

Pittsburg State University

Pittsburg State University Digital Commons

Electronic Theses & Dissertations

Spring 5-11-2018

EFFECTS OF HEART RATE VARIABILITY-GUIDED PRESCRIPTION ON THE PHYSIOLOGICAL OUTCOMES OF CROSSFIT TRAINING

Nicholas B. Drake

Pittsburg State University, nbdrake@gus.pittstate.edu

Follow this and additional works at: <https://digitalcommons.pittstate.edu/etd>



Part of the [Sports Sciences Commons](#)

Recommended Citation

Drake, Nicholas B., "EFFECTS OF HEART RATE VARIABILITY-GUIDED PRESCRIPTION ON THE PHYSIOLOGICAL OUTCOMES OF CROSSFIT TRAINING" (2018). *Electronic Theses & Dissertations*. 245.
<https://digitalcommons.pittstate.edu/etd/245>

This Thesis is brought to you for free and open access by Pittsburg State University Digital Commons. It has been accepted for inclusion in Electronic Theses & Dissertations by an authorized administrator of Pittsburg State University Digital Commons. For more information, please contact digitalcommons@pittstate.edu.

EFFECTS OF HEART RATE VARIABILITY-GUIDED PRESCRIPTION ON THE
PHYSIOLOGICAL OUTCOMES OF CROSSFIT® TRAINING

A Thesis Submitted to the Graduate School
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science

Nicholas Binder Drake

Pittsburg State University

Pittsburg, Kansas

May 2018

EFFECTS OF HEART RATE VARIABILITY-GUIDED PRESCRIPTION ON THE
PHYSIOLOGICAL OUTCOMES OF CROSSFIT® TRAINING

Nicholas Binder Drake

APPROVED:

Committee Chair: _____
Dr. Derek Crawford; Health, Human Performance and Recreation

Committee Member: _____
Dr. Michael Carper; Health, Human Performance and Recreation

Committee Member: _____
Dr. David Miller; Engineering Technology

EFFECTS OF HEART RATE VARIABILITY-GUIDED PRESCRIPTION ON THE PHYSIOLOGICAL OUTCOMES OF CROSSFIT® TRAINING

An Abstract of the Thesis by
Nicholas Binder Drake

Purpose: The purpose of this investigation is to determine the effectiveness of heart-rate variability as a monitoring and intensity-prescription tool for CrossFit.

Methods: Twenty-five recreational trained males and females were randomized into two groups, experimental (EXP) and control (CON) prior to the intervention. Prior to any assessments, all participants established a 14-day baseline period for their morning heart-rate variability. Both groups underwent pre-training assessment for work capacity, whole body strength, maximal oxygen consumption and body composition. All participants followed a 21-day training program followed by another week of testing, repeated twice. During the training, a rolling seven-day average of heart-rate variability was used to prescribe based upon windows set at .5 and 1 SD of the baseline average with the windows adjusting after the first training block. EXP would have full-intensity, moderated-intensity, or active recovery training sessions based upon morning heart-rate variability while CON always trained at full intensity/effort.

Results: There were no significant group by time interactions for any variables, but there was a significantly different amount of training sessions at a full intensity. All participants saw increases performance outcomes, while seeing significant improvement in physical work capacity, and EXP seeing positive outcomes in body composition measures.

Conclusion: Heart-rate variability is an effective tool for monitoring participants and prescribing-intensity in CrossFit Training.

TABLE OF CONTENTS

CHAPTER	PAGE
CHAPTER I	1
Definition of Terms.....	2
CHAPTER II	5
Body Composition	5
Strength.....	7
Aerobic Capacity	9
Power and Physical Work Capacity.....	10
Over-Training Syndrome	11
Heart Rate Variability and Exercise Modulation/Training Prescription.....	12
Theoretical Framework of the Proposed Intervention	15
CHAPTER III	23
Research Design.....	23
Participants	23
HRV Measurement.....	24
Determination of “Smallest Worthwhile Change” for HRV.....	24
Control Condition (CON)	25
Individualized Prescription Treatment (EXP)	26
Rationale.....	26
Methods for Modulating Intensity and Effort.....	27
Outcome Measures Assessment	28
Pre-Training Testing	28
Mid-Point Testing.....	28
Post-Training Testing	29
Data Collection Instruments	29
Statistical Analysis.....	31
Compliance.....	33
Intervention Fidelity	33
Training Sessions of High Intensity.....	35
Work Capacity	35
Maximal Oxygen Consumption	35
Maximal Strength.....	36
Body Composition	38
Heart Rate Variability	39
CHAPTER V	41
Practical Application	46
Reference List	47
APPENDIX	53
Appendix A: Tables	54
Table 1.	54
Table 2.	55
Appendix B: Figures	56
Figure 1. <i>Intervention training program</i>	56
Figure 2. <i>Intervention training program modification list</i>	57
Figure 3. <i>Representative HRV prescription graph</i>	58
Figure 4. <i>Program prescription from the CrossFit Level 1 manual</i>	59
Figure 5. <i>Group differences in days of maximum effort</i>	60_Toc513205483
Figure 6. <i>Percent of days training and submitting morning HRV data.</i>	61
Figure 7. <i>Changes in work capacity performance</i>	62
Figure 8. <i>Maximal oxygen consumption</i>	63

Figure 9. <i>Changes in 1RM Press performance</i>	64
Figure 10. <i>Changes in squat and deadlift 1RM performance</i>	65
Figure 11. <i>CrossFit Total</i>	66
Figure 12. <i>Body Composition Changes</i>	67
Figure 13. <i>Session Rate of Perceived Exertion Chart</i>	68
Appendix C: Informed Consent	69
Appendix D: Health History Questionnaire	75
Appendix E: Physical Activity Questionnaire	78
Appendix F: Primary Outcomes Data Collection Sheet	80
Appendix G: Training Session Data Collection Sheet	82
Appendix H: Overuse Injury Questionnaire	84

CHAPTER I

INTRODUCTION

Physical inactivity remains one of modern society's biggest health concerns accounting for 5.3 million deaths worldwide each year¹. In the United States, much of our population fails to meet the minimum physical activity requirements set forth by the federal government². High-Intensity Functional Training (HIFT) is a timesaving alternative to traditional exercise programs; capable of improving both measures of health and function based on the relevant body of literature in the scientific community and from anecdotal claims from practitioners in the field. HIFT has been shown³ to have positive effects on several health and fitness outcomes and thus is considered an effective approach to a generalized strength and conditioning. However, participation in HIFT is not without its concerns. High injury rates have been a concern associated with HIFT participation within academia⁴ and military.⁵ With concerns of potential overreaching, even during short-term HIFT participation⁶, there are questions with how to monitor the training status of HIFT participants.

The overarching goal of this study is to identify effective monitoring strategies to prescribe the optimal dose (i.e., timing of maximal intensity sessions) of HIFT. The objective of this study intervention is to determine the effectiveness of employing heart-rate variability (HRV) as a means of modulating exercise intensity within HIFT training protocols. The primary study hypothesis is that HRV-guided prescription of exercise intensity, or effort, during this intervention will have greater positive effects on physiologic outcomes. This hypothesis has been formulated based upon

(i) HIFT has been proven to be an effective modality of exercise, with acute improvements shown across a spectrum of fitness components, (ii) HIFT programming has been shown to have novice participants approach over-reaching ³; and (iii) HRV-guided training prescription of HIIT sessions within endurance training interventions has shown superior outcomes compared to pre-planned HIIT sessions ⁷. The rationale which formulates the basis of the proposed research is that individuals have a fixed amount of training volume from which they can recover and that individual responses to the same bout of exercise are not equal.⁸ Modulating intensity based on HRV may allow individuals to recover and adapt properly to exercise; in effect optimizing the training stimulus to maximize performance.

To determine the effects of HRV-guided HIFT prescriptions on physiologic outcomes, the present study will assess changes in: 1. maximal oxygen consumption, 2. maximal muscular strength, 3. physical work capacity, and 4. body composition. Initial hypotheses are that HRV-guided prescriptions will result in greater positive adaptations in maximal oxygen consumption, body composition, maximal strength, and physical work capacity when compared to a control condition (i.e., no HRV-guided prescription of intensity).

HIFT is an extremely popular form of exercise training that emphasizes whole body movements while consistently challenging all metabolic pathways. HIFT can be scaled to fit many different populations, yet there has been little research conducted on the effects of HIFT when its original methodologies have been employed in research settings. This will be the first study to investigate individualized prescription of intensity/effort during a HIFT intervention to optimize adaptation and recovery. The results of this investigation prove the efficacy of the methodology utilized to aid all practitioners in more accurately prescribing intensity and volume for their participants who are competent in their training skills.

Definition of Terms

High-Intensity Functional Training (HIFT). HIFT temporally combines aerobic and resistance exercise with a focus on functional, multi-joint movements⁹. HIFT has been discussed in the literature as Multi-Modal Training (MMT), High-Intensity Cardio-Resistance Training (HICRT), and High-Intensity Power Training (HIPT). HIFT encompasses a variety of methodologies, but the present study will exclusively utilize the CrossFit¹⁰ template.

CrossFit® (CF)¹⁰. CrossFit is a specific variation of HIFT with its own periodization and programming aspects that are proprietary and unique. CF has two acceptable training structures that are listed in its base certification, CF Level 1. The accepted CF training templates are three days of training followed by one day of rest or five days of training with two days of rest. CF is comprised of three training designs: Element, Task, and Time priority training that will utilize a combination of metabolic conditioning, gymnastics and weightlifting movements (Appendix B, Figure 4).

Element Priority Training. A type of CF training session that focuses on one exercise modality for the entire period. Element training sessions focused on weightlifting emphasize either technique development in more complex exercises such as the snatch or the clean and jerk as well as repetition-max efforts in the barbell lifts. Element training sessions geared toward metabolic conditioning focus on lower-intensity steady-state efforts in rowing, swimming, biking, or running. Element training sessions focused on gymnastics emphasize high skill body weight movements such as handstand push-ups, handstand walking, or muscle-ups. The goal of an element training session is to take dedicated time to improve efficiency in one specific aspect of physical fitness.

Task Priority Training. A type of CF training session that focuses on accomplishing a set amount of work (e.g., repetitions) as quickly as possible. Task priority sessions will typically

combine 2-3 modalities (gymnastics, weightlifting, or metabolic conditioning) with for 3-5 rotations of moderate-to-difficultly challenging tasks to comprise the training session.

Time Priority Training. A type of CF training session that focuses on as much work as possible in a designated amount of time. A time priority session will typically combine all modalities with 3-5 rotations of light-to-moderately challenging tasks to comprise the training session.

Heart-Rate Variability (HRV). A calculation of the time interval between heartbeats, determined by assessing the distance (in time) between the R-R intervals. HRV provides a measure of autonomic (i.e., parasympathetic versus sympathetic) balance on a systemic (i.e., whole-body) level.

Smallest Worthwhile Change (SWC). A statistical measurement that uses \pm one-half of a standard deviation of the mean to create a reference window of meaningful change in a specific variable.

Maximal Oxygen Consumption (VO₂). Amount of oxygen an individual can take in per minute of exercise per kilogram bodyweight (ml O₂/min⁻¹/kg⁻¹).

Body Composition. The amount of lean mass, fat-mass and percentage of body mass as fat-mass.

Maximal Strength. The ability of a muscle, or muscular unit, to exert a maximum amount of force.

Physical Work Capacity¹¹. Represents an individual's ability to complete a maximal amount (i.e., volume) of mechanical work across differing modalities, intensities, and time domains using the appropriate bioenergetics pathways.

CHAPTER II

REVIEW OF LITERATURE

The review of literature was completed for a 30-day period, June 2017, in which the principal investigator attempted to locate all relevant HIFT intervention using keywords such as CrossFit, High-Intensity Functional Training, Functional Training and Multi-Modal Training, and High-Intensity Power Training. Only training interventions that contained these terms from peer-reviewed sources were included within this review.

Body Composition

The body of literature behind HIFT supports the conclusion that this training method yields positive improvements on body composition, meaning that participants see decreases in overall body fat and/or increases in lean body mass. Studies show that HIFT can improve body composition in differing intervention lengths provided interventions are at least 15 sessions (e.g., 3 days/week for 5 week) of training^{[12-17](#)}. HIFT has also been shown to improve body composition measures across both healthy and clinical populations^{[12-15](#)}. Body fat percent and lean mass in trained male HIFT participants is comparable to trained-male resistance training participants^{[18](#)}. While HIFT has been shown to increase lean mass, the most notable changes appear to be in the lower extremity^{[19](#)}. Further longer duration HIFT interventions (i.e., ≥ 16 weeks) even seem to have beneficial effects on bone mineral content^{[19-21](#)}. In a literature review from Haddock et al.^{[21](#)}, authors noted that body

composition changes are most profound in interventions lasting at least 10 weeks and in participants were overweight to begin the investigation. These authors note that overweight and obese individuals lost 5.3 kg of fat mass with no reported adverse events over 36 weeks of training.

Body fat reduction of 2-5% can be found based on health populations^{12,13,17,21}. While among cancer survivors, HIFT training showed a 4.7% reduction in body fat with an average improvement of 3.8 kg in lean mass¹⁵. Body fat percent and lean mass in trained male HIFT participants is comparable to trained-male resistance training participants. While HIFT has been shown to increase lean mass, the most notable changes appear to be in the lower extremity. Further longer duration HIFT interventions (i.e., ≥ 16 weeks) even seem to have beneficial effects on bone mineral content. In a literature review from Haddock et al., authors noted that body composition changes are most profound in interventions lasting at least 10 weeks and in participants were overweight to begin the investigation. These authors note that overweight and obese individuals lost 5.3 kg of fat mass with no reported adverse events over 36 weeks of training. Body fat reduction of 2-5% can be found based on health populations. While among cancer survivors, HIFT training showed a 4.7% reduction in body fat with an average improvement of 3.8 kg in lean mass.

The factors for changing body composition is principally determined by energy balance of caloric intake versus. From the reviewed literature, no intervention has yet explored HIFT while controlling for the caloric intake of its participants. There has been one training intervention that also used a low-carbohydrate ketogenic diet; however, the intervention did not control for caloric intake but were given instructions how to eat to a low-carbohydrate diet.²² Therefore, the conclusion has been made that improvements in body composition are derived from only the training intervention via increased energy expenditure. In a review article by Haddock et al.²¹, improvements in body composition via HIFT training,²³ are centered on reducing subcutaneous and trunk fat and waist circumference when compared to other training protocols. Haddock et al.²¹ also

contends that any positive effects in improvements in measures of body composition are aided by appetite suppression stemming. The review continues and makes the contention that the effects on body composition from HIFT is a direct result of the high-intensity design of the training protocol. The training protocol has large impacts on increasing post exercise energy expenditure and fat oxidation.

The body of literature indicates that all types of HIFT help improvement measures of body composition and there has been a reported dose-response relationship in that the longer a participant engages in HIFT, the more benefit a participant will receive with a minimum target of 10 weeks of training with at least 3 days of participation per week. Based off the reviewed literature, one could expect between 2-5% reduction of fat mass and approximately 2.0-3.8 kg increase of lean mass for HIFT participation of at least 30 sessions. Future studies should focus on specific dietary protocols with participants in HIFT when comparing HIFT to traditional hypertrophy or strength training.

Strength

Due to the nature of HIFT programming, and its lack of consistent strength training elements, strength is not well defined by a specific exercise task (e.g., back squat one-repetition maximum; 1RM) within the literature.

The question that needs to be asked is what determines greater performance in the various areas of HIFT. Butcher et al.²⁴ found that whole body strength is a part of the explanation to this question. Serafini et al.²⁵ reported similar findings in a study investigating self-reported measures of strength and sport-specific skills. These authors note that the most successful participants reported greater measures of strength, based on 1RM deadlift, squat, clean and jerk and snatch in addition to other attributes. From these investigations, it should be noted that whole body strength,

emphasizing lower body strength measured by squat and deadlift, is a determinant of performance in the context of HIFT. In short and long training studies, HIFT has been shown to improve muscular strength. Investigations up to six weeks show that HIFT training can improve lower body strength in both experienced and inexperienced participants^{[26,6,16,22](#)}. Investigations up to 6 months show that strength is improved in novice (<6 months experience) participants^{[27,28,29,12,14](#)}. Further, McKenzie et al.^{[26](#)} found improvements in back squat (44 to 54 kg), clean (24 to 33 kg) and snatch (20 to 25 kg) in an all-female population after only 4 weeks of training. Heinrich et al.^{[27](#)} found an average of 13 pound increase in bench press when comparing Mission Essential Fitness, a variation of HIFT, to traditional military training programs. Serafini et al.^{[12](#)} found a statistically significant increases in 5RM front squats in both males (Pre: 86.87 ± 19.68 kg, Post: 95.71 ± 19.96 kg; $p < 0.001$) and females (Pre: 86.87 ± 19.68 kg, Post: 95.71 ± 19.96 kg; $p < 0.001$).

The specific testing of strength within HIFT is difficult to accurately measure due to the inherent variability that is desired within the training protocol. From the CF Manual, practitioners are advised to use a variety of traditional strength movements including Deadlift, Squat, Press, Clean and Jerk, and Snatch movements along with any variations underlying those movements. Within the literature there was not a consistent test used throughout all studies, which makes it challenging to compare across the body of work. Perhaps the best definition of strength within HIFT is the definition provided by Butcher et al.^{[24](#)} (i.e., “CrossFit Total” which is a 1RM in back squat, press and deadlift while being performed in that order). This definition was also used by Frye et al.^{[29](#)} when looking at CF participants that are both novices and experienced.

