart compared to a strength training program in a population of health young adults. The investigators recruited 149 participants and randomized them into an experimental (aerobic training) group and a strength training group. The study took 12 weeks and results found that the aerobic conditioning group but not the strength training enhanced the autonomic control of the heart. During this study, they also found that gender plays a significant role in this exercise-related cardioprotection.

Troup, J. (1999). The physiology and biomechanics of competitive swimming. *Clinics in sports medicine*, 18(2), 267-285.

The purpose of this article is to provide an overview of the applied swimming sciences as a reference guide to practitioners involved in the sport. Many of the information in post 1985 in physiology and biomechanics are discussed in this article. This article gives great insight as to the breakdown of what makes a swimmer, a swimmer.

Tulppo, M., Makikallo, T., Seppanen, T., Laikkanen, R., & Huikuri, H. (1998). Vagal modulation of heart rate during exercise: Effects of age and physical fitness. *American Journal of Physiology-Heart and Circulatory Physiology*, 274(2), 424-429.

This study was done to assess the effects of physical fitness and age had on the vagal modulation on the heart rate during exercise. The investigators used instantaneous R-R interval variability at rest and during different exercise intensities while performing a bicycle exercise test in a population of healthy men. They found that low physical fitness is linked with impairment of cardiac vagal function during exercise , while age alone resulted in more evident impairment of vagal function at rest.

Reyes, I., Nazeran, H., Franco, M., & Haltiwager. (2012). Wireless photoplethysmographic device for heart rate variability signal acquisition and analysis. *IEEE EMBS*, 34, 2092-2095

The purpose behind this research was to further investigate the use of photoplethysmographic (PPG) signals to aid in the acquisition and analysis of heart rate variability (HRV). This non-invasive quantitative marker of the ANS could be used to assess cardiac health and other physiological conditions. With the information that was acquired, the investigators developed a user-friendly graphical user interface (GUI) to display PPG data and there spectra. The use of Kubios HRV 2.0 analysis software was used to compare data that was acquired and validate the information.

Viveiros, L., Costa, E., Nakamura, F., & Aoki, M. (2011). Training load monitoring in judo: Comparison between the training load intensity planned by the coach and the intensity experienced by the athlete .*Revista Brasileira de Medicina do Esporte*, 17(4), 266-269.

The aim of this study was to compare the perception of the training load intensity of Judo coaches and athletes. The sample consisted of 4 coaches and 40 athletes of the Brazilian National Judo Team. The comparison between the intensity planned by the coach and the intensity experienced by the athletes was determined by the session RPE method during a “Training Camp”. In order to assess lactate responses to training, blood smaples were collected pre- and post training session. The intensity experienced by the athletes was higher than the intensity planned by coaches in all training sessions. Regarding lactate concentration, it was observed an increase at post-training as compared to pre-training in all sessions, with no differences between sessions. The results of this study demonstrates that although the training session hass been developed by experiences coaches, significant differences were detected between the intensity of external training load planned by the coach and the intensity of the internal training load experienced by the athletes. These data reinforce the relevance of training monitoring in order to maximize performance

Yamamoto, Y., Hughson, R., & Nakamura, Y. (1992). Autonomic Nervous System Response to Exercise in Relation to Ventilatory Threshold. *CHEST Journal* 101.5_Supplement (1992): 206S-210S

The purpose of this study was to approach the study of autonomic nervous system control of heart rate during exercise by means of heart rate variability spectral analysis with reference to its relationship to ventilatory threshold. The approach to this study was that HRV has been shown to reflect SNS and PNS activity with the underlying complexity of spectral analysis. The data collected demonstrated a off balance relationship between SNS and PNS during levels of ventilatory threshold.

APPENDIX C
 FIGURES AND TABLES

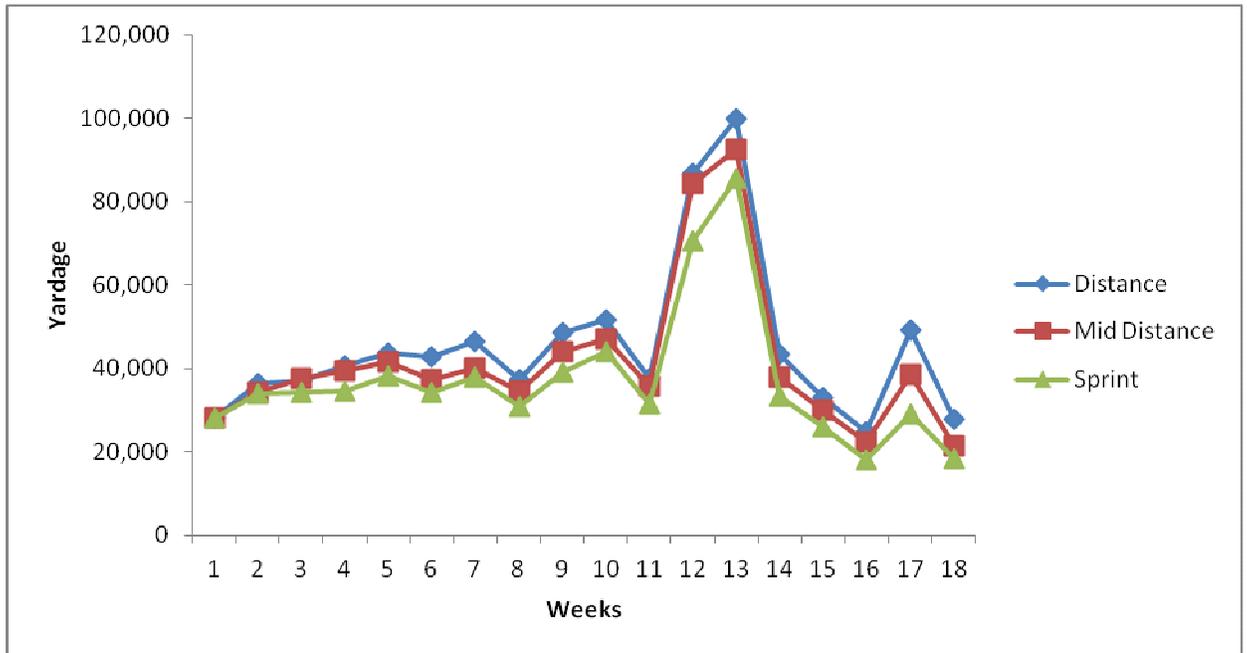


Figure 1. Weekly yardage by training group (n=9; Distance=3, Mid Distance=4, Sprint=2)