There is a need within the HIFT research field for consistently accepted performance outcome tools. It would appear that the most logical of these, with regard to muscular strength, is to use barbell movements with respect to an individual’s 1RM. Based on the reviewed literature, one can expect to see improvements in whole-body muscular strength particularly in the lower

extremity. At this time, speculation of the magnitude of change is difficult to determine due to the heterogeneity of strength testing methods used across studies in addition to training status prior to the intervention.

Aerobic Capacity

The standard measure for adaptations to the cardiovascular system following HIFT are changes in maximal oxygen consumption. The physiologic stress during one bout of HIFT combines both aerobic and anaerobic responses. Within a typical HIFT training bout, participants can expect an increase in heart rate (HR) to near maximum (i.e., 85% or higher) with a high level of perceived effort (≥ 17 on the Borg scale).^{30,31} However, HR does not immediately reach its peak with onset of exercise. Hepler et al.³² and Kliszczewicz et al.³³ found that there is a progressive increase in HR over the time during a HIFT training session that lasted 20 minutes. These authors suggest that an increase in HR may be related to thermoregulation increases as the metabolic demands of the training session remain relatively constant. The demands of the training session also change the acute physiologic response to HIFT training. Stein et al.³⁴ found that higher relative percentage achieved VO_{2max} in training sessions whose object is to finish as quickly as possible. In addition, Stein et al.³⁴ found that VO_2 oscillates during the training session based on the modality or exercise involved. This suggests that the oscillation could be a potent stimulus to adaption for individuals participating in HIFT.

Chronic HIFT participation leads to increases in maximal oxygen consumption^{13,35,36} as well as decreases in resting systolic blood pressure in healthy adults³⁷. Due to the multi-modal approach to this training methodology, it is important to note the increases in maximal oxygen consumption. Androulakis-Korakakis et al.³⁸ found that increases in maximal aerobic capacity are possible when adding in variations of high-intensity interval training in experienced powerlifting

and strongman competitors. Bellar et al.³⁹ found that a task priority training session and performance success was associated with CF experience, but time priority-sessions and performance is associated with maximal oxygen consumption. The current body of literature indicates that there is a threshold of aerobic capacity that occurs in HIFT training. Furrow et al.³⁵ found that HIFT participants that have trained for at least 1 year have a maximal oxygen consumption of 45.3 mlO₂/kg/min and participants of at least 30 months have a maximal oxygen consumption of 51.3 mlO₂/kg/min. Training interventions have seen a range of improvement up to 16%^{13,17,36} from baseline, provided that baseline is below 40 ml O₂/kg/min while Drake et al.³ found a decrease of 4.72% in maximal oxygen consumption due to their participants having a maximal oxygen consumption greater than the threshold of 51.3 mlO₂/kg/min.

Power and Physical Work Capacity

Power is not consistently measured within the body of literature of HIFT interventions, yet it is an outcome that is measured through various means. Arilson et al.¹⁸ used counter-movement jump to analyze lower body explosiveness when comparing CF and resistance trained individuals and noticed that CF participants showed greater performance. Butcher et al.²⁴ report performance cannot be determined by Wingate power/capacity, which is a common measure of power or power endurance. One of the more notable aspects of HIFT is that two consecutive days of HIFT increases pro/anti-inflammatory cytokines without effecting muscle performance or work capacity⁴⁰. However, there are noticeable declines in power after a training session is completed, especially when viewed by training session type. Mate-Munoz et al.⁴¹ found that a gymnastics (i.e., bodyweight movements) time priority sessions lead to a decrease in muscle-tendon stiffness which reduces the ability to produce force as measured by counter-movement jump. The authors theorized this is a result of both the volume and intensity of this training session type.

A key aspect of HIFT is the concept of physical work capacity (WC). WC¹⁰ is a measure of how much mechanical work one can do in a designated amount of time or completing a task in as little time as possible across a broad range of time and modal domains. In CF, this is challenged through workouts that either 1) ask participants to complete a maximal number of repetitions completed in a set time, or 2) ask them to complete a set amount of repetitions as quickly as possible. There are, in theory, limitless ways of testing this fitness construct. Butcher et al.²⁴ measured three common CF Work of the Day (WOD): Grace, Fran and Cindy; and found that the strongest predictor of performance was whole-body strength and anaerobic capacity (i.e., lower extremity peak power). It has been shown in the literature that participating in HIFT has been shown to improve WC or selected power measurements following chronic interventions^{6,16,17,22,27,42} that are 6 to 16 weeks in duration which is consistent with the principle of a specific adaptation coming from imposed demands. Based on the reviewed literature, one can expect to see substantial improvements in WC following as few as 15 HIFT sessions, and we have previously shown that these effects may be the largest potential outcomes of HIFT³.

Over-Training Syndrome

The CF Level 1 Manual has a section directly addressing concerns over exercise-induced rhabdomyolysis and there are anecdotal concerns over the program design within fitness industry about CF methods. While the current body of literature states that CF participation is just as safe as every other sport/physical training program^{4,43,44}, very few have sought to investigate whether CF causes over-training syndrome (OTS) in its participants.

OTS can be defined as a deterioration in performance even after an extended recovery period ^{45 46 47 48}. This decrease in performance is extended over a series of weeks or months. Smith

et al.⁴⁵ notes that there are four categories of signs and symptoms of OTS: psychological, physiological, biochemical, and immunological; the commonly accepted first symptom is a change in mood. An important distinction must be made between the term “over-training” and “over-reaching”⁴⁹. Over-reaching is a temporary and intentional condition for the athlete that is used as part of a training cycle to elicit a training adaption. Carter et al.⁵⁰ highlight the difference between over-training and “burnout”. Burnout, as defined by Carter et al.⁵⁰, is a psychological condition that is characterized by a decrease in motivation. These authors warn that practitioners should monitor highly-motivated athletes as they may neglect recovery.

Drake et al.³ original work in HIFT found evidence of functional over-reaching in study participants. They reported a change in mood states, specifically tension-anxiety, vigor-activity, and friendliness. In addition to negative change in mood states, Drake et al.³ also found a trend in increasing serum C-reactive protein. While traditional CF participation does not call for periods of rest to allow for adaption to occur, it would be inappropriate to assume that participation in CF automatically results in the development OTS. However, the evidence that these participants were experiencing over-reaching is valid and thus there is the potential for participants for reaching over-training. Drake et al.³ noted that future research on CF should include evaluation of strategies to help participants monitor their recovery and adaptation in order to avoid OTS. Due to the multifactorial nature of OTS, effective monitoring strategies must be based around individuals’ recovery and readiness to train/exercise.

Heart Rate Variability and Exercise Modulation/Training Prescription

Heart rate variability (HRV) is well defined within scientific literature and this section is primarily based on the work done by Hautala et al.⁵¹ and Stanley et al.⁵¹ Heart rate is governed by the competition between cardiac vagal (i.e., parasympathetic) mediation and sympathetic input from the autonomic nervous system; this balance helps determine cardiac output based on metabolic needs and psychological arousal. A chronic training adaptation, especially with aerobic training, is a shift towards parasympathetic dominance because of increased vagal modulation and decreased sympathetic input due to increased cardiac output per heartbeat⁵¹. More simply stated, the heart becomes more efficient by increasing the amount blood it pumps out each beat. HRV is a measurement of the heartrate fluctuation around the mean heart rate for a given time period⁵², which is measured via R-R intervals (within the heartbeat's QRS complex) from the heart's electrical activity, and the gold-standard tool is the electrocardiogram (ECG) the assessment of this measure. More simply stated, HRV is a measure of the time difference between each heart beat as the heart does not beat a consistent rhythm due to a constant competition within the autonomic nervous system.

HRV is affected by breathing, genetics, and other factors including exercise stimuli. The female menstrual cycle has also been shown to decrease HRV during individual cycles ⁵³. By measuring HRV, researchers and practitioners can monitor the recovery and adaptation of participants and athletes. An important aspect of training is the mediating the response between the two divisions of the autonomic nervous system in that the training week should balance between high-intensity or high-effort days and low-intensity or low-effort days. After training has concluded, a shift back towards the parasympathetic state is desired so that recovery from training can begin more effectively. The switch back into a parasympathetic dominance in the body is dependent upon the stress of the training session along with other lifestyle factors.

Reactivation⁵⁴ of the parasympathetic system is a measure of stress control and is an indicator of the fitness of an individual. Stanley et al.⁵⁴ investigated the factors that impact cardiac parasympathetic reactivation following exercise and they include: the intensity of the training (measured by percentage of heart rate max achieved), the duration of training sessions, and the amount of muscular damage (whether that it metabolic or mechanical). It is important to note that cardiac parasympathetic reactivation does not indicate total system recovery including energy stores (replenishing muscle glycogen) or of the neuromuscular system (central or peripheral fatigue). However, it does indicate that the body does not perceive a threat and can direct energy towards repair rather than the attack a threat or respond to stimuli. A limitation of HRV monitoring is that acute post-exercise parasympathetic re-activation is dependent upon accumulation of stress metabolites in blood and skeletal muscle given that longer exercise duration causes a greater depletion in muscle glycogen stores and neuromuscular fatigue and therefore, post-training HRV measurement is only indicative of the sympathetic drive from the session. HRV-based monitoring should be used upon waking to maximize the accuracy of the measurement

The time duration for parasympathetic reactivation is based on systemic markers and varying aspects of the training stimulus including exercise intensity, rate of perceived exertion, training status, fluid intake and age. Stanley et al.⁵⁴ advise that practitioners take an integrative approach to monitoring training programming and the approach should include strategies that look at both physiological and psychological measures. The group also concluded that HRV measurement, including smallest worthwhile difference, is a simple measure that can help monitor at least cardiovascular system recovery. When designing a training program, exercise intensity is the largest determinant of cardiac parasympathetic reactivation along with the fitness/training status of the athlete. Low intensity⁵⁴ exercise requires up to 24 hours for near baseline levels and up to 48 hours for high-intensity exercise. Stanley et al.⁵⁴ investigated parasympathetic reactivation in

resistance training and found that parasympathetic recovery parallels performance recovery but markers of muscular damage and perceived muscle soreness does not.

Another critical finding from Stanley et al.⁵⁴ is that light/low-intensity also aides the recovery process in individuals and that light sessions should be included in the training week. This finding is well supported anecdotally in the strength-training community with light sessions being employed often to both work on technique and aide in athletes' psychological recovery. Due the varied nature of the HIFT, it is hard to predict a standard response of HRV when coupled with the fact that prior training status effects the magnitude of a training stimulus⁸. Working on a HIFT model that was utilized by Drake et al.³, their participants reported lower perceived effort on element priority training days compared to task- or time-priority sessions. From this, it is reasonable to conclude that HRV will be most depressed following task- and time-priority training session days which comes in the middle of the week and HRV should elevate following the last element training session and two days of recovery that follow.

Theoretical Framework of the Proposed Intervention

The focus of this investigation is on HIFT, specifically CF, and HRV. Given the conclusions of Stanley et al.⁵⁴, skeptics of CF should acknowledge the thoughtful design that provides the framework for CF exercise prescription. The standard CF program design involves escalating exercise intensity and rate of perceived exertion with element, task and time priority days with three consecutive days of exercise followed by one day of recovery. An alternative schedule is five days of training (element, task, time, task, element) followed by two days of training. Drake et al.³ found that CF participants reported the lowest rate of perceived exertion and average HR within element priority sessions and highest during time priority sessions. This

naturally occurring “waving” of exercise intensity/effort within the CF methodology may attenuate any potential for chronically depressed HRV.

HRV has been proposed as a viable biofeedback system for monitoring stress and anxiety disorders in clinical populations especially with the increasing use of wearable technologies.⁵⁵ HRV application in sport fatigue management have shown strong results as a method for quick and accessible method to improve the balance of the autonomic function⁵⁶. HRV seems to be used in sports that do not have a well-defined method for quantifying training load such as wrestling⁵⁷, soccer⁵⁸, judo⁵⁹, and gymnastics⁶⁰. Tian et al.⁵⁷ investigated the possibility of predicting non-functional over-reaching, functional over-reaching, or over-training based on HRV metrics in internationally-competitive female wrestlers. Their investigation used the standard deviation of R-R intervals (SDNN), square root of the mean of the sum of the squares of differences between adjacent R-R intervals (rMSSD) along with measurements of spectral (i.e., frequency) domain (low frequency, high frequency, and the ratio between the measures) of HRV; measurements were taken one night per week. Tian et al.⁵⁷ found that HRV was able to detect an overreached state based on a significant decrease in HRV (SDNN and rMSSD) whereas other wrestlers showed a significant increase in these measures.

Flatt and Esco⁵⁸ used a smartphone-based HRV measurement tool to investigate individual training adaptations in a collegiate female soccer team using changes in mean resting HR and the coefficient of variation (CV) of resting HR along with changes in log-transformed mean rMSSD and its CV and to determine correlations between changes in HRV and HR measures with the Yo-Yo field test. HRV measurements were taken via a chest-strap and a smartphone application for daily measurement. Flatt and Esco⁵⁸ found that there was a large relationship ($r = -0.74$; $p = 0.006$) between post-training testing change in the Yo-Yo test and changes in $\text{Ln rMSSD}_{\text{CV}}$ which indicated that a decrease in HRV showed greater improvements in the Yo-Yo test. This lead the authors to

posit that is smaller fluctuations in daily HRV measures (i.e., CV) indicated a greater capacity for tolerating training stressors or that appropriate recovery had occurred.

Morales et al.⁵⁹ investigated national-level judo athletes using HRV to monitor training loads which is often difficult to quantify due to the contact nature of the sport that also has a high degree of technical skill. The training load quantification is difficult to calculate because there are a lot of situational factors that influence the training load; the investigation quantified load based on the number of sessions of judo and strength and conditioning sessions. The group that had the high training load, when compared to a moderate training load, had lower RMSSD which is indicative of a greater stress response.

Sartor et al.⁶⁰ found similar results when investigations junior national-level male gymnasts. They employed more frequent HRV measurements, using the standard deviation of R-R intervals; assessing HRV daily in odd weeks during a 10-week investigation compared to the one time per week provided by Morales et al.⁵⁹ Sartor et al.⁶⁰ found that the difference between training day HRV and baseline HRV best correlated with training session perceived effort from the previous day meaning that a greater perturbation from baseline was related with a higher perceived effort during training sessions. HRV has also been used as a performance enhancement tool in endurance athletes, showing promising results ^{7,61,62 63}. Choudhary et al.⁶⁴ used distance (5k) runners from a variety of skill levels to investigate using HRV biofeedback (Low Frequency:High Frequency) to prescribe training and found statistically significant increases in maximal oxygen consumption (56.92 to 59.5 ml/kg⁻¹/min⁻¹) for the experimental group compared to the control group.

This investigation is based on an evolving HRV prescription methodology originating from the endurance training and various training-observation literature, including gymnastics, rowers, and track and field athletes. The specific work on HRV-prescribed training^{7,63} and injury prevention posit the theory that there is an association between overuse injury and decrements in performance

with depressed HRV^{65,66}, specifically the RMSSD. Vesterinen et al.⁶³ provides a foundational methodology for using HRV as a means to prescribe training intensity. In their investigation, participants in the experimental group took morning HRV readings in which the R-R intervals were analyzed and the RMSSD was calculated. Further, the RMSSD was converted to a rolling 7-day average to increase sensitivity based on the work performed by Plews et al.⁷ Vesterinen et al.⁶³ used a 4-week preparatory period to determine mean and smallest worthwhile change (i.e., 0.5 standard deviation) to create “windows” from which the rolling 7-day average HRV measurement must stay within. When the rolling average fell outside of the window, participants trained at either low intensity or rested. Participants only resumed normal training when HRV returned to the original preparatory period mean value. After the first 4 weeks of training following the preparatory phase, a new window was created using the same methods. The experimental group (i.e., the group using HRV modulation) showed the only significant improvement in running performance. This was achieved through less full effort training sessions compared to the control. Even though both groups showed improvement in physiological variables such as maximal oxygen consumption, the experiment group had a 2.1% change in maximal running performance compared to a 1.1% increase within the control group. This may seem like a trivial change, but research has shown that as small as a 1% change in aerobic capacity can have significant performance implications for elite athletes⁶⁷.

The HRV group performed one less high-intensity training session per week compared to the control. In a case comparison performed by Plews et al.⁷, they found HRV can detect non-functional over-reaching as one of the athletes was diagnosed with this phenomena by a sports physician. Plews et al.⁷ speculated that HRV can be more sensitive to detection of NFOR when compared to resting HR. In addition, the authors’ state the importance of a daily HRV measurement compared to isolated measurements to enhance sensitivity of the measurement, positing rolling 7-

day average may be the most appropriate for detection. Within the case study, it is important to note that psychologic indices were also used along with HRV measurements with participants indicating they would intentionally not give honest answers to continue training. Both of the aforementioned investigations highlight the utility of using daily HRV measurements (i.e., the RMSSD or log-variation thereof) to monitor the 7-day rolling average within a normalized “window” of smallest worthwhile change (i.e., 0.5 standard deviation) to enhance endurance performance.

As discussed in the introduction, muscle injuries or overuse injuries are a noted concern within the HIFT community. Gisselman et al.⁶⁵ formed the hypothesis that there may be a link between HRV and overuse injuries. Overuse injuries include tendinopathy, bone stress injury, and hamstring strains which occur due to an abnormal physiologic response to the stress of tissue loading and unloading. They postulate that the accumulation of somatic tissue damage will be reflected in HRV modulations when measured in resting conditions. This hypothesis is formulated from a theme of research that indicates the autonomic nervous system via neuromediators that regulate pain, inflammation, and tissue repair play a role in reversing tendinopathy, a type of overuse injury. It is the communication between the central and peripheral nervous system that heart-rate variability can make quantifiable to aid in the recovery process and has the potential to reveal early signs of somatic tissue distress. Gisselman et al.⁶⁵ also hypothesize that accumulated fatigue associated with trauma in somatic tissues will manifest as a decreased resting HRV response or reduced parasympathetic control of HR. This hypothesis may be accurate as Williams et al.⁶⁶ found HRV can be a moderating factor when examining the relationship between workload and injury in competitive CF athletes. In addition to measuring HRV (i.e., Ln RMSSD), the investigators took into account the participants acute to chronic workload ratio. This was calculated

by multiplying their perceived effort by each workout's duration to provide arbitrary units for analysis.

From their observational period, Williams et al.⁶⁶ found that monitoring HRV trends, along with acute: chronic workload ratio, lead to the identification of an interaction between the two with respect to overuse injuries. Specifically, overuse injury risk to be reported in their participants was very likely higher (RR: 2.61; 90% CI: 1.38 – 4.93) when HRV was low (increased sympathetic activation or more accumulated stress) along with a spike in the acute: chronic workload ratio. When HRV is within normal ranges or high (indicative of increased parasympathetic overtone), higher workload ratios were well tolerated. The risk of an overuse injury appears to be highest during times of accumulated stress marked by a depressed rolling 7-day average in HRV measurements. Chronic participation in CF appears to have no effect on HRV metrics as Kliszczewicz et al.⁶⁸ found that 15 weeks training (i.e., at 2 days per week) does not influence resting HRV nor post exercise parasympathetic reactivation. It is important to note Kliszczewicz et al.⁶⁸ only measured HRV a total of two times which highlights the importance of daily measurements.

The utility of HRV as a monitoring and prescription tool is contingent upon the ability to determine trends and associated responses to training to improve performance by using the seven-day average of HRV data. The collective work shown by Stanley et al.⁵⁴, Plews et al.⁷, Vesterinen et al.⁶³, and Williams et al.⁶⁶ provide a framework by which researchers and practitioners can begin to understand HRV trends. It is important to note that current thought on HRV trend analysis is best served at the individual level at the present moment and that group statistics may be inappropriate.

A morning HRV reading that is depressed (active sympathetic response) compared to baseline is an indicator of stress and thus the body has not entered parasympathetic reactivation from the previous day's training. A morning HRV reading that is elevated compared to baseline is

an indicator that the body is still in the process of recovering the previous day of training. Current literature does not indicate if either acute response is different from the other, or if being above or below baseline is an indicator of negative adaptation to training. The response to a HRV rolling average falling outside of a baseline window is reduce training volume and/or intensity in the attempt to bring HRV back to baseline so the participant can resume full training. A more sustained average that is outside of any monitoring window is cause for concern in the participant and could be an indicator of NFOR in the participant. In addition, a decrease in the coefficient of variation for HRV has been shown to be a mal-adaptation to training when combined with a depression in RMSSD_{7d} .

Current modeling for HRV utility is based on the length of the training block (i.e. one month of training or a pre-determined three to six week window). HRV mean and statistical window(s) should be based on a baseline period of at least 14 days or the initial training block of a chronic training program and be re-calculated at the conclusion of the training block or month to create monitoring and prescription windows for the next training period. It is important to remember that a chronic adaptation to endurance training is a larger HRV compared to a sedentary individual but it is unclear what length of training is necessary to see such an adaptation; Kliszczewicz et al.⁶⁸ found that 16 weeks of HIFT training saw no significant changes in morning HRV. In theory, an HRV trend line should stay within its window, although falling outside of the window is not a negative response provided that the trend returns within the window. The trend should increase but within the statistical windows so as to indicate a chronic positive adaptation to training. Plews et al.⁷ found that optimal performance on the day of competition was found for endurance athletes when HRV RMSSD_{7d} was within relative normal ranges but it is not well understood what corresponds to an optimal performance on any other kind of performance due to a lack of research.

From the reviewed literature, it is expected that initial HIFT participation will depress HRV readings in all participants due to the novel stimulus being introduced and a varied training history from the participants⁸. The participants with higher initial fitness, based on maximal oxygen consumption, whole body strength, physical work capacity and body composition, should be able to adapt the training protocol and their HRV should elevate with continued participation due to an increased ability to recover from training⁸. The weekly trend of HRV readings will oscillate due on the training schedule with HRV reaching its lowest depression following continued days of high-intensity training and high perceived effort. Chronic HIFT participation should elicit similar HRV outcomes as chronic endurance training participation, based on the reviewed literature^{7,63}, due to HIFT improving the cardiovascular system as measured by maximal oxygen consumption³⁴. An important factor in HRV training literature is to have daily morning readings taken by the participants with the most externally valid measure using smartphone PPG and short-test times of less than two minutes⁵⁸.

CHAPTER III

METHODS

Research Design

This study will be a prospective, randomized-controlled trial design comparing HRV-guided HIFT prescription to a control condition.

Participants

25 healthy, untrained, or recreationally-trained men and women were recruited for participation in this research study (Appendix A, Table 1). Inclusion criteria included 1) being between the ages of 18-35 years of age, 2) English as a first language, 3) and no participation in a structured exercise program for at least 8 weeks prior to commencement of the study. Exclusion criteria included 1) any significant physical conditions which may have contraindicate vigorous physical activity (i.e., 2 or more coronary heart disease risk factors), 2) having participated in a structured training program within the past eight weeks, and 3) the presence of obesity, type 2 diabetes, or osteoporosis. Participants were recruited via a convenience sample from both the University and local communities. Participants were randomly assigned to one of the study treatment groups. All participants were provided informed written consent (Appendix C) and health history information (Appendix D, E) prior to any completion of study protocols.

HRV Measurement

Previous work shows that the most valid assessment of vagal tone results from a 7-day rolling average of an individual's root mean square of successive R-R interval differences (RMSSD_{7d}) [62](#). Participants were instructed to measure their R-R interval data every morning after awakening and emptying their urinary bladder using a commercially-available, scientifically-validated smartphone application (i.e., HRV4training) [69](#). The method of collection utilizes smartphone photo plethysmography to capture continuous HR from a participants' fingertip. The application software then analyzes the HR data to calculate a variety of HRV measurements including RMSSD which this study will log-transform and multiply by two. From this application, participants were able to export their data into a CSV Microsoft Excel file and email it directly to the study coordinator for storage and later analysis. The smartphone application had been selected for its validity [69](#), validated against Bluetooth heart rate monitor (Polar H7) and electrocardiogram, and for its availability in both iOS and Android devices. For participants to maintain active status in the training intervention, participants had to provide at least three measurements in a 7-day period [62](#). A measurement time of one minute is validated for use based on work done by Esco et al. and Flatt et al. [70,71](#) and this is the time duration for HRV measurement used in the present study.

Determination of “Smallest Worthwhile Change” for HRV

Using HRV in CF training prescription is based on the idea that one needs to decrease training intensity when cardiac vagal activity differs meaningfully from its regular activity [7,66](#). To distinguish between abnormal and normal vagal tone, a baseline must be established. To do this, prior to all pre-training testing, participants completed a two-week baseline HRV data collection period in which participants will be instructed to continue normal daily activities. Study researchers

will use this data to construct participants' individual smallest worthwhile change (SWC) "window", which is .5 SD, around their mean RMSSD over the baseline collection period. In the present study, we will calculate two different SWC thresholds. The first will be the mean RMSSD ± 0.5 SD (SWC₁) as in the Versterinen et al. study and the second being the mean RMSSD ± 1 SD (SWC₂) (Appendix B, Figure 3). These SWC thresholds of HRV will be used to modulate training intensity of the EXP group on an individual basis. Following the first four weeks of study protocols, defined as the lab testing week plus the first mesocycle of the HIFT intervention, we calculated new baseline means and associated SWC thresholds for both groups that were used for the remainder of the study.

Control Condition (CON)

15 participants completed six weeks of CF training. Original CF methodology will be adhered to in the training program (Appendix B, Figure 1 and 4). Within these training sessions, a consistent structure was adhered to which consisted of a warm-up (10-15 minutes), CF WOD (10-30 minutes), and a cool-down (10 minutes). Total estimated time for each training session is approximately 60 minutes. A central premise of CF is the constant variation of training variables between sessions. This results in WODs with a wide range of exercise modalities, intensities, volumes, and durations. Each training week consisted of three (3) differently structured session types. The first session was an "element priority" (EP) session. Within these sessions, participants completed either a metabolic conditioning (M) endurance exercise (e.g., 5k run), a bodyweight/gymnastic (G) exercise (e.g., pull-ups), or weightlifting (W) exercise (e.g., deadlifts) performed at either a moderate intensity, high skill level, or heavy load; respectively. The second session was a "task priority" (TskP) session. Within these sessions, two moderately to intensely challenging elements were selected (e.g., M and W). These two elements are repeated for 3 – 5 sets

in the shortest amount of time possible. The final session was a “time priority” (TmP) session. This session consists of 3 – 4 light to moderately challenging elements (e.g., G, W, and M) performed in rotation for 20 minutes attempting to perform maximum work in the prescribed amount of time. The total number of training sessions for this treatment will be 30(Appendix B, Table 1).

Individualized Prescription Treatment (EXP)

10 participants completed six weeks of CF training utilizing the exact programming as the CON group. However, unlike the CON group, the EXP group had their daily training status modulated based on changes in HRV with respect to their individual SWC. Each training day, using the RMSSD_{7d}, participants were instructed at what perceived exertion [22](#) to perform the WOD using the methods outlined below. Figures 2, Appendix B shows the full demonstration of all modulations for the experimental group. The total number of training sessions for this treatment group will be 30.

Rationale

If an individual’s RMSSD_{7d} falls within the SWC₁ participants was instructed to give maximum effort (RPE of 17 or higher) (Appendix B, Figure 13). If an individual’s RMSSD_{7d} falls above or below the SWC₁ the individual was allowed to perform the work associated with the WOD while maintaining an RPE between 12 and 15 (*hard*). If an individual’s RMSSD_{7d} falls above or below the SWC₂ the individual was asked to perform active recovery including, but not limited to mobility work, technique work for barbell movements completed with only barbell load, or cardiovascular activity at an RPE between 7 (*very, very light*) and 10. When an individual’s RMSSD_{7d} returns within SWC₂ they were allowed to perform the WOD at the lower RPE (i.e., 12 to 15) and when it returns to the mean RMSSD_{7d} they were allowed to perform the WOD with

maximum effort. This process will be consistent throughout the duration of the CF training intervention with the exception that the SWCs will be recalculated following the first 4 weeks of training for use during the second four weeks⁶³.

Methods for Modulating Intensity and Effort

Within HIFT training, there are prescriptions to each workout; however, these prescriptions do not take into account the physical capabilities of the individual nor the skills a participant may have prior to the start of training. For example, participants may not possess the capacity to do pull-ups. Participants were given modulations to the prescription based on their ability to perform movements at the intensity desired by the training day. If the participants had their prescription modified, based on ability, the PI did so in a manner in order to maintain the desired stimulus of the training session.

For the EXP, these participants had mandatory modulations based on where their $RMSSD_{7day}$ was calculated for the training session day. If an EXP participant had their $RMSSD_{7day}$ outside of their respective SWC_1 , then the participant would have a 25% volume and load reduction while maintaining the intended maximum effort for the day. For all metabolic conditioning prescriptions that were modulated, walking may be used to bring a participant back to the training area. For all weightlifting movements on an element training day (Appendix B, Figure 4), the intended load was kept but the participant would leave two “Repetitions in Reserve”⁷³⁻⁷⁶. “Repetitions in Reserve” is not doing repetitions based on the load; for example, on a 5 repetition set, the participant. If an EXP participant had their $RMSSD_{7day}$ outside of their respective $SWC_2(SD)$, participants was instructed to be active for 20 minutes with their movement being restricted to walking, tailored stretches based on movements, body weight movements done for

skill improvement, and/or barbell movements performed 40% 1RM with 5 “Repetitions in Reserve”.

Outcome Measures Assessment

Pre-Training Testing

One week before the commencement of the CF training program, all participants attended two pre-test sessions within the Applied Physiology Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. During these sessions, participants' demographic and anthropometric information, nutritional habits and status, cardiovascular status, aerobic capacity, anaerobic capacity, muscular strength, and work capacity will be assessed. Lab testing sessions were 48-72 hours in between sessions. These laboratory testing sessions should last one hour. The first laboratory testing was comprised of filling out and signing administrative documents, body composition assessment via DEXA and maximal oxygen consumption. The second laboratory assessment was used to test maximal strength assessments. Physical work capacity was tested during the first time priority training session to blind participants to the assessment so that a normal effort would be given on training days before and on the testing day.

Mid-Point Testing

Following the third week of the CF training program, all participants returned to the Applied Physiology Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. All pre-testing measurements were repeated in the same order as before with 48-72 hours between each testing session. Physical work capacity was not tested during the mid-point assessment period.

Post-Training Testing

The week following the completion of the CF training program, all participants attended two post-test sessions within the Applied Physiology Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. All pre-testing measurements were repeated in the same order as before with, 48-72 hours between each testing session Physical work capacity was tested during the last time priority session of the training schedule.

Data Collection Instruments

This section provides a description of the outcome variables in this study and the instruments used to assess them.

Demographic Data.

Participants' demographics will include age, gender, ethnicity including healthy history and physical activity history via standard questionnaires created by the research team. A copy of these documents can be found in Appendix D and E.

Anthropometrics

Participants' height and weight were collected by a trained researcher using a stadiometer and digital scale (Tanita TBF-410, Tokyo, Japan). All measurements were recorded to the nearest 0.1 kg and 0.1 cm.

Body Composition

Body composition was measured via dual energy x-ray absorptiometry (DEXA; Discovery A QDR, Hologic Inc., Marlborough, MA). DEXA is validated to assess body fat percentage (BF%), fat-free mass (FFM), fat mass (FM), and bone mineral density (BMD) in a variety of populations.

Variables collected for pre-post intervention assessment were BF%, FFM, FM, DEXA is both a valid and reliable method of body composition and BMD assessment^{77,78}.

Cardiovascular Function

Baseline resting HR was calculated based on the first 14 HR readings from the baseline HRV data collection period; only completed data sessions were included. Resting HR for the mid-intervention data point was calculated utilizing the pre-testing week and the first three-weeks of training. Resting HR for the post-intervention data point was calculated utilizing the mid-intervention testing week and the final three weeks of training.

Aerobic Capacity

VO_{2max} was used as the measure of aerobic capacity for each participant during all testing points. The specific graded exercise test used in this study will be the Bruce Treadmill test ⁷⁹. A regression equation based on time to completion of test will be the standard for determining VO₂ max ^{80,81}. Males had a standard error of the estimate of ± 3.35 ml/kg/min while females had a standard error of the estimate of ± 2.7 ml/kg/min.

Physical Work Capacity

Physical work capacity was measured via a 10-minute "as-many-repetitions-as-possible" format within a TmP session. All participants were to complete 12 Goblet Squats, 45 lbs weight for males, 25 lbs weight for females; 12 burpees, and 24 calories of work performed on a row ergometer (Model D, PM5 Monitor, Concept 2 Inc., Morrisville, VM, USA)

Muscular Strength

Both upper extremity and lower extremity was assessed during all testing sessions. Maximal strength was determined using a standard One-repetition Maximum protocol will be used

for both lower and upper extremity strength (1, 37). The exercises utilized will be those comprising the CrossFit Total which is Squat, Press, and Deadlift.

Session Intensity

Session intensity was measured using a (Polar H7 BlueTooth Heart Monitor, Polar Electro Inc. , Kempele, Finland) paired with the Polar Beat smartphone application (Apple and Android store, Polar Electro, Kempele, Finland). In addition to heart rate measures, rate of perceived exertion was measured for each participant on every training session attended^{72,82}

Overuse Injury

Overuse injuries will be assessed via the OSTRC Overuse Injury Questionnaire (Appendix H) which is equipped to assess knee, lower back, and shoulder overuse injuries⁸³. The questionnaire was validated through face validity first and then through internal consistency, Chronbach's α of 0.91. This instrument was previously used in the study linking HRV changes to overuse injuries in CF athletes⁶⁶. This assessment will only be given when a participant notifies the primary investigator that there is potentially an injury.

Statistical Analysis

Prior to performing analyses, all data were tested for normality and descriptive statistics were calculated. A two-factor [group (2) x time (3)] repeated measures MANOVA was performed for aerobic capacity, all strength measures, body mass, and HRV RMSSD. Univariate two-factor [group (2) x time (2)] repeated measures MANOVA was performed for all body composition variables and WC. Significant multivariate effects were followed up with separate univariate two-factor ANCOVAs with Bonferroni adjustments for all post-hoc comparisons. To analyze variables associated with training compliance (e.g., average HR during training sessions) a one-factor [group]

ANOVA was performed with Bonferroni adjustments for post-hoc comparisons. For descriptive purposes, evaluation of simple effects within each group was conducted to illustrate changes across time with each study group. An alpha level of 0.05 was selected for all analyses to balance the risks of Type I and Type II error. Supporting statistical information, including p-values (p), effect sizes (ES), 95% confidence intervals (CI), and the observed power (OP) are included when appropriate.