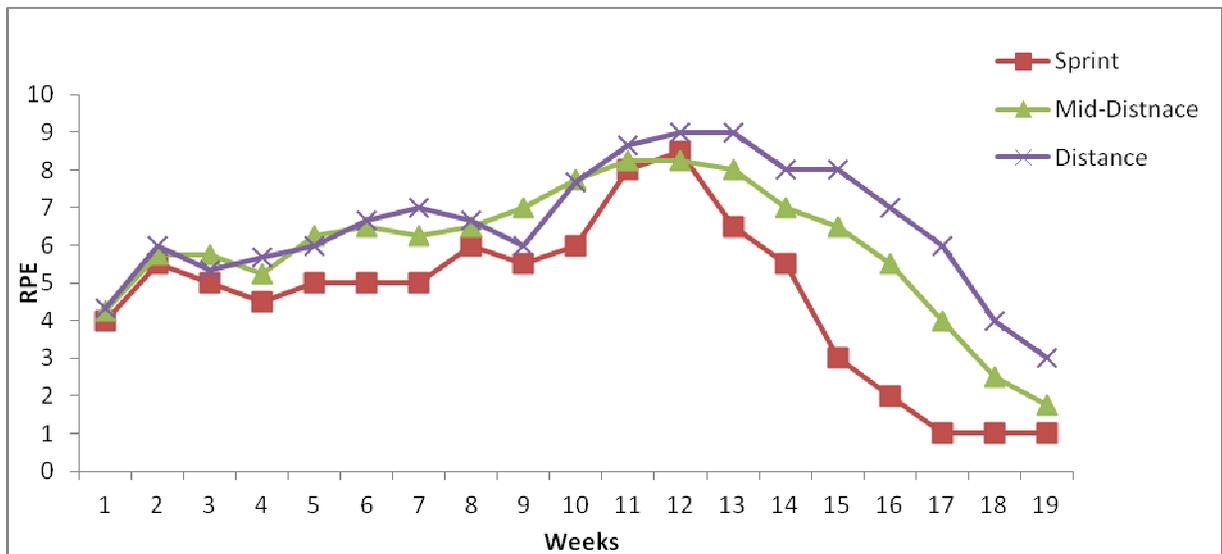


Figure 2. Weekly Average RPE by Training Group (n=9)

Table 1.*Demographic Characteristics of participants (n=9)*

Variable	Mean	Standard Deviation
Age (years)	20.556	1.014
Height (cm)	169.32	5.813

Table 2. Weekly Average Training Load by Training Group (n=9)

Weeks	Distance	Mid Distance	Sprint
1	121333.3	119000	112000
2	217800	197225	185900
3	197067	216487.5	170750
4	231200	206325	154800
5	262200	260625	190500
6	286000	242775	170750
7	324800	249375	189500
8	249333	223600	185400
9	291330	308035	215352.5
10	396367	365800	263400
11	326733	294525	252000
12	781200	696712.5	600525
13	897750	741200	556725
14	348000	266000	183700
15	263200	195650	78150
16	174300	122100	36200
17	295200	154000	28950
18	111200	53500	18500

Table 3. *Frequency domain analysis at rest*

Variable	Pre Mean	MidMean	Post Mean	F Value	df	Sign
HR Rest	82.33 ± 8.75	80.56 ± 8.08	76.56 ± 9.55	3.32	(2,16)	0.06
LFn.u. Rest	58.56 ± 26.21	70.54 ± 22.18	48.12 ± 24.98	3.03	(2,16)	0.08
HFn.u. Rest	41.07 ± 25.85	29.46 ± 22.18	51.88 ± 24.98	3.12	(2,16)	0.07
Ratio Rest	2.55 ± 2.37	5.87 ± 6.14	1.77 ± 2.09	4.46	(2,16)	0.03*

(*) = Significant difference (p<0.05). *HR= Heart rate, LFn.u= Low Frequency in normalized units, HFn.u.= High Frequency in normalized units, Ratio= LF/HF ratio*

Table 4. *Frequency Domain Analysis during 400yd freestyle swim with intensity.*

Variable	Pre Mean	MidMean	Post Mean	F Value	df	Sign
HR 400	175.00 ± 8.09	180.33 ± 5.39	182.22 ± 8.53	6.26	(2,16)	0.01*
LFn.u 400	40.90 ± 16.12	39.84 ± 22.61	34.46 ± 25.03	0.23	(2,16)	0.8
HFn.u 400	59.10 ± 16.13	60.16 ± 22.61	65.54 ± 25.03	0.23	(2,16)	0.8
Ratio 400	0.844 ± 0.64	1.26 ± 1.95	1.62 ± 3.56	0.24	(2,16)	0.8

(*) = Significant difference (p<0.05) *HR= Heart rate, LFn.u= Low Frequency in normalized units, HFn.u.= High Frequency in normalized units, Ratio= LF/HF ratio*