CHAPTER IV

RESULTS

Compliance

There is no significant difference in the percentage of number of training sessions attended between groups ($F = 0.025$, $p = .875$) (CON $M = 88.21 \pm 8.98\%$; EXP $M = 87.66\% \pm 7.86$). There is no difference for number days submitting HRV data ($F = 1.004$; $p = 0.327$; $OP = 0.161$) between the CON ($M = 92.66\% \pm 7.03$; $CI = 89.40, 95.93$) and EXP ($M = 95.16\% \pm 4.31$; $CI = 91.16, 99.16$) groups (M difference = 2.50; $CI = -2.66, 7.66$). Please see Appendix B, Figure 6 for comparison between groups.

Intervention Fidelity

There is a significant difference between training session intensity, based upon internal workload calculation, when modulation was employed ($F = 6.768$; $p = 0.001$; $OP = 0.916$). The difference is between full-intensity sessions ($n = 147$) ($M = 2385.63 \pm 1114.72$; $CI = 2222.87, 2548.39$) moderated intensity ($n = 59$) ($M = 1828.97 \pm 892.00$; $CI = 1572.07, 2085.88$) (M difference = 556.65; $p = .001$; $CI = 184.41, 928.89$). There is no difference between active recovery ($n = 26$) ($M = 2074.51 \pm 291.12$; $CI = 1687.51, 2461.52$) and the other session types.

There is a significant difference in peak HR achieved based on training session intensity ($F = 63.710$; $p = 0.000$; $OP = 1.000$) and average HR ($F = 42.211$; $p = 0.000$; $OP = 1.000$). The

peak HR for a full-intensity session ($M = 182.68 \pm 18.34$ bpm; CI = 179.49, 185.87) is not different than a moderated session ($M = 180.69 \pm 18.56$ bpm; CI = 175.67, 185.71) (M difference = 1.99; CI = -5.28, 9.26) but there is a significant difference between active recovery ($M = 136.23 \pm 27.15$; CI = 128.67, 143.78) and full-intensity (M difference = 46.45; CI = 36.41, 56.49) as well as moderate intensity (M difference = 44.46; CI = 33.36, 55.56).

There is a significant difference in the average HR ($F = 42.211$; $p = 0.000$; OP = 1.000) between the different session intensity prescriptions. The average HR for a full intensity session ($M = 157.81 \pm 26.36$ bpm; CI = 153.48, 162.14) is higher than a moderated training session ($M = 148.32 \pm 28.89$; CI = 141.51, 155.13 bpm) (M difference = 9.49; CI = -.38, 19.36) while there is a significant difference between active recovery ($M = 105.96 \pm 21.31$; CI = 95.70, 116.21) compared to both full-intensity (M difference = 51.85; CI = 36.41, 65.47; $p = 0.000$) and moderated training sessions (M difference = 42.36; CI = 27.29, 57.42; $p = 0.000$).

There is a significant difference among differing intensity prescriptions for duration of WOD completion ($F = 8.834$; $p > 0.001$; OP = 0.970). A maximum effort session ($M = 15.43 \pm 7.65$ minutes; CI = 14.31, 16.56) is longer than a moderate session (12.86 minutes ± 6.89 ; CI = 11.08, 14.64) (M difference = 2.56; CI = -0.008, 5.146) while there is a significant difference compared to an active recovery ($M = 19.75 \pm 1.22$ minutes; CI = 17.03, 22.48) session (M difference = 4.32; $p = .013$; CI = .713, 7.93). There is also a significant difference between a moderate session and active recovery (M difference = 6.66; $p > 0.001$; CI = -10.87, -2.90).

There is a significant difference between different intensity prescriptions for RPE ($F = 105.244$; $p = 0.000$; OP = 1.000). A maximum effort session ($M = 16.01 \pm 2.93$; CI = 15.55, 16.4) is significantly higher than a moderate training ($M = 13.73 \pm 3.14$; CI = 12.99, 14.48) session (M difference = 2.28; $p = 0.000$; CI = 1.20, 5.14) and an active recovery ($M = 7.07 \pm 2.43$; CI = 5.94, 8.21) session (M difference = 8.94; $p = 0.000$; CI = 7.43, -.71). There is also a significant difference

between a moderate training session and an active recovery session (M difference = 6.66; $p = 0.000$; CI = .68, -2.90). Significant correlations between all session types are noted in Appendix A, Table 2.

Training Sessions of High Intensity

There is a significant difference ($F = 27.355$; $p > 0.001$; OP = 0.999) between groups for the number of training sessions spent at high intensity. The CON group ($M = 25.67 \pm 2.94$) spent significantly more days than the EXP group ($M = 15.4 \pm 6.75$). There was a mean difference between groups of 10.26 (CI = 6.20, 14.32) (Appendix B, Figure 5)

Work Capacity

There is no significant group by time interaction for work capacity (Greenhouse-Geisser $F = 0.000$; $p = 0.995$; $\eta^2 = 0.000$; OP = 0.050) (Appendix B, Figure 7). For the CON group, there was a significant difference in WC pre- ($M = 136.0 \pm 39.5$ reps) versus post- ($M = 151.7 \pm 36.7$ reps) intervention ($F = 9.70$; $p = 0.011$; M difference = 15.7; 95% CI = 4.49, 27.07; OP = 0.801). For the EXP group, there was a significant difference in WC pre- ($M = 141.7 \pm 22.7$ reps) versus post- ($M = 155.9 \pm 26.6$ reps) intervention ($F = 37.18$; $p = 0.001$; M difference = 14.2 reps; 95% CI = 8.50, 19.89; OP = 0.999). All analyses were controlled for gender ($r = .659$, $p = 0.000$), height ($r = .397$, $p = 0.050$), and the use of oral contraceptives ($r = -0.586$, $p = 0.002$).

Maximal Oxygen Consumption

There is no significant group by time interaction for changes in maximal oxygen consumption ($F = 2.695$; $p = 0.079$; $OP = 0.505$) (Appendix B, Figure 8). In the CON group, there is a significant main effect for time ($F = 11.339$; $p = 0.002$; $OP = 0.966$). The main effect is significant between pre (M pre = 42.01 ± 7.57 ml O₂/kg/min) and mid intervention (M mid = 44.36 ± 8.21) (M difference = 2.35; CI = 1.02, 3.67). There was no significant difference between post (M post = 44.02 ± 8.47 ml O₂/kg/min) and mid intervention (M difference = -0.33; CI = -2.65, 1.97); there was no significant difference between post intervention and baseline testing (M difference = 2.01; CI = -0.41, 4.43). For the EXP group, there was no significant main effect for time ($F = 0.087$; $p = 0.918$; $OP = 0.058$) from baseline (M pre = 45.12 ml O₂/kg/min ± 5.67 ; CI = 40.96, 49.28) to post (M post = 45.49 ml O₂/kg/min ± 6.54 ; CI = 41.71, 49.27) intervention (M difference = 0.368; CI = -2.58, 3.32). All analyses were controlled for gender ($r = 0.397$; $p = 0.050$) and the use of oral contraceptives ($r = -0.428$; $p = 0.033$).

Maximal Strength

There is no significant group by time interactions for changes in press strength ($F = 0.396$; $p = 0.680$; $OP = 0.104$) (Appendix B, Figure 9). In the CON group, there is not a main effect for time ($F = 0.085$; $p = 0.919$; $OP = 0.061$) while there is an increase in press strength from the baseline (M pre = 45.43 ± 23.45 kg; CI = 42.94, 47.91) to post-intervention testing (M post = 47.06 ± 26.27 kg; CI = 44.11, 50.01) (M difference = 1.63 kg; CI = -0.64 kg, 3.91 kg). For the EXP group ($n = 9$), there is no main effect for time ($F = 0.152$; $p = 0.861$; $OP = 0.068$) while there is an increase in press strength from pre (M pre = 47.24 ± 19.93 kg; CI = 43.23, 51.24) to post (M post = 49.65 ± 18.25 kg; CI = 44.14, 55.17) intervention (M difference = 2.41 kg; CI = -3.23, 8.06). Press analyses were controlled for gender ($r = 0.961$; $p = 0.000$), height ($r = 0.800$; $p = 0.000$), and the use of oral contraceptives ($r = -0.498$; $p = 0.011$).

There are no group by time interactions for changes in squat strength ($F = 0.883$; $p = 0.432$; $OP = 0.110$). For the CON group ($n = 14$), there is a significant increase ($F = 21.145$; $p = 0.000$; $OP = 0.999$) in squat strength from baseline (M pre = 103.46 ± 53.55 kg; CI = 90.82, 116.11) compared to post-intervention (M post = 113.140 ± 55.65 kg; CI = 101.51, 124.76) (M difference = 9.672; CI = 5.236, 14.10). There is also a significant increase from baseline to mid-point testing (M mid = 107.97 ± 53.01 kg; CI = 97.37, 118.56) (M difference = 4.50; $p = .049$; CI = .025, 8.98) as well as mid-point to post intervention testing (M difference = 5.16; $p = .002$; CI = 2.04, 8.29). In the EXP group ($n = 9$), there is a significant increase ($F = 8.673$; $p = 0.035$; $OP = 0.695$) in squat strength with the significant increase coming from baseline (M pre = 102.19 ± 30.88 kg; CI = 90.98, 113.40) to mid-intervention (M mid = 106.75 ± 31.55 kg; CI = 95.75, 117.75) testing (M difference = 4.56; $p = 0.017$; CI = 1.07, 8.04). Squat analyses were controlled for gender ($r = 0.890$; $p = 0.000$), height ($r = 0.797$; $p = 0.000$), and the use of oral contraceptives ($r = -0.451$; $p = 0.027$).

There are no group by time interactions for changes in deadlift strength ($F = 0.309$; $p = 0.738$; $OP = 0.091$). In the CON group ($n = 14$), there is an increase in deadlift strength ($F = 3.602$; $p = 0.071$; $OP = 0.445$) from pre (M pre = 112.50 ± 57.28 kg; CI = 99.58, 125.41) to post (M post = 121.37 ± 61.16 kg; CI = 108.90, 133.84) intervention (M difference = 8.87; CI = -.33, 18.08). In the EXP group ($n = 9$), there is an increase ($F = 2.616$; $p = 0.188$; $OP = 0.274$) from pre (M pre = 118.70 ± 30.56 kg; CI = 110.26, 127.15) to post (128.53 ± 40.77 kg; CI = 117.00, 140.06) intervention (M difference = 9.82; CI = -3.85, 23.50). Deadlift analyses were controlled for gender ($r = 0.901$; $p = 0.000$), height ($r = 0.754$; $p = 0.000$), and the use of oral contraceptives ($r = -0.467$; $p = 0.019$). Complete analysis of changes in squat and deadlift strength are shown in Appendix B, Figure 10.

There are no group by time interactions for changes in CrossFit Total ($F = 0.198$; $p = 0.662$; $OP = 0.071$) (Appendix B, Figure 11). In the CON group ($n = 14$), there is a significant increase in

total strength ($F = 23.445$; $p = 0.001$; $OP = 0.991$) from pre (M pre = 270.64 ± 133.25 kg; CI = 244.22, 297.05) to post (M post = 284.48 ± 137.88 kg; CI = 260.40, 308.55) intervention (M difference = 13.84; CI = 7.47, 20.20). In the EXP group ($n = 9$), there is an increase ($F = 2.616$; $p = 0.188$; $OP = 0.274$) from pre (M pre = 268.14 ± 79.49 kg; CI = 248.66, 287.62) to post (282.28 ± 86.48 kg; CI = 263.38, 301.19) intervention (M difference = 14.14; CI = 4.65, 23.63). CrossFit Total analysis was controlled for gender ($r = 0.920$; $p = 0.000$), height ($r = 0.783$; $p = 0.000$), and birth control ($r = -0.449$; $p = 0.028$).

Body Composition

There is no significant group by time interactions ($F = 0.591$; $p = 0.451$; $OP = 0.114$) for changes in body mass. In the CON group, there is no statistical change ($F = 0.297$; $p = 0.596$; $OP = 0.079$) from pre (79.58 ± 15.41 kg; CI = 73.86, 85.30) to post intervention (80.56 ± 15.90 kg; CI = 74.69, 86.437) (M difference = .986; CI = -.40, 2.37). In the EXP group, there is a significant change ($F = 15.075$; $p = 0.006$; $OP = 0.912$) between pre (77.20 ± 14.52 kg; CI = 67.62, 86.77) and post (78.70 ± 15.47 kg; CI = 68.63, 88.77) intervention (M difference = 1.50; CI = .58, 2.42). Body mass analyses were controlled for gender ($r = 0.538$; $p = 0.006$) and height ($r = 0.716$; $p = 0.000$).

There is no significant group by time interactions ($F = 0.173$; $p = 0.682$; $OP = 0.068$) for changes in lean mass. In the CON group, there is no statistical change ($F = 2.813$; $p = 0.122$; $OP = 0.334$) from pre (54.22 ± 14.23 kg; CI = 51.76, 56.69) to post intervention (55.17 ± 14.38 kg; CI = 52.832, 57.51) (M difference = 0.94; CI = -0.29, 0.21). In the EXP group, there is a significant change ($F = 6.966$; $p = 0.039$; $OP = 0.598$) between pre (53.96 ± 11.42 kg; CI = 50.03, 57.88) and post (55.07 ± 11.71 kg; CI = 50.69, 59.45) intervention (M difference = 1.10; CI = .80, 2.13). Lean mass analyses were controlled for gender ($r = 0.864$; $p = 0.000$), height ($r = 0.897$; $p = 0.000$), and the use of oral contraceptives ($r = -0.485$; $p = 0.014$).

There is no significant group by time interactions ($F = 0.172$; $p = 0.682$; $OP = 0.068$) for changes in fat mass. In the CON group, there is no statistical change ($F = 0.654$; $p = 0.434$; $OP = 0.116$) from pre (23.89 ± 7.18 kg; $CI = 19.92, 27.87$) to post intervention (23.66 ± 6.99 kg; $CI = 19.71, 27.60$) (M difference = -0.23 ; $CI = -0.87, 0.40$). In the EXP group, there is no change ($F = 1.080$; $p = 0.333$; $OP = 0.147$) between pre (21.69 ± 10.30 kg; $CI = 16.50, 26.89$) and post (21.80 ± 9.70 kg; $CI = 16.54, 27.05$) intervention (M difference = $.10$; $CI = -.50, .70$). Fat mass analyses were controlled for gender ($r = -0.449$; $p = 0.024$) and the use of oral contraceptives ($r = 0.479$; $p = 0.015$).

There is no significant group by time interactions ($F = 0.784$; $p = 0.387$; $OP = 0.134$) for changes in percent of body mass as fat mass (i.e., BF %). In the CON group, there is a decrease ($F = 1.467$; $p = 0.251$; $OP = 0.198$) from pre (32.41 ± 10.74 %; $CI = 26.48, 38.34$) to post intervention (29.58 ± 8.54 %; $CI = 26.89, 32.26$) (M difference = -2.83 ; $CI = -7.98, 2.31$). In the EXP group ($n = 9$), there is significant change ($F = 10.148$; $p = 0.024$; $OP = 0.722$) between pre ($28.18\% \pm 9.95$; $CI = 22.15, 34.22$) and post ($27.65\% \pm 9.28$; $CI = 21.62, 33.69$) intervention (M difference = -0.53 ; $CI = -0.96, -0.10$). Body fat analyses were controlled for gender ($r = -0.596$; $p = 0.002$), height ($r = -0.450$; $p = 0.024$), and the use of oral contraceptives ($r = 0.538$; $p = 0.006$).

Percent change for measures of body composition can be found in Appendix B, Figure 12.

Heart Rate Variability

There are no significant group by time interactions for the meanRMSSD_{7d} measures ($F = 0.349$; $p = 0.707$; $OP = 0.102$). In the CON group, there is no change ($F = 0.240$; $p = 0.790$; $OP = 0.079$) from baseline (Mpre = 8.35 ± 1.43 ; $CI = 7.70, 9.01$) to post intervention (M post = 8.46 ± 1.41 ; $CI = 7.82, 9.09$) (M difference = 0.10 ; $CI = -0.26, 0.46$). In the EXP group, there is no change

($F = 0.163$; $p = 0.851$; $OP = 0.071$) from baseline (M pre = 8.81 ± 0.97 ; CI = 8.14, 9.49) to post intervention (M post = 8.79 ± 1.02 ; CI = 8.08, 9.50) (M difference = -0.023; CI = -0.25, 0.21).

There are no significant group by time interactions for the monthly coefficient of variation in mean RMSSD ($F = 1.733$; $p = 0.189$; $OP = 0.344$). In the CON group, there is a decrease ($F = 2.284$; $p = 0.122$; $OP = 0.422$) from baseline (M pre = 11.33 ± 3.58 ; CI = 0.961, 13.05) to post intervention (M post = 9.89 ± 3.045 ; CI = 8.15, 11.62) (M difference = -1.44; CI = -4.44, 1.56). In the EXP group, there is no change ($F = 0.546$; $p = 0.602$; $OP = 0.109$) from baseline (M pre = 9.80 ± 4.42 ; CI = 6.69, 12.92) to post intervention (M post = 9.39 ± 2.84 ; CI = 7.86, 10.91) (M difference = -0.417; CI = -3.45, 2.62).

There are no significant group by time interactions for resting HR measures ($F = 0.717$; $p = 0.494$; $OP = 0.164$). In the CON group, there is a decrease ($F = 1.826$; $p = 0.203$; $OP = 0.307$) from baseline (M pre = 75.33 ± 11.76 bpm; CI = 70.11, 80.55) to post intervention (M post = 72.94 ± 9.40 bpm; CI = 68.79, 77.08) (M difference = -2.39; CI = -5.69, 0.912). In the EXP group, there is no change ($F = .727$; $p = 0.517$; $OP = 0.130$) from baseline (M pre = 68.44 ± 13.28 bpm; CI = 60.88, 76.00) to post intervention (M post = 67.86 ± 12.36 bpm; CI = 60.98, 74.73) (M difference = -0.58; CI = -4.72, 3.55).

Gender is a controlling variable for baseline RMSSD_{7d} ($r = 0.560$; $p = 0.004$); coefficient of variation for RMSSD ($r = -0.506$; $p = 0.010$); and resting HR ($r = -0.661$; $p = 0.018$). Height is a controlling variable for resting HR ($r = -0.468$; $p = 0.018$).

CHAPTER V

DISCUSSION

The purpose of this study was to test the effectiveness of using HRV modulation to optimize the prescription of HIFT. Initial study hypotheses were the EXP group would achieve greater outcomes than the CON group with respect to maximal oxygen consumption, maximal muscular strength, physical work capacity, and body composition. These results partially support they study hypothesis as both groups achieved similar improvements in outcome measures while the EXP group participated in significantly fewer maximum intensity and/or effort training sessions (Appendix A, Table 2; Appendix B, Figure 5).

For the results of the present study to be considered valid, two conditions of the intervention had to be realized. First, adherence to study protocols (i.e., consistent reporting of daily HRV measurements and attendance at HIFT training sessions) needed to be high to ensure that any between group differences was not confounded by potential non-compliance. All participants were highly compliant in both reporting daily HRV measurements (CON M = $92.66 \pm 7.03\%$; EXP M = $95.16 \pm 4.31\%$) and in attending HIFT (CON M = $88.21 \pm 8.98\%$; EXP M = $87.66 \pm 7.86\%$) sessions through the study duration with no significant difference for either variable between groups. The second condition that had to be realized was using HRV to modulate training intensity/effort would mean that participants would actually reduce their level of perceived effort during training sessions. Using Edwards 'internal workload calculation (i.e., average HR x duration of training session), participants were able to successfully moderated training stress between full

and moderate training days. However, there was no difference between full effort and active recovery training days. This is an anticipated result due to the time function (i.e., always 20 minute) for the active recovery sessions being significantly longer than the other two prescription days. Further, participants reported significantly different RPE between full effort and active recovery sessions, but no difference between full effort and moderated effort sessions. Mirroring this, participants had significantly lower average peak HRs during full effort sessions compared to active recovery sessions, there were no differences between full effort sessions and moderated sessions. Taken together, these data highlight the fidelity of the study intervention and lend validity to the remaining study outcomes.

Participants provided high intensity/effort when asked to in full effort training sessions as evidence by near maximal peak HRs, high, RPEs, and high internal workloads. When participants were asked to moderate their training, our intervention procedures (i.e., the 25% volume and load reduction to daily WODs) allowed for reduced internal workloads without sacrificing intensity/effort as evidenced by similar peak HRs and RPEs compared to the full effort sessions. This maintenance of intensity/effort while being able to reduce the overall load (i.e., stress) on the individual is important as, according to CF methodology (CF Level 1 Manual), the first element that should be scaled back is the volume of exercise rather than its intensity. During active recovery sessions, peak HR, average HR, and RPE were all significantly lower than both full and moderate effort sessions. These very low effort days may have aided in the recovery process⁵⁴. These data illustrate that using the volume/load reduction and using RPE as an anchor, participants are able to utilize HRV monitoring as a strategy to modulate internal workloads associated with training.

The changes in high-intensity functional training work capacity (Appendix B, Figure 7) agree and support the body of literature^{11,16,22,27,42}. Both groups showed improvement in the work capacity test. Due to the general fitness training, it can be anticipated that this is the result but the

utility of an increase in work capacity is not well understood. It has been anecdotally understood in the strength and conditioning field that work capacity, or general fitness, needs to be established prior to any specific adaptations can be directed. Changes in work capacity are now thought to be not influenced by any underlying physiologic measures¹¹ which is a divergence from previous work²⁴, however this could be a function of work capacity test architecture. The change in work capacity could come from many factors but two worth noting could be increased mental fortitude⁸⁴ or changes in lactate threshold; however, neither of these measures were collected in the current investigation. While it was found in the body of literature that work capacity should have the largest magnitude of change, the magnitude of effect was not calculated for this intervention but the intervention did yield significant improvements in both groups.

There was only one change in maximal oxygen consumption which was in the control group, however the maximal oxygen consumption appears to stabilize at approximately 45 ml O₂/kg/min which indicates that there is a level of adaptation required but beyond that, there is no physiologic need for a higher ability within our sample group. The results in the control group, while significant, are not real due to the error range of the estimation equation that was used. Drake et al.³ found a decrease in VO₂ with three weeks of HIFT, but that decrease was from approximately 52 to 50 ml O₂/kg/min with the original classification being designated as excellent, with this finding strengthening the concept of a threshold of maximal oxygen consumption being necessary for HIFT performance and training. The current research body indicates that there may be a threshold of maximal oxygen consumption, future research could provide useful data if ventilatory threshold information is also reported.

Our findings in strength agree with and strengthen what currently exists in the scientific literature^{3,16,26,27} in that HIFT seems to have most benefits are shown in lower-body strength such as squat and deadlift 1RM training (Appendix B, Figure 10) as well as total body strength

(Appendix B, Figure 11) in interventions that are approximately 6 weeks. There are concerns about how to distribute training volume and intensity in programs that are considered “concurrent training”, involve aerobic and strength training⁸⁵, which is standard in HIFT methodology; however, there is a growing body of literature to advocate for concurrent training as a viable means of training for a range of adaptations including hypertrophy⁸⁶.

The results from body composition favor the experimental group (Appendix B, Figure 12) while the control group had a larger percentage change in body fat percent of total mass. The present investigation is consistent with previous literature in its findings ^{12,13,15-17,87} with specific agreement in literature with changes in body fat percentage decreasing in a study that is at least 5 weeks in length ^{12,13,17,21}. It is not within the scope of the current intervention to hypothesize the specific mechanism of changes in any of the body composition measures because nutritional status was controlled during the intervention. A change in exercise routine could account for some changes in the selected body composition by increasing caloric expenditure⁸⁸. As previously stated, concurrent training like HIFT has shown adaptations in a number of physiologic measures including hypertrophy⁸⁶ with the specific function leading to change being through muscular satellite cell activation and activity ^{87,89-91}. Satellite cells are responsible for muscular protein repair and remodel with evidence indicating that the satellite cells also help with type 1 fiber tissue hypertrophy.

The success of the current investigation serves to highlight the utility demonstrated by Vesterinen et al.⁶³ by showcasing the efficacy of heart-rate variability as a tool to monitor and prescribe intensity. The original work performed by this lab group demonstrated the effectiveness of using the smallest worthwhile change (SWC), one-half standard deviation from the baseline mean, to create a window for when to prescribe moderated training to aid in an optimal dosing of intensity to elicit the highest performance on competition day. The work done in the current investigation added in an additional window of one standard deviation due to concerns of non-

functional over-reaching³ as a mechanism to keep participants engaged in the training process while having stronger limitations to intensity. The proof of concept for using morning HRV to prescribe intensity and to monitor athletes can be extended into the HIFT field. The mechanism HRV is looking to control is the amount of volume in the training program. Isratel⁸ originally proposed an idea of a maximal recoverable volume one can train up to with differing landmarks on the way up to the maximal recoverable volume, with highlighting maximal adaptable volume being a key landmark beneath maximal recoverable volume. HRV could be a way to maintain volume in the range of maximal adaptable volume while insuring a minimally effective dose is implemented when appropriate.

The present intervention is not without its limitations that should be noted. The period to determine the baseline is not consistent with the original work done by Vesterinen et al.⁶³ although a 14-day baseline has been shown to be appropriate. This limitation was brought upon the intervention due to the population sample being constrained by a university calendar system. The HRV recording method is a limitation that should be noted even though it has been validated. Future research should consider longer recording windows and the use of a heart-rate strap connected via Bluetooth to the smartphone; however, the methods employed in this investigation seemed the most appropriate given the sample population. This study did not control for nutritional status which could have affected the selected outcomes for changes in body composition. While this was beyond the scope and budget of the current investigation, it is worth noting that the nutritional influence to training and recovery cannot be ignored. This intervention was also limited by its testing protocols in maximal oxygen consumption and also maximal strength testing. Due to equipment failure, the investigation was forced into relying upon a validated estimation equation instead of an air analyzer that is typically utilized. Maximal strength testing is also a limitation due to a performance relying a multitude of factors including biomechanics, training history⁹², and psychological status⁹³.

Practical Application

The present study shows that an HRV-guided training protocol can lead to similar outcomes compared to a traditional HIFT-CF protocol. The HRV group utilized a 14-day baseline period with utilizing the mean, SWC and SD to create prescription windows for its participants with a new mean, SWC, and SD created after each 4-week training block. Practitioners and research can utilize daily morning HRV readings for accuracy of measurement and provide time for analysis of data before beginning training. Future research should investigate the relationship between HRV and psychological status⁹³ for training session prescriptions in a variety of training modalities and systems. Additionally, future HIFT research should look at the potential utility of HRV-based prescription in clinically populations to optimize training or rehabilitation session volume prescription.

Reference List

1. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012;380(9838):219-229.
2. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181-188.
3. Drake N, Smeed J, Carper M, Crawford D. Effects of Short-Term CrossFit Training: A Magnitude-Based Approach. *Journal of Exercise Physiology Online*. 2017;20(2):111-133.
4. Hak PT, Hodzovic E, Hickey B. The nature and prevalence of injury during CrossFit training. *J Strength Cond Res*. 2013.
5. Bergeron MF, Nindl BC, Deuster PA, et al. Consortium for Health and Military Performance and American College of Sports Medicine consensus paper on extreme conditioning programs in military personnel. *Current sports medicine reports*. 2011;10(6):383-389.
6. Nicholas Drake JS, Michael J. Carper, Derek A. Crawford. Effects of Short-Term CrossFit Training: A Magnitude-Based Approach. *Journal of Exercise Physiologyonline*. 2017;20(2):111.
7. Plews DJ, Laursen PB, Kilding AE, Buchheit M. Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. *Eur J Appl Physiol*. 2012;112(11):3729-3741.
8. Isratel M, Hoffman J, Smith C. *Scientific Principles of Strength Training*. Juggernaut Training Systems: Juggernaut Training Systems; 2016.
9. Heinrich KM, Patel PM, O'Neal JL, Heinrich BS. High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: an intervention study. *BMC public health*. 2014;14:789.
10. *CrossFit Level 1 Training Manual*. Washington, D.C., USA: CrossFit, Inc.
11. Crawford DA, Drake NB, Carper MJ, DeBlauw J, Heinrich KM. Are Changes in Physical Work Capacity Induced by High-Intensity Functional Training Related to Changes in Associated Physiologic Measures? *Sports*. 2018;6(2):26.
12. Serafini PH, Wade; Mimms, Hannah; Smith, Mathew; Kliszczewicz, Brian; Feito, Yuri. Body Composition And Strength Changes Following 16-weeks Of High-intensity Functional Training. *Medicine & Science in Sports & Exercise*. 2016;48(5S):1001.
13. Murawska-Cialowicz E, Wojna J, Zuwała-Jagiello J. Crossfit training changes brain-derived neurotrophic factor and irisin levels at rest, after wingate and progressive tests, and improves aerobic capacity and body composition of young physically active men and women. *J Physiol Pharmacol*. 2015;66(6):811-821.
14. Eather N, Morgan PJ, Lubans DR. Improving health-related fitness in adolescents: the CrossFit Teens randomised controlled trial. *J Sports Sci*. 2016;34(3):209-223.
15. Heinrich KM, Becker C, Carlisle T, et al. High-intensity functional training improves functional movement and body composition among cancer survivors: a pilot study. *Eur J Cancer Care (Engl)*. 2015;24(6):812-817.

16. Gerhart HD. A Comparison of CrossFit Training to Traditional Anaerobic Resistance Training in Terms of Selected Fitness Domains Representative of Overall Athletic Performance. 2013.
17. Goins JM. *Physiological and Performance Effects of Crossfit* [Dissertation]. Tuscaloosa, Alabama: Department of Kinesiology, University of Alabama; 2014.
18. Sousa AFMd, Santos GBd, Reis Td, Valerino AJR, Rosso SnD, Boullosa DA. Differences in Physical Fitness between Recreation CrossFit and Resistance Trained Individuals. *Journal of Exercise Physiology*. 2016;19(5).
19. Hoffstetter WS, Paul; Mangine, Gerald; Feito, Yuri Regional Differences in Musculoskeletal Adaptation Following 16-Weeks of High-Intensity Functional Training. *Medicine & Science in Sports & Exercise*. 2017;49(5S):773.
20. Hoffstetter WB, Allyson; Mimms, Hannah; Serafini, Paul; Smith, Mathew; Kliszciewicz, Brain; Mangine, Gerald; Feito, Yuri. Skeletal Adaptations After 16-Weeks of High Intensity Functional Training. *Medicine & Science in Sports & Exercise*. 2016;48(5S):160-161.
21. Haddock CK, Poston WS, Heinrich KM, Jahnke SA, Jitnarin N. The Benefits of High-Intensity Functional Training Fitness Programs for Military Personnel. *Mil Med*. 2016;181(11):e1508-e1514.
22. Gregory RM. *A Low-Carbohydrate Ketogenic Diet Combined with 6 Weeks of CrossFit Training Improves Body Composition and Performance*: Graduate School, James Madison University; 2016.
23. Jager R, Kerksick CM, Campbell BI, et al. International Society of Sports Nutrition Position Stand: protein and exercise. *J Int Soc Sports Nutr*. 2017;14:20.
24. Butcher SJ, Neyedly TJ, Horvey KJ, Benko CR. Do physiological measures predict selected CrossFit((R)) benchmark performance? *Open Access J Sports Med*. 2015;6:241-247.
25. Serafini PRF, Yuri; Mangine, Gerald T. Self-Reported Measures Of Strength And Sport-Specific Skills Distinguish Ranking In An International Online Fitness Competition. *Journal of Strength and Conditioning Research*. 2017.
26. McKenzie M. Crossfit Improves Measures Of Muscular Strength And Power In Active Young Females. *Medicine & Science in Sports & Exercise*. 2015;47(5S):797.
27. Heinrich KM, Spencer V, Fehl N, Poston WS. Mission essential fitness: comparison of functional circuit training to traditional Army physical training for active duty military. *Mil Med*. 2012;177(10):1125-1130.
28. Kyle Swinford GH, Katie; Paolilli, Tammi; Frye, Jacob; Carlisle, Taran. High-Intensity Functional Training Improves Strength in Both Novice and Experienced Participants. *Medicine & Science in Sports & Exercise*. 2016;48(5S):162-163.
29. Frye JH, Katie; Stevenson, Sarah; Gilmore, Katelyn E.; Carlisle, Taran. Does High Intensity Functional Training Elicit Strength Gains In Both Novice And Experienced Participants? *Medicine & Science in Sports & Exercise*. 2015;47(5S):132.
30. Jaime Fernández Fernández RSS, Diego Moya, Jose Manuel Sarabia Marin, Manuel Moya Ramón. Acute physiological responses during crossfit® workouts. *European Journal of Human Movement*. 2015;35:114-124.
31. Jake Frye KH, Yuri Feito. Examination of Physiological Responses during CrossFit Workouts of Varying Duration. *Medicine & Science in Sports & Exercise*. 2016;48(5S):162.

32. Timothy C. Hepler JAS, Yuri Feito, Katie M. Heinrich. To Discern Differences of Cardiovascular Response Over Four Rounds of a High-Intensity Functional Training (Hift) Session. *Medicine & Science in Sports & Exercise*. 2017;49(5S):48.
33. Kliszciewicz B, Quindry CJ, Blessing LD, Oliver DG, Esco RM, Taylor JK. Acute Exercise and Oxidative Stress: CrossFit() vs. Treadmill Bout. *J Hum Kinet*. 2015;47:81-90.
34. Jesse A Stein JRS, Carl J Ade, Ryan A Broxterman, Brian Sanborn, Thomas J Barstow. Oxygen Uptake during Three Varying Duration High-Intensity Functional Training Sessions. *Medicine & Science in Sports & Exercise*. 2017;49(5s):635.
35. Furrow D, Buschmann C, Childress J, Harris M, Aron A. The Effects Of Varying Levels Of Cossfit Experience On VO2max. *Medicine & Science in Sports & Exercise*. 2017;49(5S).
36. Greenlee TA, Greene DR, Ward NJ, et al. Effectiveness of a 16-Week High-Intensity Cardioresistance Training Program in Adults. *J Strength Cond Res*. 2017;31(9):2528-2541.
37. Katelyn Gilmore KH. Crossfit & Heart Health: Effects Of Crossfit Participation On Resting Blood Pressure And Heart Rate. *Medicine & Science in Sports & Exercise*. 2016;5S(48):293.
38. Androulakis-Korakakis P, Langdown L, Lewis A, et al. The effects of exercise modality during additional 'high-intensity interval training' upon aerobic fitness and strength in powerlifting and strongman athletes. *J Strength Cond Res*. 2017.
39. Bellar D, Hatchett A, Judge LW, Breaux ME, Marcus L. The relationship of aerobic capacity, anaerobic peak power and experience to performance in CrossFit exercise. *Biol Sport*. 2015;32(4):315-320.
40. Tibana RA, de Almeida LM, Frade de Sousa NM, et al. Two Consecutive Days of Crossfit Training Affects Pro and Anti-inflammatory Cytokines and Osteoprotegerin without Impairments in Muscle Power. *Front Physiol*. 2016;7:260.
41. Mate-Munoz JL, Lougedo JH, Barba M, Garcia-Fernandez P, Garnacho-Castano MV, Dominguez R. Muscular fatigue in response to different modalities of CrossFit sessions. *PLoS One*. 2017;12(7):e0181855.
42. Smith MB, Allyson; Hoffstetter, Wade; and Mangine, Gerald,. Skill-based Performance Improves After 16-weeks Of High-intensity Functional Training. *Medicine & Science in Sports & Exercise*. 2016;48(5S):161.
43. Summitt RJ, Cotton RA, Kays AC, Slaven EJ. Shoulder Injuries in Individuals Who Participate in CrossFit Training. *Sports health*. 2016;8(6):541-546.
44. Weisenthal BM, Beck CA, Maloney MD, DeHaven KE, Giordano BD. Injury Rate and Patterns Among CrossFit Athletes. *Orthopaedic journal of sports medicine*. 2014;2(4):2325967114531177.
45. Smith LL. Tissue trauma: the underlying cause of overtraining syndrome? *J Strength Cond Res*. 2004;18(1):185-193.
46. Fry RW, Morton AR, Keast D. Overtraining in athletes. An update. *Sports Med*. 1991;12(1):32-65.
47. Fry AC, Kraemer WJ. Resistance exercise overtraining and overreaching. Neuroendocrine responses. *Sports Med*. 1997;23(2):106-129.
48. Evans WJ, Lambert CP. Physiological basis of fatigue. *Am J Phys Med Rehabil*. 2007;86(1 Suppl):S29-46.

49. Matos NF, Winsley RJ, Williams CA. Prevalence of nonfunctional overreaching/overtraining in young English athletes. *Med Sci Sports Exerc.* 2011;43(7):1287-1294.
50. JG Carter AP, KA Brooks. OVERTRAINING SYNDROME: CAUSES, CONSEQUENCES, AND METHODS FOR PREVENTION. *Journal of Sport and Human Performance.* 2014;2(1):1-14.
51. Hautala AJ, Kiviniemi AM, Tulppo MP. Individual responses to aerobic exercise: the role of the autonomic nervous system. *Neurosci Biobehav Rev.* 2009;33(2):107-115.
52. Force T. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation.* 1996;93(5):1043-1065.
53. Tenan MS, Brothers RM, Tweedell AJ, Hackney AC, Griffin L. Changes in resting heart rate variability across the menstrual cycle. *Psychophysiology.* 2014;51(10):996-1004.
54. Stanley J, Peake JM, Buchheit M. Cardiac parasympathetic reactivation following exercise: implications for training prescription. *Sports Med.* 2013;43(12):1259-1277.
55. Goessl VC, Curtiss JE, Hofmann SG. The effect of heart rate variability biofeedback training on stress and anxiety: a meta-analysis. *Psychol Med.* 2017:1-9.
56. Jimenez Morgan S, Molina Mora JA. Effect of Heart Rate Variability Biofeedback on Sport Performance, a Systematic Review. *Appl Psychophysiol Biofeedback.* 2017.
57. Tian Y, He ZH, Zhao JX, et al. Heart rate variability threshold values for early-warning nonfunctional overreaching in elite female wrestlers. *J Strength Cond Res.* 2013;27(6):1511-1519.
58. Flatt AA, Esco MR. Evaluating Individual Training Adaptation With Smartphone-Derived Heart Rate Variability in a Collegiate Female Soccer Team. *J Strength Cond Res.* 2016;30(2):378-385.
59. Morales J, Alamo JM, Garcia-Masso X, et al. Use of heart rate variability in monitoring stress and recovery in judo athletes. *J Strength Cond Res.* 2014;28(7):1896-1905.
60. Sartor F, Vailati E, Valsecchi V, Vailati F, La Torre A. Heart rate variability reflects training load and psychophysiological status in young elite gymnasts. *J Strength Cond Res.* 2013;27(10):2782-2790.
61. Rakesh Choudhary VT, Sakshi Gaur Choudhary. Effect of Heart Rate Variability Biofeedback Training on the Performance of Track Athlete. *International Journal of Therapies and Rehabilitation Research.* 2016;5(4):166-174.
62. Plews DJ, Laursen PB, Le Meur Y, Hausswirth C, Kilding AE, Buchheit M. Monitoring training with heart rate-variability: how much compliance is needed for valid assessment? *Int J Sports Physiol Perform.* 2014;9(5):783-790.
63. Vesterinen V, Nummela A, Heikura I, et al. Individual Endurance Training Prescription with Heart Rate Variability. *Med Sci Sports Exerc.* 2016;48(7):1347-1354.
64. Choudhary R, Trivedi V, Choudhary SGC. Effect of Heart Rate Variability Biofeedback Training on the Performance of Track Athlete. *International Journal of Therapies and Rehabilitation Research.* 2016;5(4):166-174.
65. Gisselman AS, Baxter GD, Wright A, Hegedus E, Tumilty S. Musculoskeletal overuse injuries and heart rate variability: Is there a link? *Med Hypotheses.* 2016;87:1-7.

66. Sean Williams TB, Matthew Watson, Daniel Rowland, Marco Altini. Heart Rate Variability is a Moderating Factor in the Workload-Injury Relationship of Competitive CrossFit™ Athletes. *Journal of Sports Sciences and Medicine*. 2017;16:443-449.
67. Currell K, Jeukendrup AE. Validity, reliability and sensitivity of measures of sporting performance. *Sports Med*. 2008;38(4):297-316.
68. Kliszczewicz B, Feito Y, Bycura D, Brown D, Price B. VAGAL RESPONSE TO 15-WEEKS OF HIGH- INTENSITY FUNCTIONAL TRAINING: A PILOT STUDY. *Journal of Sport and Human Performance*. 2016;4(3):1-10.
69. Plews DJ, Scott B, Altini M, Wood M, Kilding AE, Laursen PB. Comparison of Heart Rate Variability Recording With Smart Phone Photoplethysmographic, Polar H7 Chest Strap and Electrocardiogram Methods. *Int J Sports Physiol Perform*. 2017:1-17.
70. Esco MR, Flatt AA. Ultra-short-term heart rate variability indexes at rest and post-exercise in athletes: evaluating the agreement with accepted recommendations. *J Sports Sci Med*. 2014;13(3):535-541.
71. Flatt AA, Esco MR. Validity of the athlete Smart Phone Application for Determining Ultra-Short-Term Heart Rate Variability. *J Hum Kinet*. 2013;39:85-92.
72. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377-381.
73. Helms ER, Brown SR, Cross MR, Storey A, Cronin J, Zourdos MC. Self-Rated Accuracy of Rating of Perceived Exertion-Based Load Prescription in Powerlifters. *J Strength Cond Res*. 2017;31(10):2938-2943.
74. Helms ER, Byrnes RK, Cooke DM, et al. RPE vs. Percentage 1RM Loading in Periodized Programs Matched for Sets and Repetitions. *Front Physiol*. 2018;9:247.
75. Helms ER, Cronin J, Storey A, Zourdos MC. Application of the repetitions in reserve-based rating of perceived exertion scale for resistance training. *Strength and conditioning journal*. 2016;38(4):42.
76. Zourdos MC, Klemp A, Dolan C, et al. Novel Resistance Training-Specific Rating of Perceived Exertion Scale Measuring Repetitions in Reserve. *J Strength Cond Res*. 2016;30(1):267-275.
77. Hangartner TN. A study of the long-term precision of dual-energy X-ray absorptiometry bone densitometers and implications for the validity of the least-significant-change calculation. *Osteoporos Int*. 2007;18(4):513-523.
78. Iida T, Chikamura C, Aoi S, et al. A study on the validity of quantitative ultrasonic measurement used the bone mineral density values on dual-energy X-ray absorptiometry in young and in middle-aged or older women. *Radiological physics and technology*. 2010;3(2):113-119.
79. Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. *Am Heart J*. 1973;85(4):546-562.
80. Foster C, Jackson AS, Pollock ML, et al. Generalized equations for predicting functional capacity from treadmill performance. *Am Heart J*. 1984;107(6):1229-1234.
81. Pollock ML, Foster C, Schmidt D, Hellman C, Linnerud AC, Ward A. Comparative analysis of physiologic responses to three different maximal graded exercise test protocols in healthy women. *Am Heart J*. 1982;103(3):363-373.

82. Ferreira-Valente MA, Pais-Ribeiro JL, Jensen MP. Validity of four pain intensity rating scales. *Pain*. 2011;152(10):2399-2404.
83. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med*. 2013;47(8):495-502.
84. Duckworth AL, Peterson C, Matthews MD, Kelly DR. Grit: perseverance and passion for long-term goals. *Journal of personality and social psychology*. 2007;92(6):1087.
85. Varela-Sanz A, Tuimil JL, Abreu L, Boulosa DA. Does Concurrent Training Intensity Distribution Matter? *J Strength Cond Res*. 2017;31(1):181-195.
86. Murach KA, Bagley JR. Skeletal Muscle Hypertrophy with Concurrent Exercise Training: Contrary Evidence for an Interference Effect. *Sports Med*. Vol 46. New Zealand2016:1029-1039.
87. Murach KA, Fry CS, Kirby TJ, et al. Starring or supporting role? Satellite cells and skeletal muscle fiber size regulation. *Physiology*. 2017;33(1):26-38.
88. Hall KD, Heymsfield SB, Kemnitz JW, Klein S, Schoeller DA, Speakman JR. Energy balance and its components: implications for body weight regulation. *Am J Clin Nutr*. 2012;95(4):989-994.
89. Shamim B, Hawley JA, Camera DM. Protein Availability and Satellite Cell Dynamics in Skeletal Muscle. *Sports Medicine*. 2018:1-15.
90. Nederveen JP, Snijders T, Joannis S, et al. Altered muscle satellite cell activation following 16 wk of resistance training in young men. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*. 2016;312(1):R85-R92.
91. Damas F, Libardi CA, Ugrinowitsch C, et al. Early-and later-phases satellite cell responses and myonuclear content with resistance training in young men. *PloS one*. 2018;13(1):e0191039.
92. Vigotsky AD, Bryanton MA, Nuckols G, et al. Biomechanical, anthropometric, and psychological determinants of barbell back squat strength. *Journal of strength and conditioning research*. 2018.
93. Lewthwaite R, Wulf G. Optimizing motivation and attention for motor performance and learning. *Current Opinion in Psychology*. 2017;16:38-42.

APPENDIX

Appendix A: Tables

Table 1.

Demographic information by group and gender.

Measure	<i>Experimental</i>		<i>Control</i>	
	<u>Males</u>	<u>Females</u>	<u>Males</u>	<u>Females</u>
Frequency	6	4	7	8
Age	23	19.75	22.29	21.63
Height (cm)	180.12	164.14	185.23	166.37
Body Mass (kg)	80.42	72.37	91.02	69.56
Oral Contraceptive	0	2	0	4

Table 2.

Experimental group modulation fidelity statistics.

Measure	Maximum Effort	Moderated Effort	Active Recovery
<i>Internal Workload</i>	2385.64*	1828.97*	2074.51
<i>Peak Heart Rate (bpm)</i>	182.68*	180.69+	136.23*+
<i>Average Heart Rate</i>	157.81*	148.32+	105.96*+
<i>Session Duration (mins)</i>	15.43*	12.86+	19.75*+
<i>Session Perceived Effort</i>	16.01*	13.73*	7.07*

*Note.**, + statistically significant difference

Appendix B: Figures

Thesis Training Intervention							
Week 1							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
M	ELEMENT	No Cap	Run (Outside)	2 Miles			
G/W	TASK	5 RFT	8 Push Press	135/95	8 Pull-Ups		
M/G/W	TIME	10 Mins	12 Goblet Squat	45/25#	12 Burpees		24 Cal Row
M/G	TASK	3 RFT	400 M Run (Outside)		25 Box Jumps	18/12"	
W	ELEMENT	No Cap	Deadlift 5x5	85% Target			
Week 2							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
G	ELEMENT	25 Mins	Kipping Pull-Up Practice: Max Unbroken Pull-ups is metric				
W/M	TASK	4 RFT	10 Thrusters	135/95	200 Single Unders (2:1)		
G/W/M	TIME	12 Mins	6 HSPU		12 Deadlifts	185/135	500 M Row
G/W	TASK	4 RFT	15 Ring Rows (3:2)		20 Wall Balls	20/14	
M	ELEMENT	No Cap	8K Partner Row				
Week 3							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
W	ELEMENT	No Cap	Front Squat 10x1	85% of Back Squat is target			BW Squat Required
M/G	TASK	5 RFT	400 M Run		20 Push-Ups		
W/M/G	TIME	15 Mins	5 Cleans-Squat	135/95	10 Pull-Ups		15 Double Unders
W/M	TASK	No Cap	10-8-6-4-2 Power Clean	135/95	20-16-12-8-4 Calorie Row		
G	ELEMENT	25 Mins	HSPU Practice				
Week 1							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
W	ELEMENT	NO Cap	Back Squat 7x3	Target 90%			
M/G	TASK	3 RFT	800 M Run		25 Situps		
M/G/W	TIME	15 mins	100 Single Unders		5 Box Jumps		15 Med Ball slams
G/W	TASK	4 RFT	6 Strict Pullups		6 Front Squats	50%BS	
M	ELEMENT	NO Cap	2 Mile run				
WEEK 2							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
M	ELEMENT	25 mins	Max Double Unders	2 Tabata Rounds			
G/W	TASK	5 RFT	MAX HSPU		6 Deadlifts	75%1RM	
G/W/M	TIME	20 Mins	20 Situps		16 DB Shoulder to Overh	45/20 1	20 Cal Row
W/M	TASK	5 RFT	30 KB Swings	45/20	400 M Run		
G	ELEMENT	25 Mins	Strict Pull-Up (Loaded)				
Week 3							
Day	Priority	TIME	Stimulus #1	Load	Stimulus #2	Load	Stimulus #3
G	ELEMENT	25 Mins	10 MIN Warmup		Bar Muscle Up	10 Min	
W/M	TASK	4RFT	6 Squats	50%1RM	100 Single Unders		2:00 REST
W/M/G	TIME	10 Mins	12 Goblet Squat	45/25#	12 Burpees		24 Cal Row
M/G	TASK	5 RFT	400 M Run		10 HSPU		
W	ELEMENT	25 Mins	Clean 10x1				

Figure 1. *Intervention training program*

Thesis Training Intervention: Modification List	
Week 1 Modifications	
MOD	Light
1.5 Miles	Walk 20 Mins
25% Volume Reduction. 115/65#	Barbell Press/DB/PVC Pending Strength Levels, DEAD hang stretch or lat banded distraction
NO MODULATION	
300 Meters/Walk 100 m & 18 Jumps 16/12" Step up*	Walk 400 M, 2/Leg/Rd Sampson Stretch
5RM Load with 2 RIR "5x3" at 85%	5X3 at 40% 1RM
Week 2 Modifications	
MOD	Light
3 Strict Pull ups, Kipping practice (no kipping pull-ups)	Shoulder-strengthening exercise, light lat pull down machine (RPE LIGHT)
8 Thrusters, 150 Single Unders. 115/65	Barbell, DB, PVC thrusters and hopping in place, no rope, 20 mins
8 minutes: 4 pushups, 8 deadlifts 135/95, 375 row, RPE 13-17	20 Mins: Pushups, BB/DB/PVC deadlifts, 400m walking
3 RFT, 16/10	Ring Rows, childs pose, walking, 20 mins
6 K partner row, not for time or 3 k row if solo	Walking 20 mins
Week 3 Modifications	
MOD	Light
85% of Back Squat, 10x1, 2 RIR	KB/Goblet Squat/Barbell Squat, Walking
200 m run, walk back, 15 pushups	20 Mins: 400 m walk, knee pushups
5 Deadlifts, ring rows, 15 single unders	Med Ball Cleans, childs pose, shoulder exercise, walking, 20 mins
4 rounds, 2 min break b/t: 115/65 6 power cleans, 12 cal row	Med ball cleans, walking 20 minutes RPE 6-13
HS holds	push-ups, walking
Week 1 Modifications	
MOD	Light
7x3 2 RIR, 75% target	40% 7x3
600 m Run, 200 m walk. 20 Situps	20 Minute Walk
12 Minutes	20 Minute Walk
3 RFT	20 Minutes: Goblet Squats, Lat Pulldowns
1.5 mile Run	20 Minute Walk
Week 2 Modifications	
MOD	Light
1.5 Tabata Rounds	20 Minutes Walk
4 RFT Max Push ups 2 RIR, 6 Deadlift 50%	20 minutes: Push ups, Handstand holds, deadlifts, hamstring curls
15 mins	20 Minute Stretching
4 RFT 28 KB Swings, 200 M run, 200 walk	20 Minute Walk
30 Pull-Ups	Lat Pull-Downs, Ring Row
Week 3 Modifications	
MOD	Light
30 Pull-Ups, 20 dips	Lat Pull-Downs, Ring Row, Press
3 RFT	20 Minutes: Air Squats, Box Jumps, walking
Testing Day, no modifications	Testing Day, no modifications
4 RFT, 200 m run, 200 m walk. 9 push ups	20 Minute Walk
7x1 front squat, 2 RIR	20 min: Goblet squat, front rack mobility, barbell front squat

Figure 2. *Intervention training program modification list*

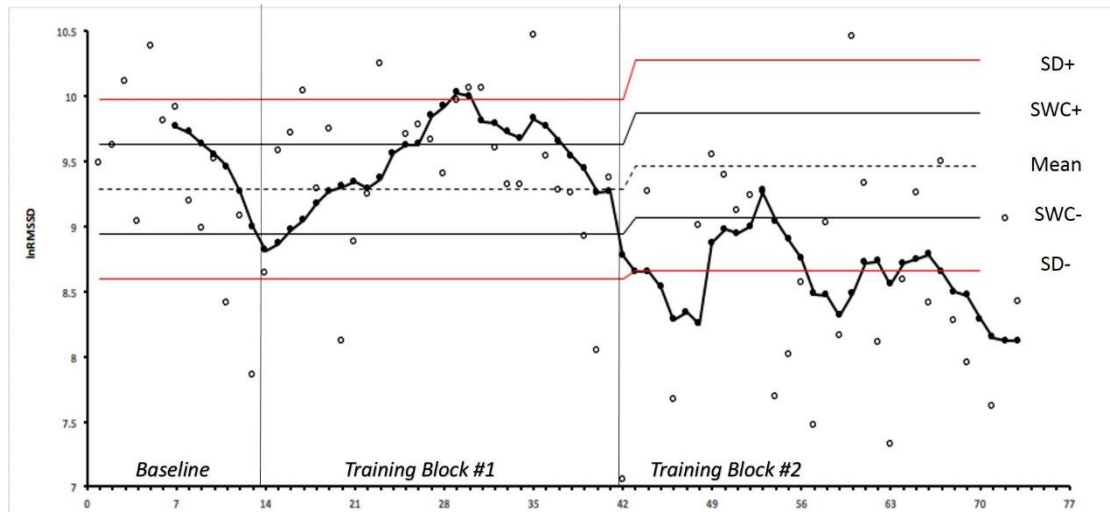


Figure 3. Representative HRV prescription graph

5-days-on, 2-days-off							
Day	1	2	3	4	5	6	7
Week 1	M	G	M	M	W	OFF	OFF
		W	G	G			
Week 2	G	W	G	G	M	OFF	OFF
		M	W	W			
			M				
Week 3	W	M	W	W	G	OFF	OFF
		G	M	M			
			G				

Modalities
M = monostructural metabolic conditioning
G = gymnastics
W = weightlifting

Table 3. Workout Structure			
Days	Single-Element Days (1, 5, 9)	Two-Element Days (2, 6, 10)	Three-Element Days (3, 7, 11)
Priority	Element priority	Task priority	Time priority
Structure (Set Structure)	M: Single effort G: Single skill W: Single lift	Couplet repeated 3-5 times for time	Triplet repeated for 20 minutes for rotations
Intensity	M: Long, slow distance G: High skill W: Heavy	Two moderately to intensely challenging elements	Three lightly to moderately challenging elements
Work/Recovery Character	Recovery not a limiting factor	Work/rest interval management critical	Work/rest interval marginal factor

Figure 4. Program prescription from the CrossFit Level 1 manual

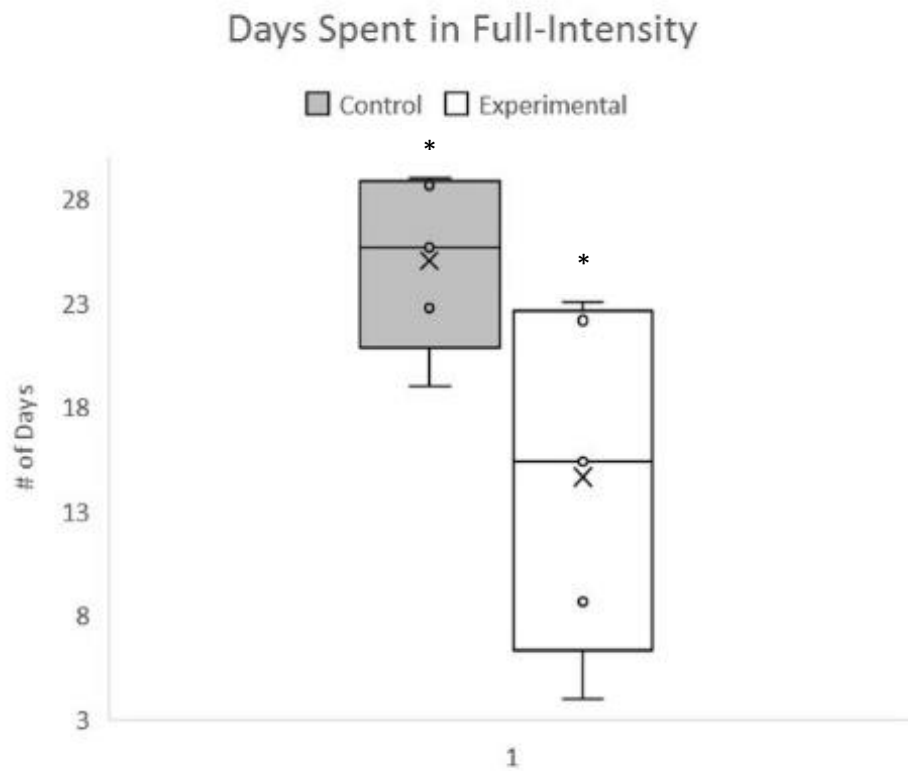


Figure 5. *Group differences in days of maximum effort*

Note. *statistically significant difference between groups

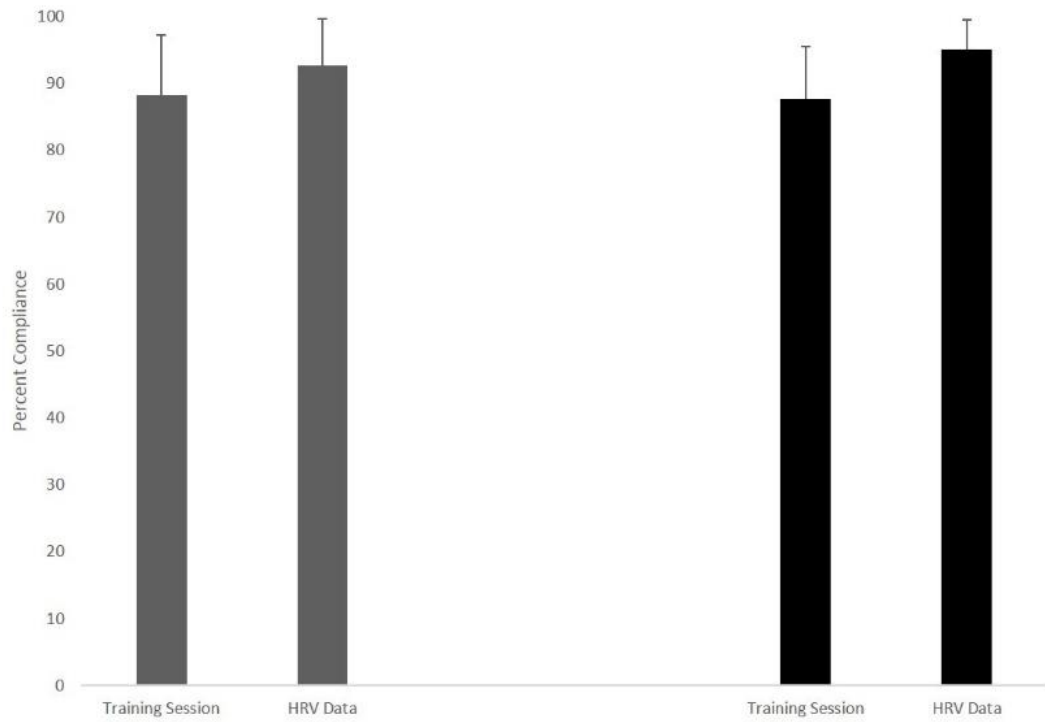


Figure 6. *Percent of days training and submitting morning HRV data by group with positive standard deviations.*

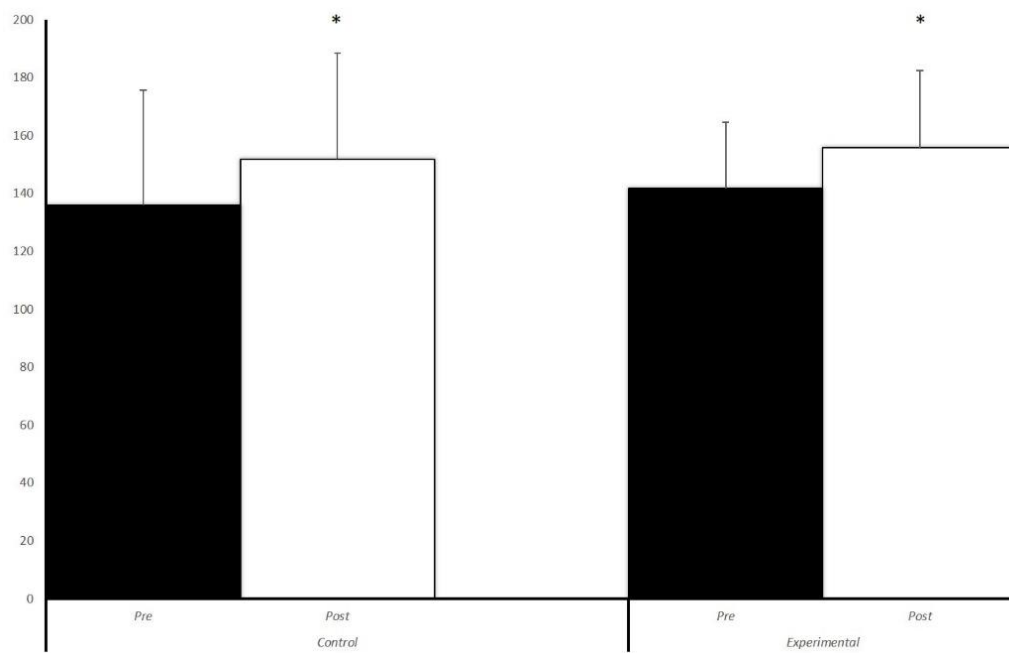


Figure 7. *Changes in work capacity performance with positive standard deviations.*

Note. *statistically different compared to baseline

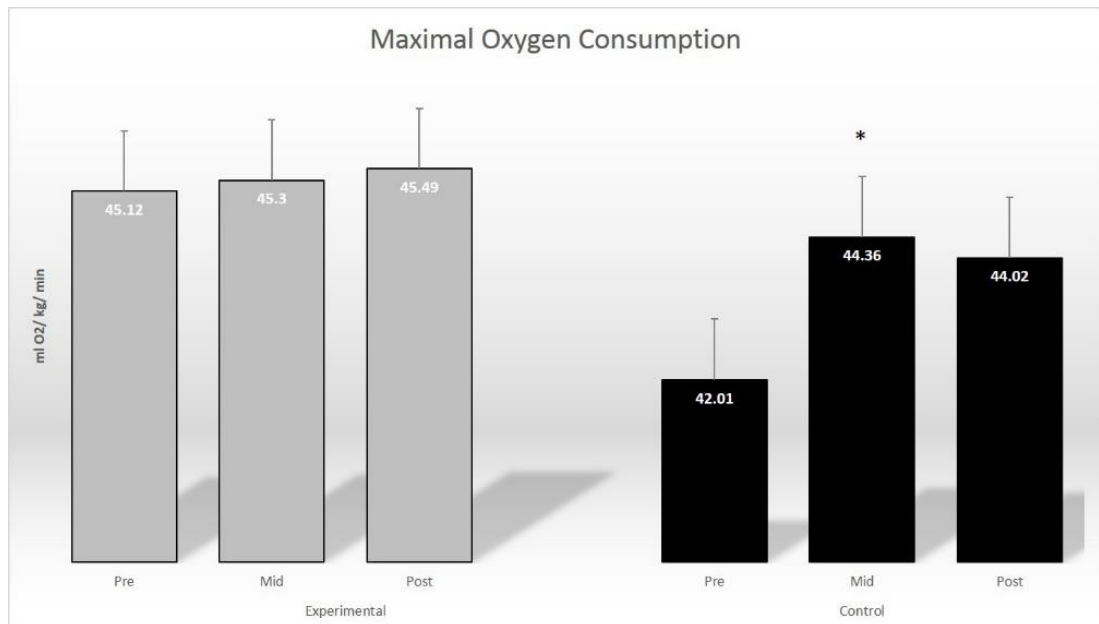


Figure 8. *Maximal oxygen consumption measured by a predictive equation based upon time to completion with positive standard deviation bars.*

Note. *statistically different compared to baseline

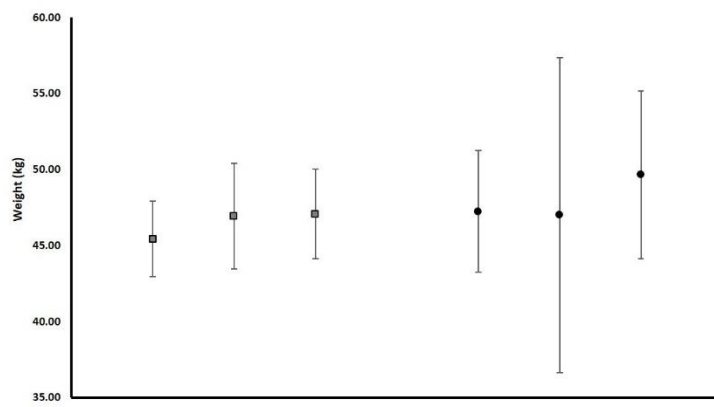


Figure 9. *Changes in 1RM Press performance for pre, mid, and post intervention assessment with standard deviations.*

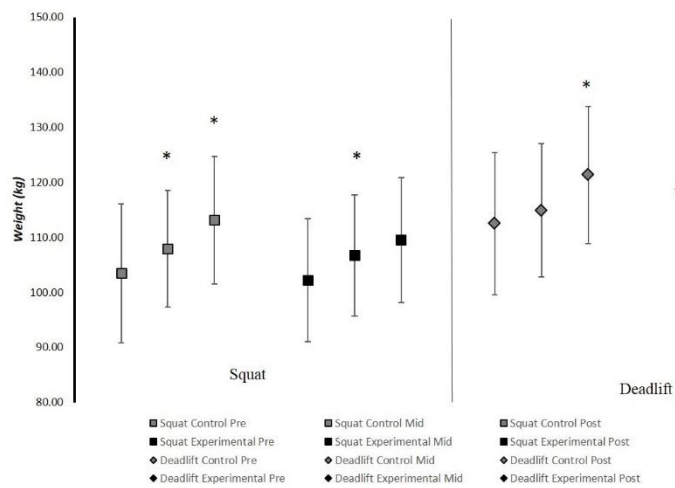


Figure 10. *Changes in squat and deadlift 1RM performance across pre, mid and post training protocol with standard deviations.*

Note.*statistically different compared to baseline

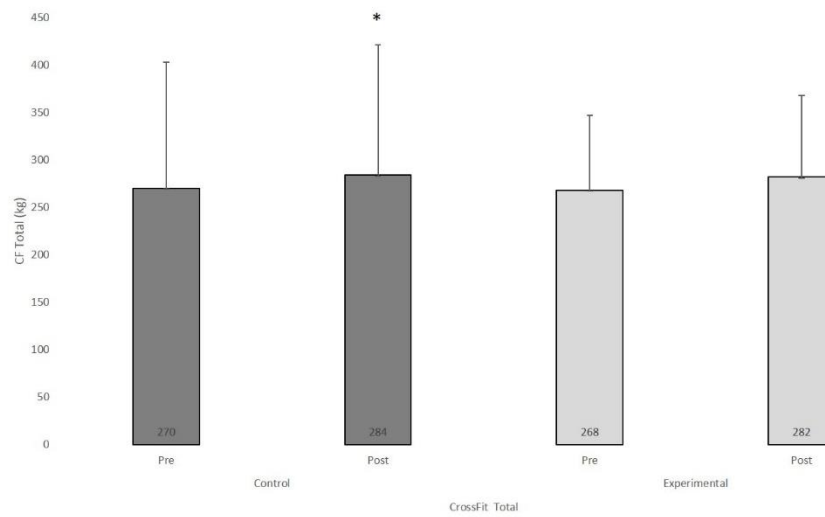


Figure 11. *CrossFit Total (1RM Squat, Press, Deadlift) at pre- and post-intervention assessments.*

Note. *statistically different compared to baseline

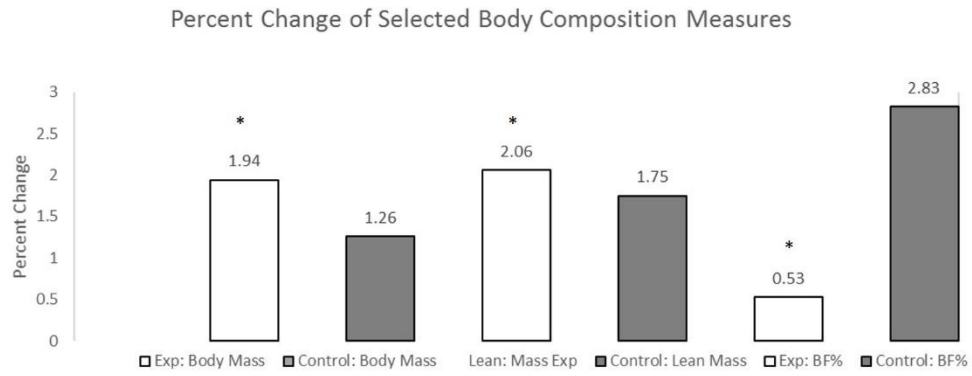


Figure 12. *Body Composition Changes*

Note. *statistically different compared to baseline

RATE OF PERCEIVED EXERTION (RPE)

BORG RPE	MODIFIED RPE	BREATHING	TRAINING ZONE	% of MHR*	EXERCISE TYPE
6	0	No Exertion	1	50%-60%	Warm up
7		Very Light			
8	1				
9					
10	2	Deeper but comfortable breathing. Able to hold a conversation.	2	60%-70%	Recovery
11					
12	3	Aware that breathing is harder; able to talk but difficult to hold conversation	3	70%-80%	Aerobic
13					
14	4				
15	5	Starting to breathe hard and getting uncomfortable	4	80%-90%	Anaerobic
16	6				
17	7	Deep and forceful breathing. Uncomfortable and not wanting to talk	5	90-100%	VO ² Max
18	8				
19	9	Extremely hard			
20	10	Maximum exertion			

* % of maximum heart rate

Figure 13. *Session Rate of Perceived Exertion Chart*

Appendix C: Informed Consent

Applied Physiology Laboratory

Pittsburg State University

Informed Consent

Effects of Individualized Training Prescription using Heart Rate Variability on the Physiological and Psychological Outcomes of High-Intensity Functional Training.

Approval Date: 8/10/2017

Expiration Date:

Student Principle Investigators: Nick Drake, B.S., B.A.

Faculty Mentor/Principle Investigators: Derek A. Crawford, Ph.D. and Michael J. Carper, Ph.D.

Contact Information for Problems/Questions:

Michael J. Carper,

Ph.D. Derek Crawford, Ph.D.

Assistant

Professor

Assistant Professor

Director, Applied Physiology Laboratory
Laboratory

Director, Applied Movement Science

202B Student Recreation Center

203 Student Recreation Center

Pittsburg State University

Pittsburg State University

Phone: 620-235-6155

Phone: 620.235.4672

Email: mcarper@pittstate.edu

Email: dcrawford@pittstate.edu

IRB Chair Contact/Phone Information

Pawan Kahol, Ph.D.

Chair, Committee for the Protection of Human Research Participants

112 Russ Hall

Pittsburg State University

Pittsburg, KS 66762-7526

620-235-4222

Purpose of the Research:

The ***overarching goal*** of this study is to determine if individualized CF training prescriptions result in superior health and fitness outcomes compared to non-individualized training.

Procedures:

Research Design: This study will be a prospective randomized-controlled trial design.

Participants: ***Thirty (30) healthy, untrained/recreationally trained men and women*** will be recruited for participation in this research study. *Inclusion criteria* includes 1) between the ages of 18-35 2) English speaking 3) not participating in a structured exercise program for at least 8 weeks prior to commencement of the study which includes more than 4 days of training. *Exclusion criteria* includes 1) significant physical conditions which may contraindicate vigorous physical activity (i.e., 2 or more coronary heart disease risk factors) 2) having participated in a structured training program within the past eight (8) weeks 3) the presence of obesity, type 2 diabetes, or osteoporosis. Participants will be recruited via a ***convince sample from both the University and local communities. Participants will be randomly assigned to one of the study treatment groups. All participants will provide informed written consent, physical activity questionnaire and health history information prior to any further study protocols.***

Pre-Training Testing: Three (3) weeks before the commencement of the training program, all participants will attend a meeting where participants will download necessary software onto their cell phone and begin initial HRV data starting the following morning. After two weeks of baseline HRV data, all ***participants will attend four (4) pre-test sessions*** within the Rehabilitative Exercise Research Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. During this session, participants' demographic and anthropometric information, body composition, aerobic/anaerobic capacity, mood states, motivation to train, and muscular fitness will be assessed. Also, during this session, a blood sample will be collected from each participant. ***These familiarization sessions should last approximately one hour.***

Control Treatment (CON): ***Fifteen (15) participants*** will complete ***eight (8) weeks*** of CF training. Original CF methodology will be strictly adhered to ¹⁰. Within these training sessions a basic structure will be present which consists of a warm-up (10-15 minutes), CF "workout of the day" (WOD) (10-30 minutes), and a cool-down (10 minutes). Total ***estimated time for each training session is approximately 60 minutes***. A central premise of CF is the constant variation of training variables between sessions. This results in WODs with a wide range of exercise modalities, intensities, volumes, and durations. Each training week could consist of three (3) differently structured sessions. The first session will be an "element priority" (EP) session. Within these sessions, participants will complete either a monostructural (M) endurance exercise (e.g., 5k run), a bodyweight/gymnastic (G) exercise (e.g., pull-ups), or weightlifting (W) exercise (e.g., deadlifts) performed at either a moderate intensity, high skill level, or heavy load; respectively. The second session will be a "task priority" (TskP) session. Within these sessions, two moderately to intensely challenging elements will be selected (e.g., M and W).

These two elements are repeated for 3 – 5 sets in the shortest amount of time possible. The final session is a “time priority” (TmP) session. This session consists of 3 – 4 light to moderately challenging elements (e.g., G, W, and M) performed in rotation for 20 minutes attempting to perform maximum work in the prescribed amount of time. ***The total number of training sessions for this treatment group is 40.***

Individualized Prescription Treatment (EXP): ***Fifteen (15) participants*** will complete ***eight (8) weeks*** of CF training utilizing the exact same programming as the CON group. However, unlike the CON group, the EXP group will have their daily training status modulated based on changes in HRV with respect to their individual SWC. Each training day, using the RMSSD_{7d}, participants will be instructed at what perceived exertion (Borg) to perform the WOD. If an individual’s RMSSD_{7d} falls within the SWC₁ participants will be instructed to give maximum effort (RPE of 17 or higher). If an individual’s RMSSD_{7d} falls above or below the SWC₁ the individual will be allowed to perform the work associated with the WOD while maintaining an RPE between 12 and 15 (*hard*). If an individual’s RMSSD_{7d} falls above or below the SWC₂ the individual will be asked to perform active recovery including, but not limited to mobility work, technique work for barbell movements completed with only barbell load, or cardiovascular activity at an RPE between 7 (*very, very light*) and 10. When an individual’s RMSSD_{7d} returns within SWC₂ they will be allowed to perform the WOD at the lower RPE (i.e., 12 to 15) and when it returns to the mean RMSSD_{7d} they will be allowed to perform the WOD with maximum effort. This process will be consistent throughout the duration of the CF training intervention with the exception that the SWCs will be recalculated following the first 4 weeks of training for use during the second 4 weeks. ***The total number of training sessions for this treatment group will be 40.***

Mid-Point Testing: Following the 3rd week of the training program ***all participants will attend four (4) mid-point testing sessions*** within the Rehabilitative Exercise Research Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. During this session, participants’ body composition, mood states, motivation to train, aerobic capacity, and muscular fitness will be assessed. ***The mid-point testing sessions should last approximately one hour.***

Post-Training Testing: The week following the completion of the training program ***all participants will attend four (4) post-test sessions*** within the Rehabilitative Exercise Research Laboratory in the Department of Health, Human Performance, and Recreation at Pittsburg State University. During this session, participants’ body composition, mood states, motivation to train, aerobic capacity, and muscular fitness will be assessed. ***The post-training testing sessions should last approximately one hour.***

Participant Requirements:

1. Participants are required to collect and send HRV data to the principal investigator each morning by 10 AM for the duration of the study. HRV collection tool will be provided to each participant at no charge.
2. Failure to submit data any more than 2 days in a row will result in withdrawal from the investigation.

3. Failure to participate in training more than 2 days in a row will result in withdrawal from the investigation
4. Participants will be required to participate in training 5 days each week.
5. Participants will be required to submit written explanation if they choose to withdraw from the investigation.
6. Participants will be required to fill out any documentation that is required by the principle investigator that is within the scope of the study: nutrition status, psychological evaluation, etc.

Length of the Study:

Participants will report to the Applied Movement Science Laboratory for a period of 14-weeks for testing and training (see above for detailed Methods).

Risks or Discomforts:

As with any exercise, there exists the possibility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorders of heart beat, and rare instances of fatal heart attack. Every effort will be made to minimize them by the preliminary examination and by observations during testing. Trained personnel are available to deal with unusual situations that may arise by using testing procedures recommended by the American College of Sports Medicine and adopted by the Applied Physiology Laboratory at Pittsburg State University.

Benefits:

You may gain useful information regarding how your body responds to exercise to volitional fatigue, body composition, anaerobic capacity, and heart rate. This may allow you to make an educated decision on how to construct an efficient exercise program.

Extent of Confidentiality:

The information which is obtained in this test will be treated as privileged and confidential and will consequently not be released or revealed to any person without your expressed written consent. You do agree to the use of the information for research purposes. The identity of all participants will remain anonymous during any presentation or publication of this study. Only the principal investigator and research technicians will have access to your personal data. Once the study is completed all personal identifying data will be destroyed.

Compensation of Availability of Medical Treatment If Injury Occurs:

If the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

Parental Approval For Minors:

If you are under 18 years of age, this form must be signed by your parent or legal guardian prior to participation in this study.

Any questions about the procedures used in the fitness assessment or the results of your assessment are encouraged. If you have any concerns or questions, please ask us for further explanations.

Do you have any questions? If so, write them below and you will receive a verbal and/or written response.

Questions:

Initials: _____

<u>Answer</u>	<u>to</u>	<u>Questions</u>

Answers given by: _____ Initials of subject: _____

Have your questions been completely answered? **YES** **NO**

If you have no questions or are satisfied with the answers to the above questions, please continue with this form.

Terms of Participation:

I understand this project is research, and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation, penalty, or loss of benefits or academic standing to which I may otherwise be entitled.

I verify that my signature below indicates that I have read and understand this consent form and willingly agree to participate in this study under the terms described, and that my signature acknowledges that I have received a signed copy of this consent form.

WITH MY SIGNATURE I AFFIRM THAT I AM ATLEAST 18 YEARS OF AGE

(IF UNDER 18 YEARS OF AGE YOUR PARENT/GUARDIAN SIGNATURE IS NECESSARY).

Printed Name of Participant

Signature of Participant Date

Signature of Interviewer Date

Signature of Witness Date

Emergency Contact Information (Required)

Emergency Contact Name

Emergency Contact Phone Number

Appendix D: Health History Questionnaire

Applied Physiology Laboratory

Pittsburg State University

HEALTH HISTORY QUESTIONNAIRE

Name:

Date: _____

Height: _____cm
_____yrs

Weight: _____kg

Age:

HAVE YOU EVER HAD ANY OF THE FOLLOWING?

X-ray, CT scan, PET scan, or nuclear medicine studies within the prior two (2) weeks	YES	NO
Myocardial infarction (heart attack)	YES	NO
Angiography	YES	NO
Coronary Surgery	YES	NO
Chest Discomfort	YES	NO
Hypertension (high blood pressure)	YES	NO
Shortness of breath on exertion	YES	NO
Pulmonary disease	YES	NO
Heart palpitation	YES	NO

Heart murmur	YES	NO
Diabetes	YES	NO
Dizziness on light exertion	YES	NO
Extremity discomfort	YES	NO
Claudication	YES	NO
Does anyone in your family have a history of cardiovascular disease?		
If yes, who? _____		
Do you smoke?	YES	NO
Are you currently taking any medications?	YES	NO
If yes, what medications? _____		
Are you allergic to anything?	YES	NO
If yes, what? _____		
What is your current cholesterol level (if known)? _____		
Are you currently training on a daily basis?	YES	NO
If yes, what type and how often do you train?		

If yes, how many miles/week or days/week are you currently training?

Participant/Subject signature

Date

Interviewer Signature

Date

Witness Signature

Date

Appendix E: Physical Activity Questionnaire

Applied Physiology Laboratory

Pittsburg State University

Physical Activity Questionnaire

Name: _____

Date: _____

Gender: M F Height: _____cm Weight: _____kg

Age: _____yrs

- 1) Are you currently participating in a regular **resistance training** (weight lifting) exercise program?

YES NO

- 2) Are you currently participating in a regular **aerobic training** (running, biking) exercise program?

YES NO

- 3) How many years have you participated in **weight training** activities? _____yrs

- 4) How many years have you participated in **aerobic training** activities? _____yrs

- 5) Are you currently taking **any performance enhancing dietary supplements** (creatine, protein powder, etc.)?

YES NO

If yes, what? _____

- 6) Are you currently taking any banned performance enhancing supplements?

YES NO

If yes, what? _____

7) Have you had, or do you have any injuries which happened because of your exercise routine?

YES NO

If yes, what injuries? _____

8) Has a physician ever instructed you to abstain from physical activity because of a medical condition?

YES NO

If yes, please explain: _____

9) Do you currently have **any other medical conditions** which limit your exercise routine?

YES NO

If yes, please explain: _____

10) Do you have any hearing impairments or require special listening accommodations?

YES NO

If yes, please explain: _____

Appendix F: Primary Outcomes Data Collection Sheet

Primary Outcomes Data Collection Sheet

Subject ID: _____

Data Collection Session: _____

Intervention Group

Circle one: Control Experimental

Demographics

Age (years): _____ Height (cm): _____ Weight (kg): _____

Sex: _____ Ethnicity: _____

Control Variables

Protein (g): _____ Carbohydrates (g): _____ Fats (g): _____

Physiological Variables

Resting Heart Rate (bpm): _____ Heart Rate Reserve (bpm): _____

Fitness Assessment

Press 1RM (kg): _____ Back Squat 1RM (kg): _____

Deadlift 1RM (kg): _____ CF "Total" (kg): _____

Max Aerobic Capacity (ml/kg/min): _____ Anaerobic Peak Power (W): _____

Fatigue Index (%): _____ CF "Work Capacity" (time): _____

Body Composition

Body Fat %: _____ Lean Mass (g): _____ Fat Mass (g):

BMD (g/cm^3): _____ Mid-Thigh CSA (g/cm^3): _____

Mid-Arm CSA (g/cm^3): _____ Visceral Fat Area (g/cm^3): _____

Post-Intervention Questions

Given the opportunity, how likely are you to continue this mode of exercise?



Appendix G: Training Session Data Collection Sheet

Training Session Data Collection Sheet

Subject ID: _____

Training Session: #

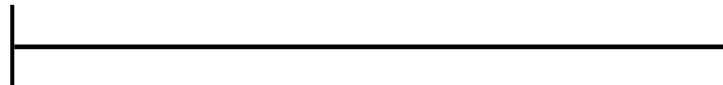
Training Intensity: _____

Pre-Training Session Data

How motivated to train are you today?

Not Much

Very

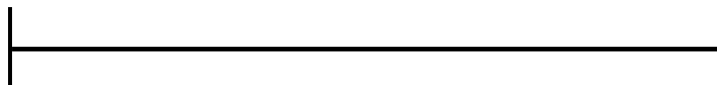


How fatigued are you this afternoon?

Less

Average

More



Training Session Variables

Session Design (circle one): Monostructural Task Priority Time Priority

Session Architecture: ___M/G_____ Training Rx (circle one): Yes No

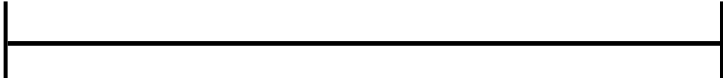
Total Workout Duration (min): _____

Perception of Training Session Performance

Rating of Perceived Exertion: _____

How did you perform during your training?

Worse As Expected Better



Physiologic Quantification of Training Session Performance

Peak HR (bpm): _____ Average HR (bpm): _____

Edwards' Internal Workload (average HR x duration): _____

Time spent in HR zones (minutes): 90-100% _____ 80-90% _____

70-80% _____ 60-70% _____

50-60% _____

Appendix H: Overuse Injury Questionnaire

Part 1: Knee Problems

Please answer all questions regardless of whether or not you have problems with your knees. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "knee problems" refers to pain, ache, stiffness, swelling, instability/giving way, locking or other complaints related to one or both knees.

Question 1

Have you had any difficulties participating in normal training and competition due to knee problems during the past week?

- ☐ Full participation without knee problems
- ☐ Full participation, but with knee problems
- ☐ Reduced participation due to knee problems
- ☐ Cannot participate due to knee problems

Question 2

To what extent have you reduced your training volume due to knee problems during the past week?

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

To what extent have knee problems affected your performance during the past week?

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

To what extent have you experienced knee pain related to your sport during the past week?

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain

OSTRC Overuse Injury Questionnaire

Part 2: Lower Back Problems

Please answer all questions regardless of whether or not you have problems in your lower back. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "lower back problems" refers to pain, aching, stiffness or other problems in your lower back.

Question 1

Have you had any difficulties participating in normal training and competition due to lower back problems during the past week?

- ☐ Full participation without lower back problems
- ☐ Full participation, but with lower back problems
- ☐ Reduced participation due to lower back problems
- ☐ Cannot participate due to lower back problems

Question 2

To what extent have you reduced your training volume due to lower back problems during the past week?

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

To what extent have lower back problems affected your performance during the past week?

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

To what extent have you experienced lower back pain related to your sport during the past week?

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain

OSTRC Overuse Injury Questionnaire

Part 3: Shoulder Problems

Please answer all questions regardless of whether or not you have problems in your shoulders. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway.

The term "shoulder problems" refers to pain, aching, stiffness, looseness or other complaints in one or both of your shoulders.

Question 1

Have you had any difficulties participating in normal training and competition due to shoulder problems during the past week?

- ☐ Full participation without shoulder problems
- ☐ Full participation, but with shoulder problems
- ☐ Reduced participation due to shoulder problems
- ☐ Cannot participate due to shoulder problems

Question 2

To what extent have you reduced your training volume due to shoulder problems during the past week?

- ☐ No reduction
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 3

To what extent have shoulder problems affected your performance during the past week?

- ☐ No effect
- ☐ To a minor extent
- ☐ To a moderate extent
- ☐ To a major extent
- ☐ Cannot participate at all

Question 4

To what extent have you experienced shoulder pain related to your sport during the past week?

- ☐ No pain
- ☐ Mild pain
- ☐ Moderate pain
- ☐ Severe pain